IOWA STATE UNIVERSITY
COLLEGE OF ENGINEERING

RESEARCH HIGHLIGHTS

ECpE

**Department
of Electrical
and Computer
Engineering**

AUGUST 2004

MISSION STATEMENT

Provide an outstanding educational program that enables our graduates to become leaders in their professions by imparting fundamental principles, skills, and tools to innovate and excel.

Pursue the discovery of fundamental knowledge and its applications to position the department among the leaders in research.

Respond to the needs of the State of Iowa and the nation by building a strong outreach program that serves industry and the engineering profession.

Recent Honors and Awards

ENDOWED CHAIRS AND PROFESSORSHIPS

David C. Nicholas Professorship Endowment
Robert Weber (2002–present)

Harpole-Pentair Faculty Development Award
Chris Chu (2004)
Nicola Elia (2004)

Jerry R. Junkins Chair
Arun Somani (2002–present)

The Litton Industries Professorship
Manimaran Govindarasu (2004)

Murray & Ruth M. Harpole Professorship in Electrical and Computer Engineering
Vijay Vittal (2000–present)

Palmer Chair in Electrical and Computer Engineering
Subrahmanyam Venkata (2003)

Richardson Professorship in Electrical and Computer Engineering
Randall Geiger (2002–present)

Thomas M. Whitney Professorship in Electrical and Computer Engineering
Vikram Dalal (2002–present)

FELLOWS

American Association for the Advancement of Science
Edwin Jones, Emeritus Professor
Joel Snow

American Physical Society
David Jiles
Joel Snow

American Society for Engineering Education
Robert Anderson, Emeritus Professor
Edwin Jones, Emeritus Professor

American Society for Nondestructive Testing
William Lord, Emeritus Professor

British Institute of Non-Destructive Testing
William Lord, Emeritus Professor

Institute of Electrical and Electronics Engineers
Robert Anderson, Emeritus Professor
Robert Grover Brown, Emeritus Professor
Aziz Fouad, Emeritus Professor
Randall Geiger
David Jiles
Edwin Jones, Emeritus Professor
William Lord, Emeritus Professor
James D. McCalley
James Melsa, Emeritus Professor
James Nilsson, Emeritus Professor
Arthur Pohm, Emeritus Professor
Gerald Sheblé
Arun Somani
Subrahmanyam Venkata, Emeritus Professor
Vijay Vittal
Robert Weber

Institute of Mathematics (UK)
David Jiles

Institute of Physics (UK)
David Jiles

Institution of Electrical Engineers (UK)
David Jiles
William Lord, Emeritus Professor

Recent Honors and Awards

FACULTY

Srinivas Aluru, associate professor, received the IBM Faculty Award and Iowa State's Young Engineering Faculty Research Award. He was elected IEEE Computer Society Distinguished Visitor.

Chris Chu, assistant professor, received the ACM International Symposium on Physical Design Best Paper Award in 2004.

Vikram Dalal, professor, received the first Micron Faculty Excellence Award (a $300,000 stipend). He also received the Warren B. Boast Undergraduate Teaching Award.

Jim Davis, associate professor, was appointed as the university's chief information officer. He also leads Iowa State's $2.6-million National Science Foundation award to develop a cohort of 30 students studying computer security.

Julie Dickerson, associate professor, received the Warren B. Boast Undergraduate Teaching Award and was named Outstanding Professor by the Engineering Student Council.

Randall Geiger, professor, received the Warren B. Boast Undergraduate Teaching Award.

Manimaran Govindarasu, assistant professor, received the Young Engineering Faculty Research Award.

Richard Horton, professor, received Iowa State's Mervin S. Coover Distinguished Service Award.

Doug Jacobson, associate professor, received an R&D 100 Award, sponsored by *R&D Magazine*, for "FireBlock," a network security software package. He has also received the Ernst & Young Entrepreneur of the Year Award, Iowa State's Warren B. Boast Undergraduate Teaching Award, the Louis Thompson Distinguished Undergraduate Teaching Award, and the Regents Faculty Excellence Award. In addition, Jacobson testified before a U.S. Senate Judiciary Committee on Internet file sharing of pornography.

David Jiles, professor, was named Anson Marston Distinguished Professor of Engineering.

Ahmed El-Sayed Kamal, professor, was named to *Who's Who in Engineering Education*.

James McCalley, professor, was elected a Fellow of the Institute of Electrical and Electronics Engineers and designated chair of the IEEE's PES PEEC working group.

Mani Mina, adjunct assistant professor, received the VEISHEA Faculty of the Year Award and was designated Outstanding Electrical and Computer Engineering Faculty Member of the year. Additionally, he and graduate student **Norm Anderson** received an American Society for Nondestructive Testing Fellowship Award for their proposed research.

Steve Russell, associate professor, received the Warren B. Boast Undergraduate Teaching Award.

Gerald Sheblé, professor, was named visiting professor at the University of Porto in Portugal.

Arun Somani, professor and department chair, and **G. Krishnamurthy** were awarded U.S. Patent No. 6,718,173 for *Location information recovery and management for mobile networks*.

Arun Somani and **Jianwei Zhou** received a Best Paper Award at the IEEE International Performance Computing and Communications Conference.

Gary Tuttle, associate professor, was awarded U.S. Patent No. 6,593,894 for *Highly directional receiver and source antennas using photonic band gap crystals*.

Vijay Vittal, professor, was elected to the National Academy of Engineering and named a leader in the simulation of large-scale power systems in the February 2004 issue of *Technology Review*. In addition, Vittal was named Anson Marston Distinguished Professor of Engineering and received an ISU Foundation Award for Outstanding Achievement in Research.

Zhengdao Wang, assistant professor, received the *Signal Processing Magazine* Award for 2003 from the Signal Processing Society. He also received the IEEE Marconi Paper Prize Award in Wireless Communications for 2004.

Robert Weber, professor, received the Warren B. Boast Undergraduate Teaching Award.

Former ECpE faculty members **Marwan M. Hassoun** and **Weibiao Zhang** were awarded U.S. Patent No. 6,563,444 for *Apparatus for and method of performing a conversion operation*.

STAFF

Nancy Knight, coordinator of Graduate Student Services, received the 2004 University Member of the Year Award from the National Consortium for Graduate Degrees for Minorities in Engineering and Science, Inc. (GEM).

Vicky Thorland-Oster, coordinator of Undergraduate Student Services, received the Iowa State University Foundation Award for Excellence in Academic Advising.

STUDENTS

2003–2004 Graduate Fellowships
Alliance for Graduate Education and the Professoriate Fellowship
Lewis Hill II
Enrique Silva

The David C. Nicholas Fellowship (Dr. Robert Weber)
Michael Reid

ECpE Graduate Excellence Fellowship
Jonathan Crandall
Jarrod McDonald
Joshua Olson
Joseph Schneider

GEM Fellowship (National Consortium for Graduate Degrees for Minorities in Engineering and Science, Inc.)
Miguel Contreras
Enrique Silva

The Jerry R. Junkins Chair Fellowship (Dr. Arun Somani)
Pallab Datta
Jing Fang

The Murray & Ruth M. Harpole Fellowship (Dr. Vijay Vittal)
Daniel Nack
Wenzheng Qiu

NSF IGERT Fellowship
Scott Emrich
Sarah Orley

The Palmer Chair Fellowship (Dr. Subrahmanyam Venkata)
Brad Retterath

Pioneer Hi-Bred Fellowship
Anantharaman Kalyanaraman

The Thomas M. Whitney Fellowship (Dr. Vikram Dalal)
Matthew Ring

USDA MGET Fellowship
Benjamin Jackson

2004–2005 National Merit Scholarships
Anthony Barsic, Jesse Bartley, Mikel Bezdek, Keith Dahlby, Samuel Degree, Michael Dierickx, Michael Ekstrand, Ryan Ferneau, Benjamin Flessner, Nathaniel Gibbs, Joseph Heiniger, Paul Jennings, Alan Johnson, Debra Lauterbach, Matthew Lichti, Derek Light, Jeremy Meeks, Aaron Sartor, Taylor Schreck, Cory Simon, Jason Wilkinson

Mark Hansen, undergraduate student, received Iowa State's Honors Poster Award from the College of Engineering.

Le Jin, graduate student, received a Best Paper in the Session Award from the Semiconductor Research Corporation.

Anantharaman Kalyanaraman, graduate student, received the Pioneer Hi-Bred Fellowship and IBM PhD Fellowship awards and Iowa State's Research Excellence Award.

Research Excellence Awards
Jamal Al-Karaki (PhD'04), Wenzheng Qiu (PhD'04), Abu Sebastian (PhD'04), Anirban Chakrabarti (PhD'03), Rama Subba Reddy Sangireddy (PhD'03), Tao Wu (PhD'03), Bhanu Hariharan (MS'03), Shashank Krishnamurthy (MS'03), Yongjua Cong (PhD'02), Srinivasan Ramasubramanian (PhD'02), Aaron Striegel (PhD'02), Swaminathan Sivasubramanin (MS'02), Zhaoxia Xie (MS'02), Ra'ed Al-Omari (PhD'01), Curtis Sell (PhD'01), Sashisekaran Thiagarajan (PhD'01), Yuan Zhou (PhD'01), Bin Zhu (PhD'01), Vijayanand Vishwanathan (MS'01)

Teaching Excellence Awards
Norman Anderson, Pallab Datta, Benjamin Graubard, Steven Hines, Jiang Huang, Abbadi Imad, Edward Jackson, Noah Korba, Carl Lebsack, Greg Rice, Swaminathan Sivasubramaniam, Lucas Wagner, Robert Walstrom, Hao-Li Wang, Xuezhan Wang, Jonathan Williams

ALUMNI

Hamid Elahi (BSEE'77, MSEE'79, PhDEE'83), currently with General Electric International, received the Iowa State College of Engineering Professional Achievement Citation in Engineering.

David J. Miller (BSEE'75), director of Iowa State's Facilities, Planning, and Management office, received the Superior Service Award from the Iowa State Alumni Association.

Indumini W. Ranmuthu (PhD'93), manager of the Preamp Design Group at Texas Instruments, received the 2004 Professional Progress in Engineering Award from the Iowa State College of Engineering.

Aaron Striegel (PhD'02) is a faculty member at the University of Notre Dame.

ADVANCED ELECTRONICS AND MATERIALS

The Advanced Electronics and Materials group includes three synergistic engineering areas represented by the Center for Nondestructive Evaluation, the Microelectronics Research Center, and the Analog and Mixed-Signal VLSI Design Center. Many ECpE faculty work at these centers, while others work wholly within the ECpE department. Research includes three-dimensional electromagnetic field simulation and modeling, nondestructive material evaluation instrumentation and research, advanced materials processing, thin film semiconductor devices, photonic bandgap materials and devices, solar energy conversion, magnetics, and mixed-signal VLSI design from low frequencies up through millimeter wavelengths.

Robert Weber, Chair

NONDESTRUCTIVE EVALUATION AND ELECTROMAGNETICS
Primary Members
John Bowler
Nicola Bowler
Brian Hornbuckle (Agronomy)
David Jiles
Mani Mina
Jiming Song

MICROELECTRONICS AND PHOTONICS
Primary Members
Vikram Dalal
Gary Tuttle
Clive Woods
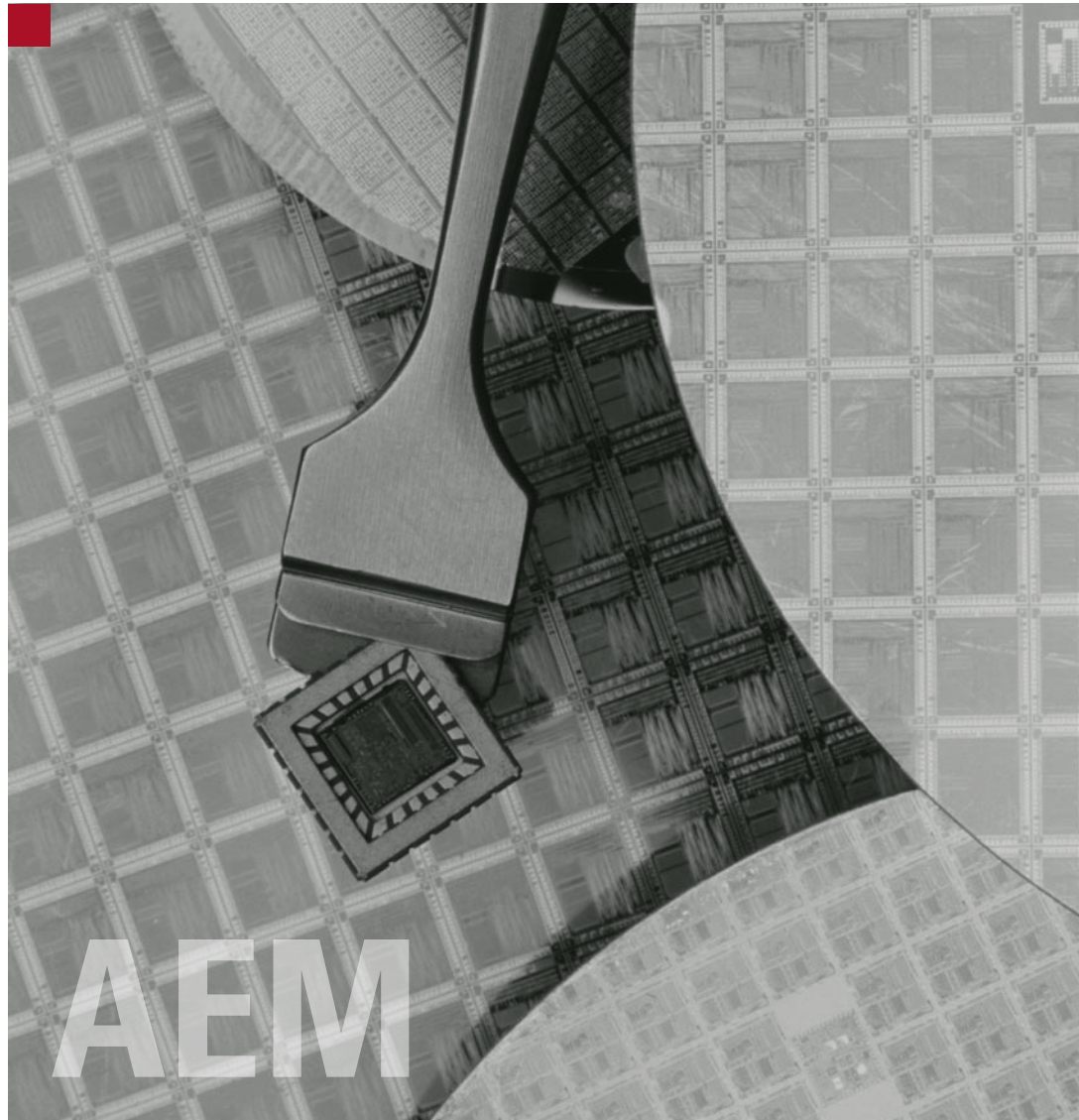**Secondary Members**
David Jiles
Jiming Song

VLSI
Primary Members
Degang Chen
Chris Chu
Randall Geiger
Secondary Members
Gary Tuttle
Robert Weber
Clive Woods

AEM

FAST AND EFFICIENT ALGORITHMS IN COMPUTATIONAL ELECTROMAGNETICS

The goal of this project is to explore and develop fast and efficient algorithms in computational electromagnetics in order to solve scattering and radiation from complex, large-scale objects. As a principal research scientist in the Center for Computational Electromagnetics at the University of Illinois, the PI developed a three-dimensional fast multipole method, a multilevel fast multipole algorithm, and the fast Illinois solver code (FISC) for use in large-scale electromagnetic analysis. To date, more than 400 copies of FISC have been distributed to government and industrial users. In addition, higher-order methods for applying the method of moments have been developed for solving integral equations, resulting in faster convergence, less CPU time, and fewer memory requirements. We also developed fast algorithms for low-frequency applications of EMC/EMI and approaches for broadband simulations of electromagnetic scattering using frequency domain methods. We are developing well-conditioned integral equations, fast and efficient algorithms for electromagnetic scattering and radiation, light scattering from biological cells, and de-embedding algorithms and electromagnetic modeling and simulations for interconnects and RF components over conducting silicon.

Publications:
1. Lloyd, T. W., J. M. Song, G. Kang, and C. C. Lu. 2004. Numerical study of surface integral formulations for homogeneous bodies. In *IEEE AP-S International Symposium* 4:3895–8. June. Monterey, California.
2. Velamparambil, S., W. C. Chew, and J. M. Song. 2003. 10 million unknowns, is it that big. *IEEE Antenna Propag. Mag.* 45 (2, April): 43–58.
3. Chew, W. C., T. J. Cui, and J. M. Song. 2002. A FAFFA-MLFFA algorithm for electromagnetic scattering. *IEEE Trans. Antenna Propag.* 50 (11, November): 1641–9.
4. Song, J. M., and W. C. Chew. 2001. FMM and MLFMA in 3D and fast Illinois solver code. Chapter 3 in *Fast and Efficient Algorithms in Computational Electromagnetics.* Ed. Chew, Jin, Michielssen, and Song. Artech House.
5. Kang, G., J. M. Song, W. C. Chew, K. C. Donepudi, and J. M. Jin. 2001. A novel grid-robust higher-order vector basis function for the method of moments. *IEEE Trans. Antenna Propag* 49 (6, June): 908–15.

ANALOG AND MIXED-SIGNAL VLSI DESIGN CENTER

The students associated with this work devoted a great deal of effort toward designing CMOS-based circuits for the 802-11 specification. The majority of this effort was associated with the receiver design for these systems. The low-noise amplifier sets the noise level of the receiver. Historically, this circuit was fabricated with discretes for use in conjunction with CMOS circuits. In order to have a completely integrated CMOS receiver, the low-noise amplifier and associated circuitry needs to be integrated on the CMOS chip. Other devices such as MEMS (Micro-Electro-Mechanical Systems) also need to be integrated on the CMOS chip. The students working on microwave-based circuits at the center attempted to further the state of the art in low-noise receivers and integrated sensors using MEMS. Inductor design, CMOS low-noise amplifier circuits, and microwave-based readout circuits for MEMS were developed. Of particular note is a correct noise analysis of inductively degenerated cascode circuits used for the low-noise receiver and a patent application for a low pull-in voltage (less than 3 volts) for MEMS cantilevers, which allows the integration of MEMS devices with high-speed, high-frequency CMOS circuits.

Publications:
1. Wang, X., R. J. Weber, and D. Chen. 2004. A novel 1.5V CMFB CMOS down-conversion mixer design for IEEE 802.11A WLAN systems. In *ISCAS 2004.* 23–26 May, Vancouver, Canada.

Display output of microwave network analyzer

2. Long, J., and R. Weber. 2004. An integrated 2.4GHz CMOS RF front-end. In *IEEE Aerospace Conference*. 6–13 March, Big Sky, Montana.
3. Long, J., and R. J. Weber. 2004. A low voltage low noise CMOS RF receiver front-end. In *17th International Conference on VLSI Design, VLSI Design 2004*, Session 4A-RF Design.
4. Wang, X., and R. J. Weber. 2003. A novel low-voltage low-power 5.8 GHz CMOS down-conversion mixer design. In *2003 IEEE Radio and Wireless Conference (RAWCON 2003)*, Session: P2.13. 10–13 August, Boston, Massachusetts.
5. Long, J., and R. J. Weber. 2003. A 1.2V 2.4GHz integrated direct downconversion receiver front-end. In *The 15th International Conference on Wireless Communications, Wireless 2003*. 7–9 July, Calgary, Alberta, Canada.
6. Wang, X., and R. J. Weber. 2003. Design of a CMOS low noise amplifier (LNA) at 5.8 GHz and its sensitivity analysis. In *IEEE, NASA Symposium on VLSI Design, 2003, 11th Annual NASA Symposium on VLSI Design*. 28–29 May, Coeur d'Alene, Idaho.
7. Wang, C-H., and R. J. Weber. 2002. RF measurement techniques for micromechanical cantilever characterization and application. In *2002 ACRS Joint Meeting, Fifth International Conference on Modeling and Simulation of Microsystems, MSM 2002*. 22–25 April, San Juan Marriott Resort and Stellaris Casino, San Juan, Puerto Rico.

HIGH-TEMPERATURE SUPERCONDUCTORS

Recent independent peer-reviewed reports have claimed that high-temperature superconductors can interact with gravitation under certain non-relativistic conditions. Common to these reports is the claim that the observed gravitational field may be modified using $YBa_2Cu_3O_{7-}$ (YBCO) below its superconducting critical temperature, $T_c \sim 93K$, and in a magnetic field $B \sim 1T$. This project began by attempting to replicate these experiments; no reports arising either from this or other projects reporting later have confirmed the observations. Current conclusions are that these experiments are extremely difficult to replicate exactly and that no complete replication confirming the effects has yet taken place. However, no one has conclusively disproved the existence of the effects.

Hertzian Dipole
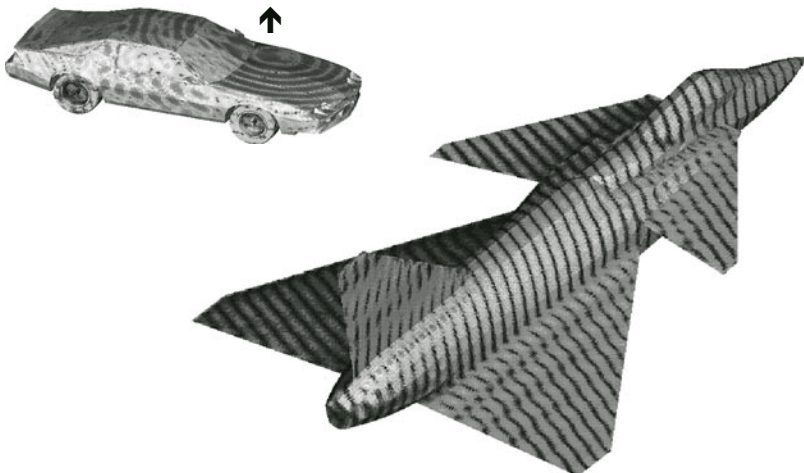

Eddy current analysis on structures

Publications:
1. Woods, R. C., and R. M. L. Baker. Accepted. Gravitational wave generation using acoustic resonators and detection using coupled resonance chambers. In *AIP Space Technology and Applications International Forum*. Albuquerque, New Mexico.
2. Woods, R. C. 2004. Review of claims of interaction between gravitation and high-temperature superconductors. In *Proc. AIP Space Technology and Applications International Forum* 699:1085–92. Albuquerque, New Mexico. (Invited paper F01.2.)
3. Woods, R. C. 2003. A critique of theoretical explanations of gravity shielding phenomena. In *Proc. AIP Space Technology and Applications International Forum*, 654:917–21. Albuquerque, New Mexico. (Invited paper D03.1.)
4. Woods, R. C. 2003. Gravitation and high-temperature superconductors: The current position. In *Proc. 1st Int. High-Frequency Gravitational Wave Working Group*. McLean, Virginia. (Invited paper.)
5. Woods, R. C., S. G. Cooke, J. Helme, and C. H. Caldwell. 2001. Gravity modification by high-temperature superconductors. In *Proc. 37th AIAA/ASME/SAE/ASEE Joint Propulsion Conf.* Salt Lake City, Utah A01-34137. (Invited paper AIAA-2001-3363.)

QUANTITATIVE DETERMINATION OF RATER BIAS

To assess a large number of projects rapidly, a procedure often adopted is to use a panel consisting of a large number of raters, only a small number of which assess each project. Since no single rater assesses all projects, conscious or unconscious bias regarding overall

standards by any rater will advantage or disadvantage projects assessed by that particular rater. "Rater bias" is the tendency for a project rater to return assessments that deviate from the required and established standards of impartiality, such that the project(s) assessed by that rater are systematically advantaged or disadvantaged. Until recently, only ad hoc methods of determining rater bias were available. This project has demonstrated how a quantitative determination of rater bias may now be obtained from the complete set of assessments alone, based upon a comparison of the "paired assessments" of each rater with those of others assessing the same projects. Two methods, slightly different in the way that averaging is conducted, have been demonstrated.

PI: Roger Clive Woods
Funding: ECpE Initiation

Publications:

1. Woods, R. C. Accepted. Least square differences method for quantitative determination of rater bias. In *Int. Conf. Eng. Ed.* Gainesville, Florida.
2. Woods, R. C. 2003. Iterative processing algorithm to detect biases in assessments. *IEEE Trans. Ed.* 46: 133–41.

3. Woods, R. C., and K. L. Chan. 2003. Comparison of two quantitative methods of determining rater bias. *ASEE J. Eng. Ed.* 92:295–306.

SURFACE-ACOUSTIC WAVE DEVICES

Work on surface-acoustic wave (SAW) devices has included an investigation of a novel gyroscope structure recently proposed independently, a new technique for measuring the performance of high-speed acoustic devices, and an independent determination of the electromechanical coupling factor (k^2) in GaN thin films. The novel gyroscope technology uses an array of metal dots reacting to the Coriolis force and acting as secondary sources of SAW under rotation. This opens up the possibility of a MEMS gyroscope with no moving parts, with the potential for great reliability. High-speed acoustic devices have traditionally been tested using pulsed RF signals that are incompatible with many network analyzers currently in wide use; however, a new technique enables pulsed RF testing with almost any network analyzer covering the correct frequency range.

Recently, an extremely high value of k^2 for GaN thin films was reported independently. Large k^2 is desirable in many devices because it eases the design of wide-bandwidth, low-loss SAW transducers. Because of the potential significance of this result, researcher R. C. Woods undertook an independent determination of k^2 together with a more rigorous interpretation of results than had been undertaken previously.
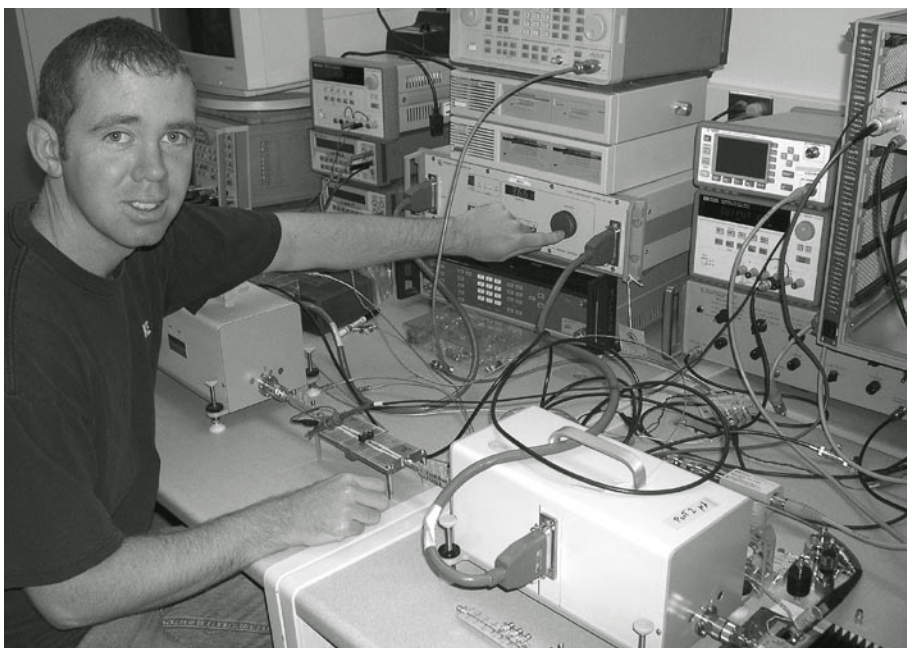
PI: Roger Clive Woods
Funding: First Inertia Switch, Engineering and Physical Sciences Resource Council (UK)

Publications:

1. Woods, R. C., and F. A. Boroumand. Accepted. Comments on "Epitaxially grown GaN thin-film SAW filter with high velocity and low insertion loss. *IEEE Trans. Electron Devices.*
2. Woods, R. C. 2003. Time-resolved measurements using conventional analogue network analyser. *IEEE Trans. Microwave Theory and Techniques* 51:1781–6.
3. Woods, R. C., and H. Kalami. 2002. Evaluation of a novel surface-acoustic wave gyroscope. *IEEE Trans. Ultrasonics, Ferroelectrics, and Frequency Control* 49:136–41.

HIGH-FREQUENCY INTERFACE CIRCUITS

CMOS interface circuits in the GHz frequency range present challenges to the circuit designer. The capacity of conventional ESD (electrostatic discharge) protection circuits is too large for reasonable operation in the multi-GHz region. In addition, CMOS circuit devices—the FETs in particular—have a large parasitic capacity that limits the gain of circuits using the devices. In conventional circuit design, the designer parallel resonates the parasitic capacity with an inductor. CMOS implementation of inductors is a difficult task. At lower frequencies

Two-port characterization of nonlinear microwave power devices

(100 MHz), the inductors are very large and consume an inordinate amount of chip area. In the multi-GHz region, while the inductors are still very large with respect to device areas, the loss of the inductor and its parasitic capacity is a very real problem. In addition to the loss and parasitic capacity, design of the CMOS inductor is currently limited by the accuracy of current computational programs. This work concentrated on geometric modeling of inductors and the interface circuits using them.

Publications:

1. Lee, A. O., and R. J. Weber. 2004. Design of a 5-Gb/s PRBS generator in 0.18mm CMOS process. In *2004 Great Lakes Symposium on VLSI (GLSVLSI)*. 26–28 April, Boston, Massachusetts.
2. Badr, N., and R. J. Weber. 2002. Design of RF integrated inductors by geometric scaling. In *WAM2L-211, 45th Midwest Symposium on Circuits and Systems 2002*. 4–7 August, Tulsa, Oklahoma.
3. Long, J., N. Badr, and R. Weber. 2002. GHz sub-1dB CMOS low noise amplifier with on-chip interstage inductor and parallel intrinsic capacitor. In *RAWCON 2002 Proceedings, Poster, 2002 IEEE Radio and Wireless Conference*, 165–8. 11–14 August, Boston, Massachusetts.

NONDESTRUCTIVE TESTING— ELECTROMAGNETICS-JOSEPHSON JUNCTION

The PI and other group members are researching different ways to formulate planar Josephson junctions. They have introduced a new vector potential formulation for the system and will be looking at ways to identify junction flaws based on the detection of propagation pathways through the junction. A byproduct of the research is an article in an ASEE publication about new ways of teaching electromagnetics at the undergraduate level.

TESTING OF ANALOG AND MIXED-SIGNAL INTEGRATED CIRCUITS IN PRODUCTION TEST AND BIST ENVIRONMENTS

The major goal of this project is to develop cost-effective testing strategies that can be used in both production test and BIST applications. In the production test applications, the major goal is to reduce the cost of the test equipment so that less expensive testers can be used and to reduce the time that the device under test (DUT) must be on the tester. A secondary goal is to provide test solutions for the highest-end parts in which the performance of the DUT exceeds the test capabilities of the best available commercial test equipment. We developed test strategies that do not require precision signal generators or precision measurement devices. With this approach, the performance requirements for signal generators and measurement devices in the tester can be a full order of magnitude or more lower than that of the DUT. This significantly reduces the performance requirements and thus the cost of the tester. Major emphasis has been placed on using this technique for testing data converters, but the technique is applicable as well to a host of other analog and mixed-signal functions. It has been demonstrated both by simulation and measurement in an industrial production test environment that this approach not only provides test validity comparable to state-of-the-art commercial testers, but is also computationally efficient. In BIST applications, dramatically reduced performance requirements for the signal generator and measurement devices with the FRE/FRM approach offer the potential for including a complete test environment on silicon. A second distinct testing strategy has also been introduced that uses deterministic dynamic element matching (DDEM) in both the signal generator and measurement devices to dramatically reduce the accuracy requirements in these devices. Simulation results for the DDEM approach are encouraging and a comparison of the DDEM approach with the FRE/FRM approach is ongoing.
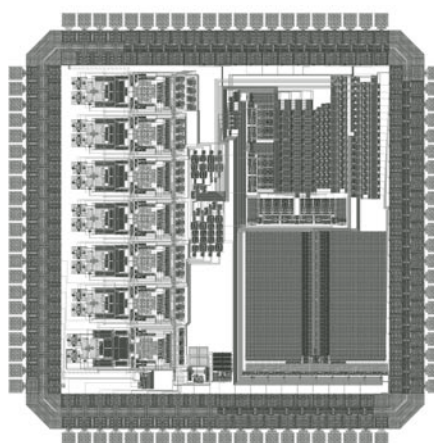
Publications:

1. Yu, Z., D. Chen, and R. L. Geiger. 2004. The SRE/SRM approach for spectral testing of AMS circuits. In *IEEE International Symposium on Circuits and Systems* 1:249–52. May, Vancouver, Canada.

Functionally related excitations/ functionally related measurements- based digital analog converter
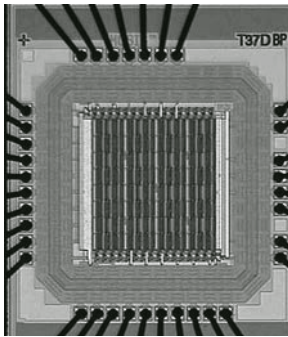
Die photo of a deterministic dynamic element matching digital analog converter

LOW-VOLTAGE DATA CONVERTER DESIGN IN EMERGING SOC-SCALE PROCESSES

This initiative concentrates on the design of data converters in low-voltage system on chip (SoC)-scale processes. One task focuses on DAC design and a second on ADC design. In the DAC design, a current DAC steering architecture is adopted in which the physical size of the current sources for the MSB array are intentionally made very small in order to achieve good high-frequency spectrum performance. A unique and aggressive self-calibration algorithm is used to overcome the linearity degradation inherent with small current sources. In the ADC design, emphasis is on designing pipelined data converters in the all-digital part of SoC-scale processes. Self-calibration is used to compensate for process and temperature-derived mismatches. Significant effort has been expended on one of the major challenges in such designs: realizing a high-speed, high-gain operational amplifier with very low supply voltages. Three new operational amplifier architectures suitable for very low voltage operation have been introduced. One uses positive feedback for dc gain enhancement and dynamic self-adjustment of the poles when very high gain is required. A second uses a cascaded architecture for gain enhancement and feed-forward compensation to achieve good high-frequency performance. A dynamic compensation network is used to circumvent the slow-settling time constant inherent with most feed-forward compensation schemes. A third uses supply voltage boosting to achieve strong-inversion operation with supply voltages below the threshold. The ADC self-calibration is being developed around input/output-based measurements of the ADC to circumvent perturbation of the signal path, an inherent limitation of most existing calibration algorithms.

Publications:

1. He, C., L. Jin, D. Chen, and R. L. Geiger. 2004. Robust design of high gain amplifiers using dynamical systems and bifurcation theory. In *IEEE International Symposium on Circuits and Systems* 1:481–4. May, Vancouver, Canada.
2. Cong, Y., and R. L. Geiger. 2003. A 1.5-v 14-bit 100-MS/s self-calibrated DAC. *IEEE Journal of Solid State Circuits* 38 (12, December): 2051–60.
3. Amourah, M. M., H. Bilhan, F. Ying, L. Fang, G. Xu, R. Chandrasekaran, and R. L. Geiger. 2003. A 9b 165MS/s 1.8V pipelined ADC with all digital transistors amplifier. In *IEEE Custom Integrated Circuits Conference*, 421–4. September.
4. Tang, Y., and R. L. Geiger. 2003. High-frequency 750mV operational amplifier standard bulk CMOS process. In *IEEE Custom Integrated Circuits Conference*, 689–92. September.
5. Parthasarathy, K., L. Jin, T. Kuyel, D. Price, D. Chen, and R. Geiger. 2003. Experimental evaluation and validation of a bist algorithm for characterization of A/D converter performance. In *Proceedings of the 2003 International Symposium on Circuits and Systems* 5:537–40. 25–28 May, Bangkok, Thailand.
6. Cong, Y., and R. L. Geiger. 2003. A 1.5 V 14 b 100 MS/s self-calibrated DAC. In *IEEE International Solid-State Circuits Conference Digest of Technical Papers,* 128–9. February.

2. Olleta, B., H. Jiang, D. Chen, and R. L. Geiger. 2004. Testing high resolution ADCs using deterministic dynamic element matching. In *IEEE International Symposium on Circuits and Systems* 1:920–3. May, Vancouver, Canada.
3. Jin, L., C. He, D. Chen, and R. L. Geiger. 2004. An SOC compatible linearity test approach for precision ADCs using easy-to-generate sinusoidal stimuli. In *IEEE International Symposium on Circuits and Systems* 1:928–31. May, Vancouver, Canada.
4. Parthasarathy, K., T. Kuyel, D. Price, L. Jin, D. Chen, and R. Geiger. 2003. BIST and production testing of ADCs using imprecise stimulus. *ACM Trans. Design Automation of Electronic Systems* 8 (4, October): 522–45.
5. Jin, L., K. Parthasarathy, T. Kuyel, D. Chen, and R. L. Geiger. 2003. Linearity testing of precision analog-to-digital converters using stationary nonlinear inputs. In *Proceedings of the 2003 International Test Conference*, 218–27. October.

VLSI PHYSICAL DESIGN AUTOMATION

As features in advanced VLSI technologies grow ever smaller, physical design plays an even more critical role in the cost and performance of VLSI systems—at the same time, it becomes an increasingly difficult task. The PI and other project members have developed novel techniques to tackle these challenges, including development of an extremely efficient VLSI placement technique to handle the huge circuit size in advanced VLSI designs. Called FastPlace, this novel analytical placement algorithm is one to two orders of magnitude faster than any other existing placers with comparable solution quality. Solutions also include circuit retiming with both interconnect and gate-delay considerations. Retiming is a powerful technique for optimizing the performance of sequential circuits by relocating registers. However, previous algorithms ignore interconnect delay, which has become a significant problem in deep submicron designs. The group has proposed a polynomial-time optimal algorithm and a much faster near-optimal algorithm for this problem. Another algorithm has been developed to reduce coupling noise in
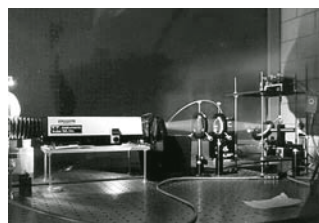
Quantum efficiency measurement

deep submicron design by adjusting the size of the nets' driver gates. The algorithm, which has been validated experimentally by multiple simulations of large circuits, considers gate sizing as a fixpoint computation on a complete lattice. The significance of this algorithm lies in its ability to guarantee an optimal solution.

PI: Chris Chu
Funding: ECpE Research Initiation

Publications:
1. Viswanathan, N., and C. Chu. 2004. FastPlace: An efficient analytical placement technique using cell spreading and iterative local refinement. In *ACM International Symposium on Physical Design*, 26–33.
2. Sinha, D., H. Zhou, and C. Chu. 2004. Optimal gate sizing for coupling-noise reduction. In *ACM International Symposium on Physical Design*, 176–81.
3. Chu, C. C. N., E. F. Y. Young, D. K. Y. Tong, and S. Dechu. 2003. Retiming with interconnect and gate delay. In *IEEE/ACM International Conference on Computer-Aided Design*, 221–6.

GROWTH AND PROPERTIES OF LOW-BANDGAP AMORPHOUS (Si,Ge) ALLOY MATERIALS AND DEVICES

Amorphous silicon-germanium alloys are important materials for low-bandgap solar cells in a tandem cell structure. The PI and his team have investigated the properties of low-bandgap alloy materials and devices using low pressure, high-dilution ECR plasma-deposition techniques. Significant reduction in dihydride-type bonding has been achieved by using low pressure, high-ion flux conditions for alloys with Tauc gaps ranging from 1.1 to 1.4 eV. The defect density was measured in n+nn+ devices using space-charge limited current techniques and found to be in the low 10^{16}/cm3-eV range. Growth at higher pressures led to materials with significantly poorer quality. It was found that one had to use a-(Si,Ge) n+ contacts in order to obtain reliable and reproducible space-charge limited current measurements. Photo

and dark conductivity and subgap absorption measurements were made on films prepared on 7059 glass substrates. These measurements also revealed that the material was of high quality when grown at low pressures, with valence-band Urbach energies below 50 meV. P-i-n junction devices were fabricated on stainless steel substrates, and they showed good fill factors and voltages. Subgap quantum efficiency techniques were also used to measure valence-band Urbach energies, which were found to be consistent with the results obtained from subgap photoconductivity measurements. This is the first time that high-quality materials and devices have been fabricated in low bandgap a-(Si,Ge):H alloys.

PI: Vikram Dalal
Collaborator: Keqin Han
Students: Yong Liu, Zhiyang Zhou
Funding: USDOE National Renewable Energy Laboratory

Publications:
1. Dalal, V. L., Y. Liu, Z. Zhou, and K. Han. 2002. Growth and properties of low bandgap amorphous (Si,Ge) alloy materials and devices. *Journal of Non-Cryst. Solids* 1127:299–302.
2. Sheng, S. R., M. Boshta, R. Braunstein, and V. L. Dalal. 2002. On the transport properties of a-(Si,Ge) alloys. *Journal of Non-Cryst. Solids* 303:202.
3. Yong. L., and V. Dalal. 2002. Properties of a-(Si,Ge) films and devices deposited at higher growth rates. In *Proceedings, Mater. Res. Soc.* 715:515.
4. Sheng, S. R., R. Braunstein, and V. L. Dalal. 2001. Electronic and optical properties of high quality, low bandgap a-(Si,Ge) alloys. In *Proceedings, MRS* 664:A8.4.

MEASUREMENT OF DEFECT DENSITY AND DIFFUSION LENGTH OF HOLES IN NANOCRYSTALLINE Si:H SOLAR CELLS

This project measured the doping density, defect density, and minority carrier diffusion length in nanocrystalline Si:H solar cells. The solar cells were of the p+nn+ type, with light shining from the p+ side, and were made using both low-pressure ECR-plasma deposition and VHF-plasma deposition. The research team found that, as deposited, base layers in the cells were always n-type. Both the doping and mid-level defect densities were estimated from a measurement of capacitance vs. voltage at different frequencies. The n-type doping could either be reduced by compensating the material during growth with ppm levels of boron or increased by adding ppm levels of phosphorus. It was found that there was a distinct correlation between shallow-donor density, and deep-defect density situated at 0.38-0.5 eV below the conduction band, even in intentionally non-doped materials. As doping increased, the mid-level defect density also increased. These observations suggest that the same accidental dopant (probably oxygen) may be responsible for both donor and deeper states. The diffusion length of holes was measured using combinations of capacitance and quantum efficiency measurements. As the mid-level defect density increased, the diffusion length decreased. From the measurements, the group concluded that the nanocrystalline Si:H solar cell is not a drift-controlled but rather diffusion-controlled device.

Publications:
1. Dalal, V. L., P. Sharma, D. Staab, M. Noack, and K. Han. Accepted. Defect densities, diffusion lengths and device physics in nanocrystalline Si:H solar cells. In *Materials Research Society Proceedings.*
2. Dalal, V. L., J. Zhu, J. Graves, and J. Koch. In press. Electronic transport in microcrystalline Si:H. *Journal of Non-Cryst. Solids.*
3. Dalal, V. L., M. Welsh, M. Noack, and J. H. Zhu. 2003. Microcrystalline Si:H cells grown using ECR plasma process. *IEE Proc.-Circuits, Devices and Syst.* 150: 316. (Invited.)

View of plasma used for depositing nanocrystalline Si photovoltaic devices

PROPERTIES OF A-Si:H AND A-(Si,Ge):H FILMS GROWN USING COMBINED HOT WIRE-ECR PLASMA PROCESSES

This research demonstrates that low-energy ion bombardment is needed to promote the growth of high-quality amorphous materials. The group's experiment consisted of growing a-Si:H and a-(Si,Ge):H using hot wire deposition, while simultaneously subjecting the growing film to low-energy (~10 eV) H and He ions generated in a low-pressure ECR reactor. Experiments show that the primary mode of film growth is from the catalytic decomposition of silane and germane from the hot wire, with less than 10 percent growth resulting from plasma decomposition. A systematic set of measurements of film properties made at different substrate temperatures and ion bombardment conditions reveals that ion bombardment results in a decrease of H concentration and in the ratio of dihydride- to monohydride-bonded silicon and germanium. The presence of ions resulted in a significant decrease of the Urbach energy of valence-band tails to below 50 meV. Photoconductivity improves by orders of magnitude, as does the photosensitivity ratio. This experiment offers definitive proof that low-energy ion bombardment is useful for improving the properties of a-Si:H and a-(Si,Ge):H films and devices.

Publications:
1. Ring, M. A., V. L. Dalal, and K. Muthukrishnan. Accepted. Properties of a-Si and a-(Si,Ge) films grown using combined ECR-hot wire processes. *Journal of Non-cryst. Solids.*
2. Dalal, V. L., P. Seberger, M. Ring, and P. Sharma. 2003. Growth of a-Si films using combined hot wire-ECR process. *Thin Solid Films* 430:91.
3. Dalal, V. L. 2002. Fundamental considerations governing the growth of a-Si and a-(Si,Ge). *Current Opinions in Solid State Materials* 6: 455. (Invited.)

COMMUNICATIONS, CONTROL, AND SIGNALS

The Communications, Control, and Signals group focuses on innovative research in the areas of wireless communications and the control of complex dynamic systems. Major research areas are statistical signal processing; wireless communications; coding and modulation; bioinformatics, modeling and visualization of uncertain information; nanoscale systems; and the design of hybrid, real-time, and discrete-event systems. This diversity of expertise facilitates leading edge research in signal processing, communications, and control system design and modeling.

Sang Kim, Chair

COMMUNICATIONS AND SIGNAL PROCESSING

Primary Members
Viren Amin
Jennifer Davidson
Julie Dickerson
Aleksandar Dogandzic
Yao Ma
Ralph E. Patterson
Zhengdao Wang

Secondary Members
Eric Bartlett
John Bowler
Nicola Bowler
Randall Geiger
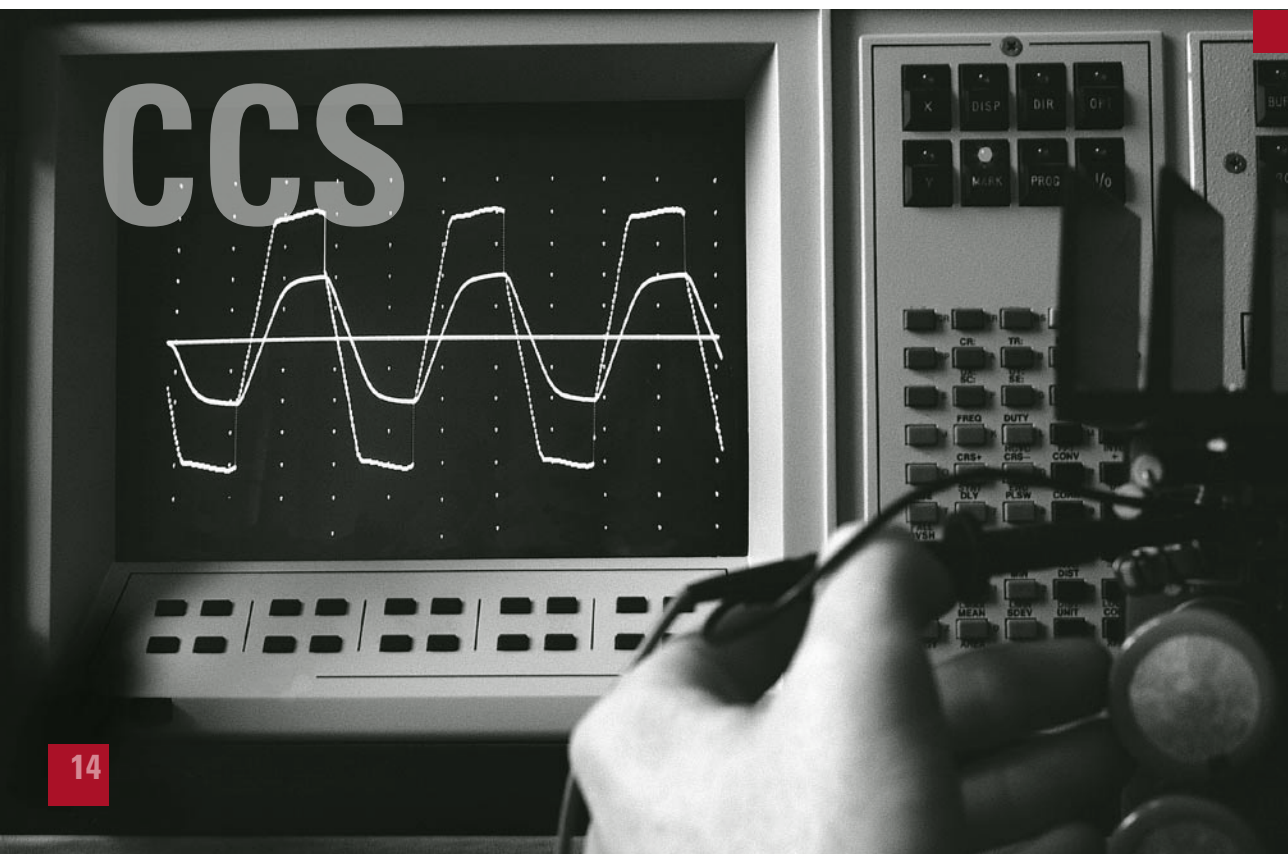Steve Russell
Robert Weber
Clive Wood

SYSTEMS AND CONTROLS

Primary Members
Nicola Elia
Ratnesh Kumar
Murti Salapaka

Secondary Members
Venkataramana Ajjarapu
Degang Chen
James McCalley
Vijay Vittal

CCS

WIRELESS MULTIMEDIA COMMUNICATIONS FOR VIRTUAL ENVIRONMENTS

An NSF Combined Research Curriculum Development (CRCD) project at Iowa State University integrates research from the areas of wireless communications, low-power embedded systems, virtual environments, and human factors in an interdisciplinary program. The project involves both research and education activities. The research goal is to design and implement low-power wireless communications systems for wearable sensor networks in virtual environments. The new communication systems are expected to provide unified and extensible communication mechanisms between heterogeneous sensing devices (e.g., accelerometer, data glove, and wand) and virtual reality applications. The C6, a three-dimensional, full-immersion synthetic environment at Iowa State University, serves as a testbed to demonstrate these systems. The education goal of the project is to develop an integrated program in which faculty members from different disciplines work closely together to mentor students to solve complex interdisciplinary problems that combine real-time systems, wearable computers, human factors, virtual reality (VR), and wireless devices.

PIs: Julie A. Dickerson, Carolina Cruz-Neira, Robert J. Weber, Diane Rover
Students: Feng Chen, Eric Eekhoff, Galen Faidley, Jayme Hero, Kukjin Lee, Bernard Lwakabamba, Rob Walstrom
Funding: National Science Foundation

Publications:

1. Lwakabamba, B., J. E. Hero, and J. A. Dickerson. Submitted. Using virtual reality environments to enhance the undergraduate communications systems laboratory. *IEEE Transactions on Education.*

Wireless multimedia communication for C6

2. Lee, K., D. T. Rover, J. Dickerson, R. Weber, C. Cruz-Neira, B. Lwakabamba, F. Chen, and R. Walstrom. 2004. CRCD: Low-power wireless communications for virtual environments—Design document. In *2004 ASEE Annual Conference.* June, Utah.

3. Rover, D., J. Dickerson, R. Weber, C. Cruz-Neira, K. Lee, and Z. Min. 2003. Using a design document to support interdisciplinary learning. In *33rd ASEE/IEEE Frontiers in Education Conference.* November, Boulder, Colorado.

4. Dickerson, J., D. Rover, R. Weber, C. Cruz-Neira, E. Eekhoff, B. Lwakabamba, F. Chen, and Z. Min. 2003. CRCD: Low-power wireless communications for virtual environments—Course integration. In *2003 ASEE Annual Conference.* June, Nashville.

5. Chen, F., and R. J. Weber. 2003. Optimization technique for simultaneous noise and input/output impedance match of an integrated 5 GHz CMOS low-noise amplifier. In *15th International Conference on Wireless Communications*, 148–53. Canada.

6. Dickerson, J. A., D. T. Rover, C. Cruz-Neira, R. J. Weber, B. Graubard, F. Chen, and Z. Min. 2002. CRCD: Low power wireless communications for virtual environments. In *2002 American Society for Engineering Education.* June, Toronto. (Invited.)

7. Graubard, B., F. Chen, Z. Min, B. Lwakabamba, R. J. Weber, D. Rover, C. Cruz-Neira, and J. A. Dickerson. 2002. Lessons learned: Installing a wireless system in the C6 virtual reality environment. In *IEEE Virtual Reality 2002 Immersive Projection Technology Symposium.* Orlando, Florida.

Networks in Feedback and Feedback in Networks

This research focuses on understanding the interaction between information and control and applying the findings to problems of control over communication networks, network controls, cooperative multi-agent systems, and biological systems.

Quantization and Hybrid Systems

The main logical difficulty in the coexistence of control and communication systems is that, at some level, the analog dynamics need to be quantized to interface properly with the digital communication system. In this context, PI N. Elia has developed results on stability and performance guarantees for linear systems with quantized state information.

Stabilization over Communication Channels

The PI has analyzed the remote stabilization of an unstable plant over a network that drops packets under a new unifying viewpoint. This analytical approach interprets the channels' stochastic models as uncertain stochastic systems and includes them within the robust control framework.

Feedback in Networks

In studying the interaction and integration of communication and control, important questions arise with regard to the benefits of feedback in communication systems. The objective of this research is to analyze the feedback communication schemes from a feedback system theory viewpoint. The most important result for Gaussian channels states that the communication rate achievable by the communication system is given by the Bode integral formula, which characterizes a fundamental limitation of feedback systems.

Publications:
1. Elia, N. Accepted. Stabilization of systems over analog memoryless channels. *Systems and Control Letters.*
2. Elia, N. In press. When Bode meets Shannon: Control oriented feedback communication schemes. *IEEE Transactions on Automatic Control* (special issue on networked control).
3. Liu, J., and N. Elia. 2004. Quantized stabilization of single-input nonlinear affine systems. In *International Journal of Control.*
4. Liu, J., N. Elia, and S. Tatikonda. 2004. Capacity achieving feedback scheme for Markov channels with channel state information. In *Proc. IEEE ISTS.*
5. Elia, N. 2002. Stabilization of systems with erasure actuation and sensory channels. In *Proceedings of the 40th Allerton Conference on Communication, Control, and Computing.*
6. Elia, N., and S. K. Mitter. 2001. Stabilization of linear systems with limited information. In *IEEE Transactions on Automatic Control.*

HIGH BANDWIDTH AND MINIMALLY INVASIVE MICRO-CANTILEVER SENSING BASED ON TRANSIENT DYNAMICS AND THERMAL NOISE EFFECTS

To investigate material and processes at the nanoscale, it is becoming increasingly evident that the probing device, a micro-cantilever in atomic force microscopes (AFMs), has to be maintained at sub-nanometer separations from the sample being probed for long periods of time. For example, the cantilever tip is held at sub-nanometer separations for extended periods to observe the spin flips. The NanoDynamics Lab has developed such a method without introducing any external forcing of the micro-cantilever. This method introduces, for the first time, a static, non-contact mode of operation to the AFM that facilitates the unaltered observation of physical processes at the nanoscale level. The method utilizes the effective resonant frequency of the micro-cantilever, estimated by means of the thermal noise response needed to regulate the probe-sample separation. Separation as small as three nanometers was maintained for twenty minutes. This enabling

method is poised to open a new level of capabilities for the discovery and study of phenomena in the nanometer regime. The figure above shows that topographic profiles at Angstrom scales can easily be detected using this method.

In the typical dynamic mode operation of AFMs, steady-state signals such as amplitude and phase are used for the detection and imaging of material. In these methods, resolution and bandwidth are dictated by the quality factor (Q) of the cantilever. The PI's group has developed a methodology that exploits the *transient* part of the cantilever motion. The new principle overcomes the fundamental limitations of the trade-off between resolution and bandwidth in existing methods and makes them independent of the quality factor, thereby providing an ultra-fast method for detection. Experimental results in which a *twofold increase in bandwidth was observed* corroborate the theoretical development. Significantly enhanced resolution of small time-scale
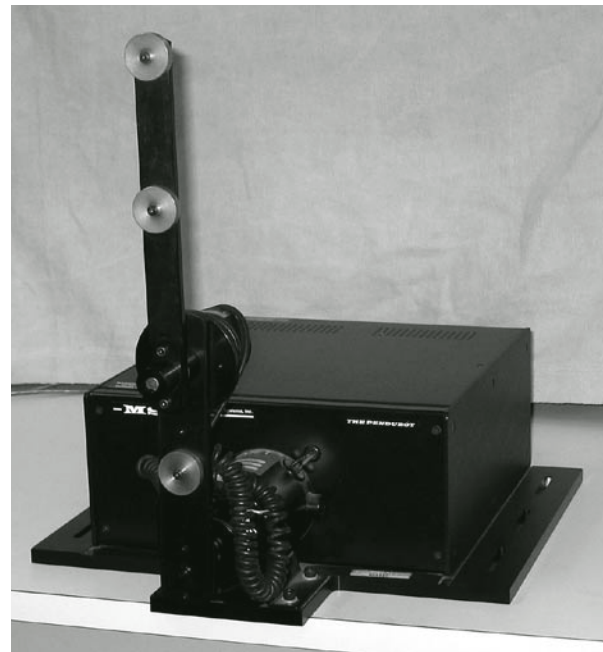
Network-limited control of pendubot

events is another added benefit. This is a pioneering model-based approach for imaging at the nanoscale.

Publications:
1. Sahoo, D., A. Sebastian, and M. V. Salapaka. 2003. Transient signal based sample-detection in atomic force microscopy. *Applied Physics Letters* (December).
2. Gannepalli, A., A. Sebastian, J. P. Cleveland, and M. V. Salapaka. Thermal noise response based control of tip-sample separation in AFM. In *American Control Conference*, 3122–7. Boston, Massachusetts.

INTEGRATED PARAMETER AND CONTROL DESIGN

A new approach was recently developed to solve the l_1 robust performance problem, with an emphasis on obtaining global optimal solutions. This approach is based on using linear approximation for the bilinear nonconvex constraints that result in the l_1 robust performance problem. It was established that converging upper and lower bounds could be obtained by solving a sequence of linear programming (LP) problems, a method that applies to problems with any number of uncertainty blocks. Furthermore, since the solution is obtained using only LP problems, existing LP tools can be utilized effectively. A software tool incorporating this method has been developed, and all solutions demonstrate its effectiveness. This significant new paradigm solves an important open problem and can be used for the simultaneous design of plant and controller.

Publications:
1. Xin, Q., M. Khammash, and M. V. Salapaka. 2002. Integrated parameter and control design. In *American Control Conference* 6:4888–93. Anchorage, Alaska.
2. Khammash, M., M. V. Salapaka, and T. VanVoorhis. 2001. Robust synthesis in l_1: A globally optimal solution. *IEEE Trans. Automatic Control* 46 (11, November): 1744–54.

MODEL DEVELOPMENT, CONTROL DESIGN OF BROADBAND NANOPOSITIONERS, AND APPLICATION TO MICROCANTILEVER-BASED IMAGING

In collaboration with Asylum Research, a new nano-positioning device suitable for imaging biological samples as part of an AFM was designed and fabricated. It was demonstrated that the conventional architecture does not meet the bandwidth and resolution requirements for positioning. The design and implementation of a robust control paradigm demonstrated substantial improvements in positioning speed and precision, while eliminating the undesirable nonlinear effects of the actuator. This work resulted in bandwidth that was 70 times greater than the bandwidth of existing architectures. The design of controllers that can incorporate structure is also being developed, with emphasis on the development of algorithms that can also address multiple objectives.

Publications:
1. Qi, X., M. V. Salapaka, P. G. Voulgaris, and M. Khammash. Accepted. Structured optimal and robust control with multiple criteria: A convex solution. *IEEE Trans. Automatic Control.*
2. Salapaka, S., A. Sebastian, J. P. Cleveland, and M. V. Salapaka. 2002. High bandwidth nano-positioner: A robust control approach. *Review of Scientific Instruments* 73 (9, September): 3232–324.

SPACE-TIME TRANSMITTER AND RECEIVER DESIGN FOR NEAR-CAPACITY COMMUNICATIONS

Due to frequency resource limitations and increasing demand for high-rate services, space-time communications are likely to become instrumental for future high-rate wireless communication systems. In space-time communications, multiple antennas are employed at the transmitter and/or receiver. This project addresses the problems of delay-constrained, medium-length space-time code design; high decoding complexity; and the development of low-complexity decoding algorithms. It also addresses the problem of space-time channel estimation by developing an expectation maximization-based channel estimation algorithm that can iteratively refine its estimate based on estimated information symbols.

Publications:
1. Mo, W., Z. Wang, and A. Dogandzic. Submitted. An iterative receiver for coded MIMO system in unknown spatially colored noise. *Wiley's Wireless Communications and Mobile Computing.*

2. Dogandzic, A., W. Mo, and Z. Wang. 2004. Maximum likelihood semi-blind channel and noise estimation using the EM algorithm. *IEEE Trans. Signal Processing* 52 (6): 1791–7.

3. Mo, W., and Z. Wang. 2004. Average symbol error probability and outage probability analysis for general cooperative diversity system at high signal to noise ratio. In *Conference on Information Sciences and Systems.* March, Princeton, New Jersey.

4. Mo, W., Z. Wang, and A. Dogandzic. 2003. Iterative channel estimation and decoding for coded MIMO system in unknown spatially correlated noise. In *Proc. of Allerton Conf.* October, Urbana-Champaign, Illinois.

5. Dogandzic, A., W. Mo, and Z. Wang. 2003. Maximum likelihood semi-blind channel and noise estimation using the EM algorithm. In *Proc. of 37th Conf. on Info. Sciences and Systems.* 12–14 March, Johns Hopkins University, Baltimore, Maryland.

CONTROL OF MARKOV CHAINS WITH QUALITATIVE CONSTRAINTS

This research addresses the issues in stochastic systems modelled by Markov processes and studies control problems that satisfy qualitative properties such as the following:

- Safety: The state probability distribution at each step lies in a 'safe' set.
- Progress/Non-blocking: The probability of hitting a target set of states stays above a certain minimum value.
- Recurrence/Liveness: The probability of hitting a target set of states infinitely often is bounded below by a constant.
- Convergence/Stability: The state probability distribution enters and stays in a 'safe' set within a finite number of steps.

PI: Ratnesh Kumar
**Collaborator:** A. Arapostathis (University of Texas at Austin)
Funding: National Science Foundation

Publications:
1. Arapostathis, A., R. Kumar, and S. Tangirala. 2003. Controlled Markov chains with safety upper bounds. *IEEE Transactions on Automatic Control* 48(7): 1230–4.

2. Arapostathis, A., R. Kumar, and S.-P. Hsu. 2003. State-feedback control of Markov chains with safety bounds. In *2003 IEEE Conference on Decision and Control.* December, Maui, Hawaii.

3. Arapostathis, A., R. Kumar, and S. Tangirala. 2001. Controlled Markov chains and safety criteria. In *2001 IEEE Conference on Decision and Control,* 1675–80. Orlando, Florida.

DIVERSITY RECEPTION OF WIRELESS COMMUNICATION WITH PARTIAL CHANNEL KNOWLEDGE AND GENERALIZED FADING

Future wireless communication systems with high data rates and multimedia traffic will demand higher spectral efficiency and more reliable communication links than are available today. Most research of the analysis and design of advanced wireless communication systems (e.g., MIMO, MC-CDMA) either has been confined to unrealistic or restrictive fading channel conditions or has assumed perfect channel state information at the transmitter or receiver. There is a lack of understanding of the effects of partial channel knowledge and generalized fading conditions on the achievable performance of existing systems and techniques.
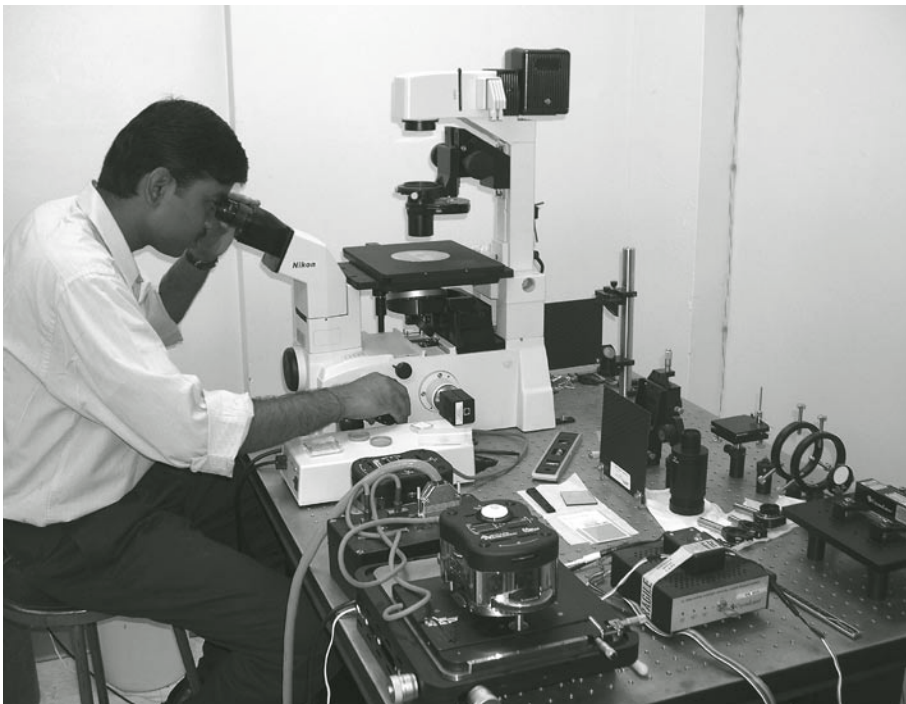
Optical tweezer for control application

This research investigates the effects of imperfect channel estimation (ICE) and generalized fading conditions on high-rate and high-diversity-gain communication systems (e.g., OFDM and MIMO) and determines their performance limits. It also seeks design criteria and methods for MIMO, OFDM, and adaptive modulation that are robust to ICE and near optimal when operating in generalized fading conditions.

Publications:

1. Ma, Y., Q. T. Zhang, R. Schober, and S. Pasupathy. Accepted. Diversity reception of DAPSK over generalized fading channels. *IEEE Transactions on Wireless Communications.*
2. Ma, Y., and S. Pasupathy. 2004. Efficient performance evaluation for generalized selection combining on generalized fading channels. *IEEE Transactions on Wireless Communications* (January): 29–34.
3. Ma, Y., R. Schober, and S. Pasupathy. 2004. Effect of imperfect channel estimation on MRC diversity in fading channels. In *Proceedings, IEEE ICC.* June, Paris.
4. Ma, Y., S. Pasupathy, and T. J. Lim. 2003. Analysis of differentially coherent linear receivers over rician-faded CDMA channels. *IEEE Transactions on Wireless Communications* 2 (4, July): 758–72.
5. Ma, Y., Z. Wang, and S. Pasupathy. 2003. Asymptotic gains of generalized selection combining. In *Proceedings, IEEE VTC'03* (October). (Invited paper.)

DIVERSITY COMBINING AND INTERFERENCE CANCELLATION BASED ON THE LOG-LIKELIHOOD RATIO

This work deals with new techniques for diversity selection combining and interference cancellation based on the log-likelihood ratio (LLR). The motivation for using the LLR is that it provides instantaneous information on the reliability of the maximum a posteriori probability decision, which minimizes the probability of symbol error. The proposed techniques provide significant power savings and increased data reliability compared to conventional signal-to-noise, ratio-based diversity selection or ordering and can be used in numerous wireless communication systems, such as MIMO systems and wireless sensor networks.

Publications:

1. Kim, S. W., Y. G. Kim, and M. K. Simon. 2004. Generalized selection combining based on the log-likelihood ratio. In *IEEE Transactions on Communications* (April): 521–4.
2. Kim, Y. G., and S. W. Kim. 2004. Log-likelihood ratio based generalized selection combining for M-ary signalling. In *IEEE International Conference on Communications (ICC)*. June, Paris, France.
3. Kim, Y. G., and S. W. Kim. 2003. Difference threshold test for M-ary orthogonal FSK signalling in Rayleigh fading channels. In *IEEE International Conference on Communications (ICC)*. May, Anchorage, Alaska.
4. Kim, S. W. 2003. Log-likelihood ratio based detection ordering for the V-BLAST. In *IEEE Globecom*. December, San Francisco, California.
5. Kim, Y. G., and S. W. Kim. 2003. Difference threshold test for M-ary signaling with coherent detection. In *IEEE Globecom.* December, San Francisco, California.

COOPERATIVE DIVERSITY AND SPATIAL MULTIPLEXING IN WIRELESS NETWORKS

Typically, communication environments are constrained by resources and space. System designs in such highly constrained scenarios are challenging because communication patterns can be very complicated. This project investigates cooperative diversity and spatial multiplexing techniques using distributed antennas belonging to different wireless terminals. Such cooperative communication allows a user terminal to act as a relay and assist another terminal in transmitting, detecting, and estimating information. Goals of the project include maximizing diversity gains and multiplexing gains in cooperative communication networks by finding the optimum rate and power allocation between the source and the relay.

Publication:

1. Cherukuri, R., and S. W. Kim. 2004. Optimum power allocation in log-likelihood ratio based cooperative. In *IEEE Vehicular Technology Conference.* September, Los Angeles, California.

## SIGNAL AND IMAGE PROCESSING FOR NONDESTRUCTIVE EVALUATION OF MATERIALS

This project deals with the development of a user-friendly software package that integrates a broad spectrum of basic algorithms for detecting, enhancing, classifying, and interpreting nondestructive evaluation (NDE) signals and images from multiple NDE inspection modalities. Project investigators have developed methods for flaw detection in correlated noise [1,2], a statistical model for eddy-current defect signals from steam generator tubes [3], Cramer-Rao bound-based performance and design measures for eddy-current NDE systems [4], and a maximum a posteriori method for estimating and detecting NDE defect signals using hidden Markov models [5].

Publications:

1. Dogandzic, A., and N. Eua-anant. In press. Maximum a posteriori defect estimation and detection using hidden Markov models. In *Proceedings Annual Review Progress Quantitative Nondestructive Evaluation.* July, Golden, Colorado.

2. Dogandzic, A., and N. Eua-anant. 2004. Defect detection in correlated noise. In *Rev. Progress Quantitative Nondestructive Evaluation.* Ed. D. O. Thompson and D. E. Chimenti 23: 628–35. Melville, New York: Amer. Inst. Phys.

3. Dogandzic, A., and P. Xiang. 2004. A statistical model for eddy-current defect signals from steam generator tubes. In *Review of Progress Quantitative Nondestructive Evaluation.* Ed. D. O. Thompson and D. E. Chimenti 23:605–12. Melville, New York: Amer. Inst. Phys.

4. Dogandzic, A., and A. Nehorai. 2003. Generalized multivariate analysis of variance: A unified framework for signal processing in correlated noise. *IEEE Signal Processing Magazine* 20 (September): 39–54.

5. Bowler, J. R., W. Zhang, and A. Dogandzic. 2003. Application of optimization methods to crack profile inversion using eddy current data. In *Rev. Progress Quantitative Nondestructive Evaluation.* Ed. D. O. Thompson and D. E. Chimenti 22: 742–9. Melville, New York: Amer. Inst. Phys.

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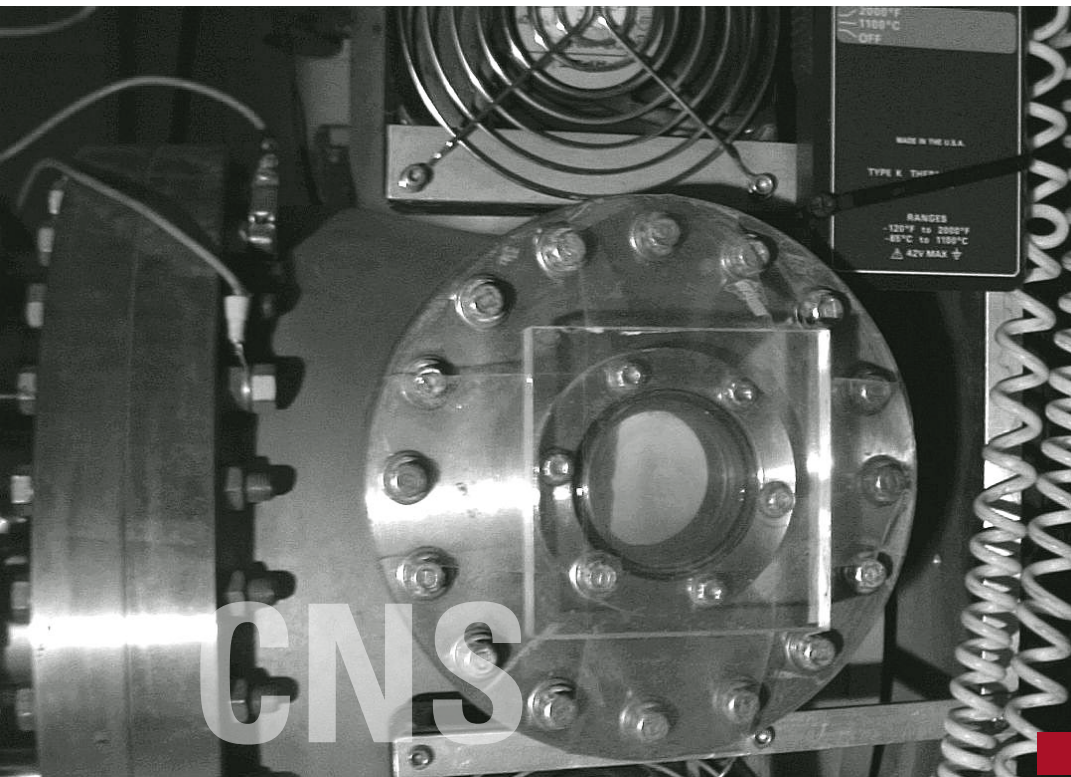
Akhilesh Tyagi, Chair

Primary Members
   Morris Chang
   Ahmed Kamal
   Daji Qiao
   Arun Somani
   Zhao Zhang
Secondary Members
   Chris Chu
   Manimaran Govindarasu
   Yong Guan
   Doug Jacobson
   Sang W. Kim
   Yao Ma
   Mani Mina
   Ralph Patterson
   Diane Rover
   Jiming Song
   Srikanta Tirthapura
   Zhengdao Wang

COMPUTING AND NETWORKING SYSTEMS

The mission of this group is to address issues of performance, power management, security, reliability, and cost in computer and network systems and the development of distributed programming models. In computer system design, active research projects include developing microarchitecture solutions to achieve high levels of integrity, security, privacy, and energy efficiency, as well as designing embedded systems, high-speed processors, and memory systems. In network systems, major research thrusts are in WDM-based optical networking, wireless and ad hoc networks, network quality of service, data structures and algorithms for distributed computer systems, and middleware solutions.

PERFORMANCE ENHANCEMENT IN WIRELESS LOCAL AREA NETWORKS

The main objective of this project has been to address, from various related but distinct angles, the problem of enhancing the performance of the IEEE 802.11 distributed coordination function (DCF) systems that dominate the U.S. WLAN market. Due to the inherent trade-off between maximization of channel utilization and fair allocation of bandwidth, it is very difficult to achieve both design goals at the same time in an 802.11 DCF system. In the first part of the project, we studied this challenge and proposed a simple weighted-fair and bandwidth-efficient enhancement to the DCF, particularly for data communications. In the second part of the project, we investigated the problem of minimizing energy consumption in the emerging 802.11a/h systems that will provide a structured means to support intelligent transmit power control (TPC). We developed a novel scheme, called "MiSer," as an optimal solution. The key idea is to combine TPC with physical layer (PHY) rate adaptation and compute offline an optimal rate-power combination table; then, at runtime, a wireless station determines the most energy-efficient transmission strategy for each data frame transmission by a simple table lookup. Using a similar table-driven idea, we also developed an intelligent link adaptation scheme for 802.11a DCF systems that fully exploits the multiple transmission rates of the 802.11a PHY. As the final component of the project, we implemented a new RT-WLAN device driver module that extends the original Linux device driver for the popular Agere ORiNOCO cards to support soft real-time communications.

PI: Daji Qiao
Funding: ECpE Research Initiation

Publications:
1. Qiao, D., S. Choi, A. Jain, and K. G. Shin. 2003. MiSer: An optimal low-energy transmission strategy for IEEE 802.11 a/h. In *Proc. ACM MobiCom 2003.* 14–19 September, San Diego, California.
2. Jain, A., D. Qiao, and K. G. Shin. 2003. RT-WLAN: A soft real-time extension to the ORiNOCO Linux device driver. In *Proc. IEEE PIMRC 2003.* 7–10 September, Beijing, China.
3. Qiao, D., and K. G. Shin. 2003. UMAV: A simple enhancement to the IEEE 802.11 DCF. In *Proc. of the 36th Hawaii International Conference on System Sciences (HICSS-36).* 6–9 January, Hawaii.
4. Qiao, D., S. Choi, and K. G. Shin. 2002. Goodput analysis and link adaptation for IEEE 802.11a wireless LANs. *IEEE Transactions on Mobile Computing (TMC)* 1 (4, October-December).
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6. Qiao, D., and K. G. Shin. 2002. Achieving efficient channel utilization and weighted fairness for data communications in IEEE 802.11 WLAN under the DCF. In *Proc. of the Tenth International Workshop on Quality of Service (IWQoS 2002).* 15–17 May, Miami Beach, Florida.

WDM-based Optical Fiber Networks: Algorithms, Architectures, and Issues in Design and Operation

Wavelength division multiplexing (WDM) has emerged as a dominant technology. Members of the research team have been studying the following aspects of WDM-based optical fiber technology:

Power efficient VLSI design

## Routing, Wavelength Assignment, and Wavelength Converter Placement

Routing, wavelength assignment, and wavelength converter placement are important issues for the effective use of resources. The team has developed the first analytical framework for the accurate analysis of networks employing a given number of converters in an arbitrary topology as well as a computationally efficient algorithm for wavelength converter placement to minimize call-blocking probability.

Modeling and Analysis of Optical Grooming Networks

Providing low-rate bandwidth on high-speed channels is performed by equipping nodes with switching capabilities in wavelength and/or time-slot/code domains. The research group has developed a trunk switched network (TSN) model and has used it to study several connection-establishment algorithms and protection strategies. Moreover, it has been shown that the existing routing and wavelength assignment solutions are unfair to different capacity requests and an admission-control algorithm has been developed to attain fairness in capacity without unduly penalizing the overall blocking performance.

Light Trail Realization: A High-speed Solution for LANs/MANs

A light trail is a unidirectional optical bus between a start and an end node, with the characteristic that intermediate nodes can also access this bus. Light trail technology avoids costly OEO switching at intermediate nodes and offers complete transparency to the bit-rate, format, and protocol of a signal. Utilizing the Xilinx Virtex II Pro FPGA with embedded Power PC microcontroller and 8-channel Rocket IO serial/deserializer (SERDES) controllers, a 4-node prototype light trail has been developed that optimizes the MAC protocol and fairness within a single light trail.
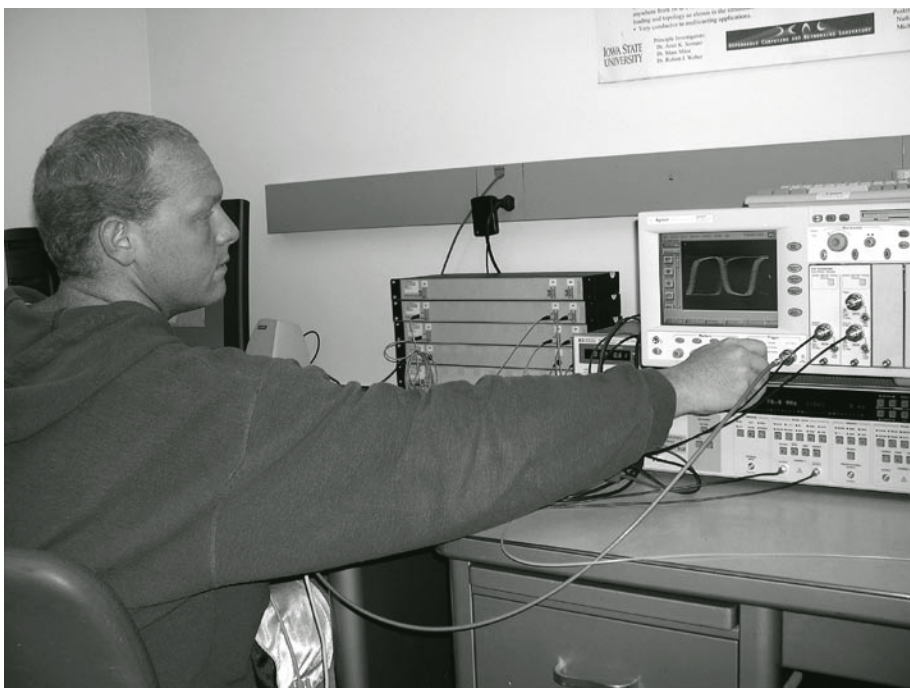
Light trail architecture for high-speed networks

Design and Operation of Survivable WDM Networks

The team has developed link-based and path-based restoration models for surviving single- and dual-link failures in mesh optical networks using the concept of backup multiplexing. The team has also developed an alternative known as sub-graph routing-based fault tolerance, in which backup paths for each connection are pre-computed proactively and optimized offline for a specified set of link failure situations. This strategy has been shown to outperform the aforementioned backup multiplexing scheme.

Attack Management, Diagnosis, and Monitor Placement

In a WDM-based optical network, the effects of an attack channel can propagate quickly to different parts of a transparent all-optical network. The team developed diagnostic algorithms that use idle wavelengths to set up diagnostic connections. A relatively small number of monitors are placed on a selected set of nodes in a network, with the resulting solution achieving the required level of performance. Necessary and sufficient monitoring conditions for detecting and localizing the malicious channels have also been identified. A scalable diagnosis method has also been developed.

ISTOS: Iowa State Optical Network Simulator

The research team has developed a simulation tool called ISTOS to simulate and analyze the performance of connection establishment and network survivability protocols in optical wavelength division multiplexing (WDM) networks. ISTOS consists of a front-end Windows graphical user interface and a back-end simulator engine. The back end is based on the MICRON framework for heterogeneous switching architectures and includes a variety of standard and fault-tolerant routing and trunk-assignment protocols.

PIs: Arun Somani, Ahmed Kamal, Mani Mina
Students: S. Balasubramaniam, Pallab Datta, Jing Fang, M. T. Frederick, W. He, Nitin Jose, Ling Li (PhD'00), Murari Sridharan (PhD'02), R. Srinivasan (PhD'02), S. Thiagarajan (PhD'01), N. Vanderhorn, Tao Wu (PhD'03), Yana Yong
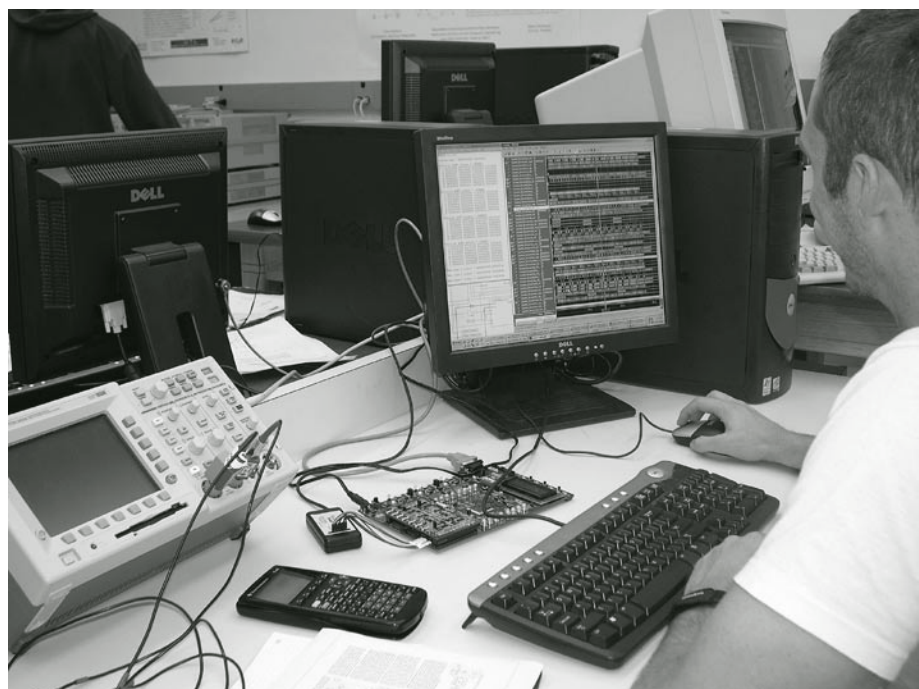
Publications:

1. Srinivasan, R., and A. K. Somani. In press. Analysis of optical networks with heterogeneous grooming architectures. *IEEE/ACM Transactions on Networking.*
2. Somani, A. K., M. Mina, and L. Li. 2004. On trading wavelengths with fibers: A cost-performance based study. In *IEEE/ACM Transactions on Networking.* October.
3. Frederick, M. T., N. A. VanderHorn, and A. K. Somani. 2004. Light trails: A sub-wavelength solution for optical networking. Workshop on High Performance Switching and Routing. 2–4 February.
4. He, W., J. Fang, and A. K. Somani. 2004. On survivable design in light trail optical networks. In *Proceeding of 8th IFIP Working Conference on Optical Network Design and Modeling.* 2–4 February.
5. Balasubramanian, S., A. Kamal, and A. K. Somani. 2004. Medium access control protocols for light trail and light bus networks. In *Proceeding of 8th IFIP Working Conference on Optical Network Design and Modeling.* 2–4 February.
6. Datta, P., M. T. Frederick, and A. K. Somani. 2003. Sub-graph routing: A novel fault-tolerant architecture for shared-risk link group failures in WDM optical networks. In *4th International Workshop on the Design of Reliable Communication Networks (DRCN 2003).* Banff, Alberta, Canada.
7. Jose, N., and A. K. Somani. 2003. Connection rerouting/network reconfiguration. In *4th International Workshop on the Design of Reliable Communication Networks (DRCN 2003).* Banff, Alberta, Canada.
8. Srinivasan, R., and A. K. Somani. 2003. On achieving fairness and efficiency in high-speed shared medium networks. *IEEE/ACM Transactions on Networking* 11 (1, February): 111–24.
9. Wu, T., and A. K. Somani. 2002. Attack monitoring and localization in all-optical networks. In *OptiComm 2002.* July. (Best paper award winner.)
10. Srinivasan, R., and A. K. Somani. 2002. A generalized framework for analyzing time-space switched optical networks. *IEEE Journal of Selected Areas in Communications* (January): 202–15.
11. Sridharan, M., M. V. Salapaka, and A. K. Somani. 2002. A practical approach to operating survivable WDM networks. *IEEE Journal of Selected Areas in Communications* 20 (1, January): 34–46.
12. Mohan, G., A. K. Somani, and M. Salapaka. 2001. Efficient algorithms for routing dependable connections in WDM optical networks. *IEEE/ACM Transactions on Networking* 9 (5, October): 553–66.
13. Thiagarajan, S., and A. K. Somani. 2001. Traffic grooming for survivable WDM mesh networks. *Opticomm: Optical Networking and Communications* 4599:54–65.
14. Li, L., and A. K. Somani. 2000. A new analytical model for multifiber WDM networks. *IEEE Journal on Selected Areas in Communications* 18 (10, October): 2138–45.

RECONFIGURABLE COMPUTING AND ON-CHIP ADAPTIVE COMPONENTS FOR BALANCED COMPUTING

The goal of this research is to study and evaluate the effects of integrating reconfiguration components such as register files and cache memory systems, which also can act as on-chip function units (FUs) for computation-intensive functions. This requires (1) dynamically programmable cache memory, register files, and FUs, so that memory space mapping and effective management of data and configuration flow reduce the application's I/O bandwidth requirement; (2) caches and register files that are reconfigurable as multi-function FUs; and (3) reconfigurable multiple buses, which will provide effective connectivity among the FUs and cache memories.

A powerful concept called adaptive balanced computing (ABC) was developed. ABC performs a dynamic resource configuration of on-chip cache memory by converting the cache into a specialized computing unit. A reconfigurable functional cache (RFC) was designed by employing a fixed-size cache memory with a small

Reconfigurable computing for computer vision application

amount of additional logic and slightly modified microarchitecture. A part of the cache memory can be configured to perform specialized computations in a conventional processor. A similar technique can also be used in the design of a register file where registers and functional units can be traded. The group designed and evaluated the ABC using RFCs in various cache configurations.

Simulations with multimedia and DSP applications show that increases in speed can be achieved ranging from 1.04X to 3.94X in overall applications and from 3 to 27 times in core computations. Thus, multimedia applications can benefit from these schemes.

Publications:
1. Sangireddy, R., H. Kim, and A. K. Somani. In press. Low-power high-performance adaptive computing architectures for multimedia processing. *IEEE Transactions on Computers.*
2. Sangireddy, R., and A. K. Somani. 2003. Application-specific computing with adaptive register file architectures. In *Proceedings of the IEEE Conference on Application-specific Systems, Architectures and Processors*, 183–93. June.
3. Sangireddy, R., H. Kim, and A. K. Somani. 2003. Timing issues of operating mode switch in high performance reconfigurable architectures. In *Proceedings of HiPC2003, the Tenth Annual International Conference on High Performance Computing*, 23–33.
4. Gossett, K., and A. Tyagi. 2003. The use of a reconfigurable functional cache in a digital signal processor: Power and performance. *Digest of 1st Workshop on Optimization for DSP and Embedded Systems (ODES) at International Symposium on Code Generation and Optimization (CGO).*
5. Sangireddy, R., H. Kim, and A. K. Somani. 2002. Low-power high-performance adaptive computing architectures for multimedia processing. In *Proceedings of HiPC2002, the Ninth Annual International Conference on High Performance Computing,* 124–34. December.
6. Kim, H., A. K. Somani, and A. Tyagi. 2001. A reconfigurable multi-function computing cache architecture. *IEEE Transactions on Very Large Scale Integration Systems* 9 (4, August): 509–23.
7. Singhal, A., A. K. Somani, and A. Tyagi. 2001. Evaluation of a reconfigurable cache module architecture. In *Proceedings of IEEE International Symposium on Field Programmable Custom Computing Machines* (FCCM).
8. Kim, H., A. K. Somani, and A. Tyagi. 2000. A reconfigurable multi-function computing cache architecture. In *Proceedings of FPGA 2000,* 85–94. February.

INTEGRITY MONITORING AND RECOVERY TECHNIQUES FOR MICROPROCESSORS

Microprocessors are being used in increasingly diverse ways and their dependability has become an important measure of their quality. Temporary hardware malfunctions caused by unstable environmental conditions can reduce circuit dimensions, and low-power operation can induce transient or soft errors in the processor's functioning. The goals of this research are (1) to characterize soft error behavior of commercial microprocessors through fault-injection experiments; (2) to provide guidelines for exploiting soft error susceptibility in integrity-checking strategy and predicting error characteristics from the processor's architecture; and (3) to develop comprehensive micro-architectural solutions short of full duplication that go beyond localized solutions for specific aspects of pipeline or cache memory or register file in order to realize high dependability with low hardware and performance overhead. The localized fault protection mechanisms for individual logic blocks were backed up by one or more global protection mechanisms. The area overhead-versus-fault coverage trade-off shows the effectiveness of the proposed solutions. There is ongoing development and analysis of chip- and system-level techniques. This research will provide a basis for enhancing the dependability of cost-sensitive products.

Publications:
1. Somani, A. K., and S. Kim. Under review. Area efficient architectures for information integrity checking in cache memories. (An earlier version of this paper also appeared in *Proceedings of International Symposium on Computer Architecture*, 246–56. May 1999.)
2. Kim, S., and A. K. Somani. 2001. On-line integrity monitoring of microprocessor control logic. *Microelectronics Journal.* (An earlier version of this paper also appeared in *Proc. of ICCD-2001.* September.)
3. Kim, S., and A. K. Somani. 2001. SSD: An affordable fault-tolerant architecture for superscalar processors. In *Proc. of IEEE 2001 Pacific Rim International Symposium on Dependable Computing (PRDC).* December.

4. Nickel, J. B., and A. K. Somani. 2001. REESE: A method of soft error detection in microprocessors. In *Proc. of International Conference on Dependable Systems and Networks*. June.

FAST AND SCALABLE IP LOOKUPS USING RECONFIGURABLE COMPONENTS

With the rapid increase of Internet traffic comes a corresponding increase in the demand for fast packet forwarding at high speed. The key issue in router performance is the IP address lookup mechanism based on the longest prefix matching scheme. Techniques such as software search mechanisms, hardware content-addressable memory, memory lookups, and CPU caching are limited by memory access technology. We have developed binary decision diagrams based on optimized combinational logic for an efficient implementation of a fast address lookup scheme in reconfigurable hardware. The group also explored a software algorithm-based approach for scalable and efficient packet-forwarding mechanisms.

PI: Arun Somani
Collaborator: Srinivas Aluru
Students: N. Futamura (PhD'02), R. Sangireddy (PhD'02)
Funding: Jenkins Chair

Publications:
1. Sangireddy, R., N. Futamura, S. Aluru, and A. K. Somani. To appear. Scalable, memory efficient, high-speed lookup and update algorithms for IP routing. *IEEE Transaction on Networking*.
2. Sangireddy, R., and A. K. Somani. 2003. High-speed IP routing with binary decision diagrams based hardware address lookup engine. *IEEE Journal on Selected Areas in Communications, IEEE J-SAC* 21 (4, May): 513–21.
3. Futamura, N., R. Sangireddy, S. Aluru, and A. K. Somani. 2003. Scalable, memory efficient, high-speed lookup and update algorithms for IP routing. In *Proceedings of ICCCN2003, The IEEE 12th International Conference on Computer Communications and Networks*, 257–63. October.
4. Sangireddy, R., and A. K. Somani. 2001. Binary decision diagrams for efficient hardware implementation of fast IP routing lookups. In *Proceedings of ICCCN2001, Tenth IEEE International Conference on Computer Communications and Networks*, 12–7. October.

WIRELESS COMMUNICATION ISSUES

Important issues involved in wireless data communication include user mobility, location management of user data, channel allocation, bandwidth availability, and high latencies. The PI and his research group are working on several of these areas in traditional infrastructure-based wireless networks and in infra-structure-less ad hoc networks. Ad hoc networks are important because of their ease of deployment and decentralized operation. They are currently used for military applications and may soon be used for commercial applications such as telemedicine and virtual navigation. However, fault tolerance remains a challenging issue in mobile ad hoc networks. Issues being addressed include (1) improving the end-to-end performance of TCP when an interference-prone wireless link may be part of the connection, (2) the efficient management of the service and location information of each mobile phone or other communications device registered in the PCS network, and (3) assuring fairness in ad hoc networks.

PI: Arun Somani
Students: Jinran Chen (MSEE'02), G. Krishnamurthi (PhD'00), I. Peddibhotla (MSEE'00), Jianwei Zhou (MSEE'02)
Funding: Nicholas Chair

Publications:
1. Chen, J., and A. K. Somani. 2003. Fair scheduling in wireless ad-hoc networks of location dependent channel errors. In *Proceedings of IEEE International Performance, Computing, and Communications Conference (IPCCC)*, 103–10. April.
2. Somani, A. K., and J. Zhou. 2003. Achieving fairness in distributed scheduling in wireless ad-hoc networks. In *Proceedings of IEEE International Performance, Computing, and Communications Conference (IPCCC)*, 95–102. April. (Received 'Best Paper' award in the conference.)
3. Krishnamurthi, G., M. Azizoglu, and A. K. Somani. 2001. Optimal distributed location management in mobile networks. *Mobile Applications and Networking (MONET)*. Also appeared in *MOBICOM* 1998.
4. Krishnamurthi, G., S. Chessa, and A. K. Somani. 2000. Fast recovery from database/link failures in mobile networks. *Journal of Computer Communications* 23 (5–6, March): 561–74.

HIGH-SPEED SYSTEMS ENGINEERING

In this project, team members integrate various concepts of high-speed systems engineering to help faculty and students see common issues in networking, VLSI, electromagnetic, microwave, communication, and related groups. In the particular area of optical research, the group has worked on new devices needed for all optical data and communication networks, particularly optoelectronics. Current efforts are directed toward the design of a new fiber-based magneto-optical on-on switch for optical networks. The team is preparing material for intellectual disclosure as well as first publication in *IEEE Transactions on Magnetics*.

PIs: Mani Mina, Arun Somani, Robert Weber, Hans Hauser (Vienna University of Technology)
Student: Rashmi Bahaguna

COMPILER AND MICROARCHITECTURE SUPPORT FOR TRUST MANAGEMENT AND SECURITY

This project develops compiler and processor architecture support for some of the security vulnerabilities in networked computing systems and for establishing trust between multiple computing principals to bypass otherwise computationally expensive security mechanisms. All parties start with some default trust value that is updated on the basis of the transaction history. The compiler inserts appropriate self-monitoring primitives. Such a trust value is continually updated to reflect the most recent program state. We have also developed computational characterizations of various trust management policies that can be implemented as a finite state machine.

We have developed a microarchitectural solution to address the buffer overflow problem and distributed denial of service (DDOS). The buffer overflow places an adversarial value without the ability to correctly encode it. The contents of program values that are program counter-bound are encoded before they are stored in memory. Each memory lookup of these values decodes them. This decoding step subverts the adversary's goals. For the DDOS, we have modeled the normal network traffic behavior with wavelet theory-based analysis. The deviations from this behavior are used to help flag DDOS attacks.

PI: Akhilesh Tyagi

Publications:
1. Tyagi, A., and G. Zhu. 2004. Protection against indirect overflow attacks on pointers. In *Proceedings of IEEE Information Assurance Workshop*. April. IEEE Computer Society Press.
2. Tyagi, A., and G. Zhu. 2004. Program level trust: A compiler managed paradigm for self-assessment. In *Proceedings of Workshop on Secure Knowledge Management (SKM 2004)*. September.
3. Tyagi, A., P. Ramarao, and G. Lee. 2003. Run-time support for detection of memory access violations to prevent buffer overflow exploits. In *Proceedings of Information Security: 6th International Conference, Lecture Notes in Computer Science #2851*, 366–80. Springer Verlag.
4. Tyagi, A., and G. Lee. 2000. Encoded program counter: Self protection from buffer overflow attacks. In *Proceedings of International Conference on Internet Computing (IC '2000)*, 387–94. June.

Programming security

SOFTWARE OBFUSCATION, TAMPER RESISTANCE, AND WATERMARKING

Software piracy resulted in losses up to $12 billion in 2002. This project develops key technologies to prevent software piracy. Program obfuscation transforms a program so that the amount of information derived by an adversary is equivalent for both black-box and white-box observations. Watermarking establishes a proof of software producer identity. Tamper resistance introduces mechanisms to detect any tampering (e.g., code insertion) dynamically.

The basic premise of this project is to compile the program into a two-process program in which one process monitors the other process for certain properties. For obfuscation, the main process's static control-flow ordering is permuted. The correct control-flow ordering permutations are stored in the monitor process. For tamper resistance, the correct control flow is captured as a control-flow data structure within the monitor process. The program process sends the instantiated control flow to the monitor process so that any tampering of the control flow can be detected.

PI: Akhilesh Tyagi
Collaborator: S. Chaudhuri

Publications:

1. Tyagi, A., and B. Blietz. Submitted. Software tamper resistance through dynamic program monitoring. *ACM CCS 2004.*
2. Tyagi, A., G. Jun, and S. Chaudhuri. Submitted. Software obfuscation by hiding control flow information. *ACM Workshop on DRM.*
3. Tyagi, A., and G. Mahadevan. Submitted. How to hide secrets from operating system: Architecture level support for dynamic address trace obfuscation. *ACM/IEEE Micro 2004.*
4. Tyagi, A., and B. Vankatachalam. Submitted. Software watermarking as a proof of identity: Zero knowledge proof based software watermarking. *ISC 2004.*

ROUTING, WAVELENGTH ASSIGNMENT, DIMENSIONING, AND PERFORMANCE OF OPTICAL NETWORKS WITH MULTICAST SERVICE

The PIs and their collaborator have several objectives in their work with multicast services. First, they are developing multicast tree construction algorithms for optical networks, which take into account optical network constraints such as the power budget, wavelength collisions, wavelength continuity, and the cost and type of splitters and wavelength converters. Another objective is optimal network provisioning and dimensioning under multicast service, given traffic demands and cost constraints. The team is also developing routing and wavelength selection algorithms for multicast services in optical networks. In addition, they plan to develop accurate analytical models for the evaluation of call-blocking probabilities under different routing and wavelength selection algorithms. Because the efficient support of multicast traffic requires that traffic branches out at several points in the network, these models are expected to be instrumental.

Publications:

1. Hamad, A., and A. E. Kamal. 2004. Optimal power-aware design of all-optical multicasting in wavelength routed networks. In *Proceedings, IEEE International Conference on Communications, ICC 2004.* June, Paris, France.
2. Ul-Mustafa, R., and A. E. Kamal. 2004. On the grooming of multicast traffic in WDM networks. In *Proceedings, International Symposium on Computers and Communications (ISCC 2004).* June, Alexandria, Egypt.
3. Balasubramanian, S., A. E. Kamal, and A. K. Somani. 2004. Medium access control in light trail and light bus networks. In *Proceedings, IFIP Conference on Optical Networks Design and Modeling (ONDM).* February, Ghent, Belgium.
4. Kamal, A. E., and R. Ul-Mustafa. 2003. Multicast traffic grooming in WDM networks. In *Proceedings of Opticomm 2003*, 25–36. October, Dallas, Texas.
5. Hamad, A., and A. E. Kamal. 2002. A survey of multicasting protocols for broadcast-and-select single-hop networks. *IEEE Network* 16 (3, July): 36–48.

ROBUST REAL-TIME SYSTEM RESOURCE MANAGEMENT USING FEEDBACK

Increasingly, real-time computing systems are expected to be highly dynamic and operate in fault-prone, deterministic environments under strict timing constraints. Therefore, these systems need to be robust while delivering high performance, requiring management techniques that dynamically address real-time requirements and provide graceful degradation in the presence of uncertainty. In the past few decades, feedback control theory has made impressive strides in the area of modelling systems operating in uncertain environments. Correct adaptation as illustrated by feedback control theory will yield significant dividends with respect to robustness. This research focuses on developing a robust resource management framework and scheduling algorithms for real-time systems employing feedback control strategies.

Embedded Java system

Publications:

1. Omari, R. A., A. K. Somani, and G. Manimaran. 2004. Efficient overloading techniques for primary-backup scheduling in real-time systems. *Journal of Parallel and Distributed Computing* 65 (5, May): 629–48.
2. Lin, S., G. Manimaran, and B. Steward. 2004. Feedback-based-real-time scheduling in autonomous vehicle systems. In *Proceedings, IEEE Real-Time Technology and Applications Symposium*, 316–23. May, Toronto, Canada.
3. Omari, R. A., G. Manimaran, M. V. Salapaka, and A. K. Somani. 2003. Novel algorithms for open-loop and closed-loop scheduling of real-time tasks in multiprocessor systems based on execution time estimation. In *Proceedings, IEEE Intl. Parallel and Distributed Processing Symposium*, 7–14. April, Nice, France.
4. Swaminathan, S., and G. Manimaran. 2002. An adaptive value-based scheduler and its RT-Linux implementation. In *Proceedings, International Conference on High Performance Computing (HiPC)*, 163–73. December, Bangalore, India.

5. Sahoo, D., S. Swaminathan, R. A. Omari, M. V. Salapaka, G. Manimaran, and A. K. Somani. 2002. Feedback control for real-time scheduling. In *Proceedings, American Control Conference*, 1254–9. May, Anchorage, Alaska.

DIFFSERV-AWARE MULTICASTING

The proliferation and increasing importance of quality of service (QoS)-aware group applications, coupled with advances in high-speed networking, is driving the need for scalable and deployable group communication architectures, algorithms, and protocols over the Internet. Examples include on-demand audio/video services, teleconferencing, server-push operations, multimedia presentations in distance education and entertainment, and real-time information dissemination. These applications consume high network bandwidth and demand QoS assurances. Multicasting and differentiated services (DiffServ) are the two technologies that effectively address these requirements. DiffServ attempts to provide scalable QoS over the Internet, whereas multicasting aims at maximizing bandwidth sharing among the members of a group. Although these technologies have complementary goals, their coexistence introduces several unique challenges. The goal of this research is to develop architectures, algorithms, and protocols that address these challenges. This collaborative project concentrates in particular on viable approaches for DiffServ-aware multicasting, addressing key issues such as scalability, multicast tree construction and maintenance, heterogeneous QoS and SLA management, and receiver-initiated differentiated services. The research will answer many key questions pertaining to DiffServ multicasting, which will enable QoS multicasting over the Internet to become a reality.

Publications:

1. Striegel, A., and G. Manimaran. 2004. DSMCast: A scalable approach for DiffServ multicasting. *Computer Networks* 44 (6, April): 713–35.
2. Chakrabarti, A., and G. Manimaran. 2004. A case for mesh-tree interaction in end system multicasting. In *Proceedings, 3rd IFIP-TC6 Networking Conference*, 186–99. May, Athens, Greece.
3. Chakrabarti, A., and G. Manimaran. 2003. A case tree migration and integrated tree maintenance in QoS multicasting. *Computer Communications* 26 (9, June): 1007–17.
4. Striegel, A., A. Bouabdallah, H. Bettahar, and G. Manimaran. 2003. EBM: Edge-based multicasting in DiffServ networks. In *Proc. Network Group Communications (NGC)*, 131–42. September, Munich, Germany.

CONCURRENT GARBAGE COLLECTION FOR MULTITHREADED MULTIPROCESSOR ENVIRONMENTS

Memory management consumes a great deal of time on today's computer systems and will take even longer in the future. Software techniques have successfully hidden most of this overhead on personal workstations by shifting the work to times when the system is waiting for user interaction. However, such techniques are less effective on SMP servers, where the overall computational overhead is of greater concern. The dynamic memory management unit (DMMU), a special-purpose hardware mechanism based on bitmaps and combinational logic, can greatly diminish this overhead. Preliminary results for three languages show that this approach is much faster than software memory allocation and consumes only slightly more memory than software-allocation techniques. This proposal calls for the integration of this hardware unit into SMP systems, which would allow concurrent garbage collection in multithreaded multiprocessor environments. Such an approach can speed up the performance of server applications written in O-O languages such as C++ and Java.

Publications:

1. Huang, W., W. Srisa-an, and J. M. Chang. 2004. Object allocation and memory contention study of Java multithreaded applications. In *Proceedings, 23rd IEEE International Performance, Computing, and Communications Conference, (IPCCC)*, 375–82. 14–17 April, Phoenix, Arizona.
2. Huang, W., W. Srisa-an, and J. M. Chang. 2004. Adaptive pretenuring for generational garbage collection. In *Proceedings, IEEE International Symposium on Performance Analysis of Systems and Software (ISPASS-04)*, 133–40. 10–12 March, Austin, Texas.
3. Skotiniotis, T., and J. M. Chang. 2002. Estimating internal memory fragmentation for Java programs. *Journal of Systems and Software* 64 (December, 3): 235–46.
4. Chang, J. M., W. Srisa-an, C. D. Lo, and E. F. Gehringer. 2002. DMMX: Dynamic memory management extensions. *Journal of Systems and Software* 63 (September, 3): 187–99. Elsevier Science.

LOW ENERGY VLSI DESIGN AND MICROARCHITECTURES

This project investigates various circuit-level and microarchitecture-level low-energy design techniques. The increase in sub-threshold leakage current levels has been identified as one of the major roadblocks in sustaining scaling, not only in memory arrays, but also for high-performance logic. Techniques for reducing the sub-threshold leakage current also end up reducing the drive current, which affects performance. A decoder line or a bus node with 20

pull-down paths is hard to pull up by a single pull-up path. We propose a CMOS design style called warm-up CMOS to reduce the leakage current in SRAM cell arrays (as in a processor cache) by a significant factor (100 or more). The warm-up CMOS biases the CMOS gates appropriately to reduce the leakage energy by two to three orders of magnitude.

We also propose to integrate another component for low-leakage energy—leakage charge recycling with adiabatic charge pumps—into SRAM cell arrays such as processor register files and caches in order to save another 20–30% on leakage energy. This circuit energy characteristic argues for a processor microarchitecture that keeps all microarchitectural units active at all times. We propose to develop the detailed microarchitecture with IPC valves and an accompanying IPC-aware compiler backend to deliver a uniform IPC for a given program.

PI: Akhilesh Tyagi
Funding: IBM

Publications:
1. Tyagi, A., and G. Mahadevan. 2004. WARM SRAM: A novel scheme to reduce static leakage energy in SRAM array. In *Proc. of IEEE International Symposium on VLSI (ISVLSI)*. February, IEEE Computer Society Press.
2. Tyagi, A., and P. Ramarao. 2003. An adiabatic framework for a low energy microarchitecture and compiler. In *Proceedings of 7th Workshop on Interaction between Compilers and Computer Architectures, Interact-7*, 65–72. February, IEEE Computer Society Press.
3. Tyagi, A., and V. Manne. 2003. An adiabatic charge pump based charge recycling design style. In *Proceedings of PATMOS 2003, Lecture Notes in Computer Science #2799.* September, Springer Verlag.
4. Tyagi, A., and S. Nadathur. 2003. A dependence driven efficient dispatch scheme. In *Proc. of IEEE International Conference on Computer Design (ICCD)*, 299–306.

A LOW-POWER, HIGH-EFFICIENCY GARBAGE COLLECTOR FOR EMBEDDED JAVA SYSTEMS

Garbage collection (i.e., automatic dynamic memory management) is an attractive feature of Java. However, while it allows for a more productive programmer and more robust software, it is also intrusive and consumes large amounts of power due to frequent memory accesses. As a result, garbage collection can severely degrade the performance and affect the viability of Java-embedded devices. The PI and other project members are analyzing current garbage collection schemes used in Java Virtual Machine for embedded devices and are proposing a system that may improve garbage collection performance by lowering the memory footprint, improving predictability, and reducing the frequency of garbage collection calls and their resulting power consumption.

PI: Morris Chang
Students: Mohammad Fraiwan, Paul Griffin, Andrew Jones
Funding: National Science Foundation

Publications:
1. Srisa-an, W., C. D. Lo, and J. M. Chang. 2003. Active memory processor: A hardware garbage collector for real-time Java embedded devices. *IEEE Transactions on Mobile Computing* 2 (2): 89–101.
2. Srisa-an, W., C. D. Lo, and J. M. Chang. 2002. Performance enhancements to the active memory system. In *Proceedings, IEEE International Conference on Computer Design, (ICCD 2002)*, 249–56. 16–18 September, Freiburg, Germany.
3. Srisa-an, W., C. D. Lo, and J. M. Chang. 2002. A performance perspective on the active memory system. *International Journal of Microprocessors and Microsystems* 16 (9–10, December): 421–32. Elsevier Science.

4. Srisa-an, W., C. D. Lo, and J. M. Chang. 2002. Scalable hardware-algorithms for object resizing and reclamation. *International Journal of Microprocessors and Microsystems* 25: 459–67. Elsevier Science.

OPTIMIZING MEMORY SUBSYSTEMS FOR MEMORY-INTENSIVE WORKLOADS RUNNING ON HIGH-SPEED, MULTITHREADED PROCESSORS

As processor speed continues to increase, the system performance bottleneck for many memory-intensive programs has been shifting to memory subsystems, which include on-chip caches, off-chip caches, and main memory. The optimization of memory subsystems is increasingly important. (Note: This research complements and is an extension of a similar project undertaken by Professor Xiaodong Zhang at the College of William and Mary.)

PI: Zhao Zhang
Funding: ECpE Research Initiation

Publications:
1. Zhang, Z., Z. Zhu, and X. Zhang. 2004. Design and optimization of large size and low overhead off-chip caches. *IEEE Transactions on Computers* 53 (7, July): 843–55.
2. Zhu, Z., Z. Zhang, and X. Zhang. 2002. Fine-grain priority scheduling on multi-channel memory systems. In *Proceedings of the 8th International Symposium on High Performance Computer Architecture (HPCA-8)*. 2–6 February, Cambridge, Massachusetts.
3. Zhang, Z., Z. Zhu, and X. Zhang. 2001. Breaking address mapping symmetry at multi-levels of memory hierarchy to reduce DRAM row-buffer conflicts. *Journal of Instruction-level Parallelism (JILP)* 3 (October).
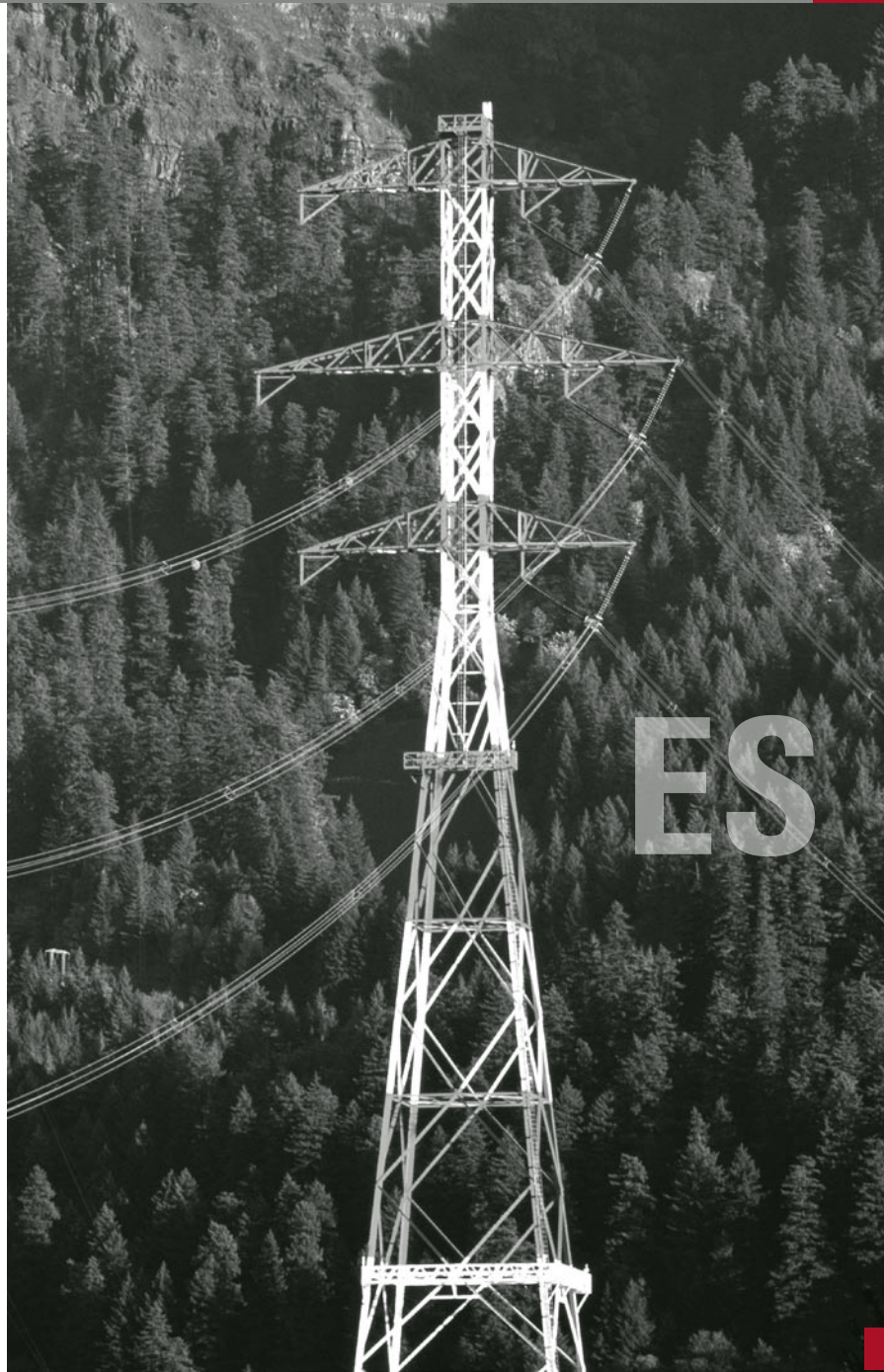
James McCalley, Chair

Primary Members
Venkataramana Ajjarapu
Tom Baird
Eric Bartlett
Kenneth Kruempel
John Lamont
Gerald Sheblé
Vijay Vittal
Secondary Members
Daniel Berleant
David Jiles

ES

ENERGY SYSTEMS

The Electric Power and Energy Systems group is one of the most active university groups in the country in the area of power and energy research. Primary research thrusts include power system dynamics and control, operational decision making, distribution systems, reliability, voltage security, economic systems and markets, asset management, and power electronic systems. More recent areas of work include self-healing networks, adaptive protection, multi-agent systems, market dynamics, and integrated energy systems.

ROBUST ANALYSIS AND SYNTHESIS OF CONTROLS FOR POWER SYSTEMS

This project explored and developed effective techniques for the analysis of power system robustness. Included was a good understanding of how dynamical system equations change with parameter variations and how these changes can be incorporated into uncertainty models. The team considered the change in power system operating conditions as an uncertainty and developed an approach to characterize this uncertainty without significant over-bounding. The team then developed techniques to analyze the robustness of given controller structures as well as procedures to synthesize new controller structures using the SSV approach. The technique has been verified for a variety of test systems and for several different control components in power systems. Our recent work in this area has dealt with extending the application of the SSV approach to large power systems. As the size of the system increases, the number of independent uncertainty blocks also increases. This imposes a large computational burden on the Mu calculations. The group is developing new techniques to increase the efficiency of the calculations and reduce the computational burden. This includes applying linear parameter varying approaches to control design.

PI: Vijay Vittal
Collaborator: M. H. Khammash
Students: Qian Liu, Charles Pawloski, Wenzheng Qiu, Dede Subakti, Sundar Venkataraman, Xuechun Yu, Chuanjiang Zhu
Funding: National Science Foundation, Electric Power Research Institute, EPRC, PSERC

Publications:

1. Qiu, W., V. Vittal, and M. H. Khammash. In press. Decentralized power system stabilizer design using linear parameter varying approach. *IEEE Transactions on Power Systems.*
2. Zhu, C., M. H. Khammash, V. Vittal, and W. Qiu. 2003. Robust power system stabilizer design using H_∞ loop shaping approach. *IEEE Trans. Power Systems* 18 (2, May): 810–8.
3. Qiu, W., M. Khammash, and V. Vittal. 2002. Power system stabilizer design using LPV approach. In *Proceeding of the 34th North American Power Symposium*, 67–74. October, Tempe, Arizona.
4. Yu, X., M. Khammash, and V. Vittal. 2001. Robust design of a damping controller for static var compensators in power systems. *IEEE Transactions on Power Systems* 16 (3, August): 456–62.
5. Subakti, D. O., M. H. Khammash, and V. Vittal. 2001. Robustness analysis for TCSC in power systems and its performance comparison against SVCs. In *Proceedings of the North American Power Symposium*, 229–36. October, College Station, Texas.
6. Djukanovic, M., M. H. Khammash, and V. Vittal. 2000. Sensitivity based structured singular value approach to stability robustness of power systems. *IEEE Transactions on Power Systems* 15 (2, May): 825–30.

AN AGENT-BASED SELF-HEALING SCHEME FOR LARGE POWER SYSTEMS USING ADAPTIVE ISLANDING

The approach to this research is based on adaptive islanding. The multi-agent scheme includes tools to conduct vulnerability analysis using wide-area measurements and conventional analysis techniques. If the vulnerability analysis indicates that the system is susceptible to a disturbance and a catastrophic failure will result, then the self-healing agent will be invoked. This agent will incorporate innovative methods to adaptively island the system into smaller islands at a slightly reduced capacity. The basis for forming the islands is to minimize the generation-load imbalance in each island, thereby facilitating the restoration process. By exploring a carefully designed load-shedding scheme based on the rate of frequency decline, the extent of the disruptions is limited and the system can be restored rapidly. The project will also explore efficient algorithms to form the islands, taking into account generation-load balance, reactive power capability, black start capability, and other constraints related to efficient restoration. Agent technologies are particularly useful for the detection of problematic system conditions, and island design calculations use both local and system-wide measurements. The distributed computation gives potentially high reliability.
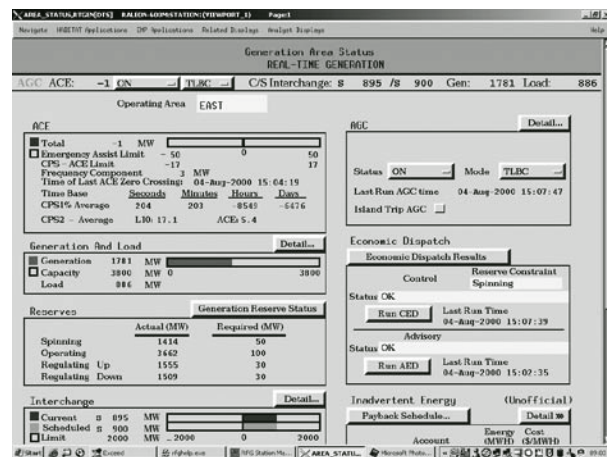
PI: Vijay Vittal
Students: Xiaoming Wang, Zhung Yang, Haibo You
Funding: Electric Power Research Institute, Department of Defense, CERTS

Publications:

1. You, H., V. Vittal, and X. Wang. 2004. Slow coherency based islanding. *IEEE Transactions on Power Systems* 19 (1, February): 483–91.

Operator training simulator (OTS) screen of generation status

2. You, H., V. Vittal, and Z. Yang. 2003. Self-healing in power systems: An approach using islanding and rate of frequency decline based load shedding. *IEEE Trans. Power Systems* 18 (1, February): 174–81.
3. Wang, X., and V. Vittal. 2003. Slow coherency grouping based islanding using minimal cutsets. In *Proceeding of the 35th North American Power Symposium*, 315–20. October, Rolla, Missouri.
4. Jung, J., C. C. Liu, S. L. Tanimoto, and V. Vittal. 2002. Adaptation in load shedding under vulnerable operating conditions. *IEEE Trans. Power Systems* 17 (4, November): 1199–205.
5. You, H., and V. Vittal. 2002. A slow coherency identification algorithm considering load dynamics. In *Proceedings of the 34th North American Power Symposium*, 538–44. October, Tempe, Arizona.
6. You, H., V. Vittal, J. Jung, C-C. Liu, M. Amin, and R. Adapa. 2002. An intelligent adaptive load shedding scheme. In *Proceedings of the 14th Power System Computation Conference*, Paper 6, Session PS17 Wide-Area Control. June, Seville, Spain.

DEFENSE AGAINST CATASTROPHIC EVENTS

This project developed techniques for control room monitoring of high-consequence cascading outages in electric transmission systems. Researchers developed algorithms and associated software that identifies high-risk multi-component outages and provides operators with a decision-making aid to mitigate outage consequences.

Publications:
1. Chen, Q., and J. McCalley. Submitted. Operational defense of cascading sequences. *IEEE Transactions on Power Systems.*
2. Chen, Q., and J. McCalley. Submitted. Use of system topology data for identifying high risk N-k contingencies in transmission security analysis. *IEEE Transactions on Power Systems.*
3. Chen, Q., and J. McCalley. 2004. A cluster distribution as a model for estimating high-order event probabilities in power systems. In *The 8th International Conference on Probabilistic Methods Applied to Power Systems.* September, Ames, Iowa.
4. McCalley, J., K. Zhu, and Q. Chen. 2001. Dynamic decision-event trees for rapid response to unfolding events in bulk transmission systems. In *Proceedings, 2001 IEEE PES Summer Meeting.* 15–19 July.
5. Chen, Q., and J. McCalley. 2001. High order contingency identification from system topology analysis. In *2001 North American Power Symposium.* October, College Station, Texas.

MODELLING OF BIDDING STRATEGIES AND DATA MINING BIDDING STRATEGIES

Companies wishing to profit from commodity markets must base their bidding strategies on a number of factors, including the uncertainties of raw commodities, demand, and production processes. This research examines the bidding strategies of a competitive commodity supplier using the Porter Five Forces Model, the Leontief Model, supply chain models, market models, and microeconomic models. The primary focus of the research addresses how to bid properly in a complex multiple-market environment beyond traditional game theory or optimization theory analysis. Negotiation for the best price is
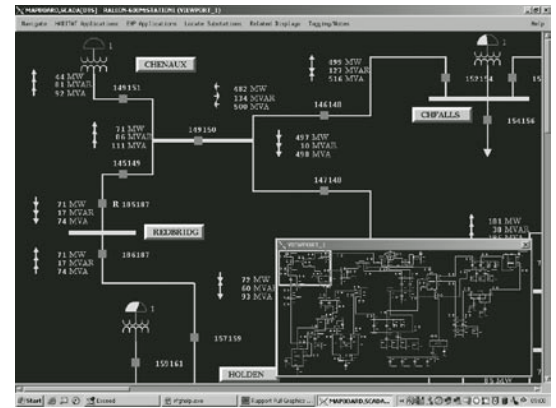
One-line diagram of system being analyzed in OTS

emulated under various assumptions of information analysis and market rules. The research is then directed toward mining the bidding behaviors of customers or competitors to determine the structure and parameters of those behaviors. Advanced bidding strategies consider the valuation of competitors, suppliers, and customers, as well as opportunities to provide advanced services or products. The primary goal of this research is to provide the most complete decision support system for a company in order to maximize profit. A secondary goal is to enable a company to model its competitors or determine if those competitors can model the company itself.

Publications:
1. Cheng, H. Z., H. F. Zhu, M. L. Crow, and G. B. Sheblé. 2004. Flexible method for power network planning using the unascertained number. *Electric Power Systems Research* 68 (1, January): 41–6.

2. Berleant, D., M. P. Cheong, C. Chua, Y. Guan, A. Kamal, G. Sheblé, S. Ferson, and J. F. Peters. 2003. Dependable handling of uncertainty. *Reliable Computing* 9 (6): 407–18.
3. Cheong, M., D. Berleant, and G. B. Sheblé. 2003. On the dependency relationship between bids. In *35th North American Power Symposium.* 20–21 October, University of Missouri-Rolla.
4. Gutierrez-Alcaraz, G., and G. Sheblé. 2003. I-O model in the energy market: A GENCOs perspective. In *35th North American Power Symposium.* 20–21 October, University of Missouri-Rolla.
5. Sheblé, G., and D. Berleant. 2002. Bounding the composite value at risk for energy service company operation with DEnv, an interval-based algorithm. In *SIAM Workshop on Validated Computing 2002, Extended Abstracts*, 166–71. 23–25 May, Toronto, Canada. (Refereed.)
6. Yang, W., and G. B. Sheblé. 2002. Discrete generation decisions simulation with market dynamic interactions. In *Proceeding of the 15th Conference on Systems Engineering*, 470–6. International Systems Engineering Conference, Las Vegas, Nevada.

COMPUTER SIMULATION OF ELECTRIC MARKETPLACES USING ARTIFICIAL ADAPTIVE AGENTS

The analysis of complex multiple-market commodity trading includes consideration of the detailed modeling of each trading player. Each trading player consists of a collection of experts and decision support systems for maximizing profit over several rounds of auctions. To faithfully replicate behaviors, simulations of market rules, environments, and exogenous markets require complex multiple-agent modelling. The goal of simulating the overall industry operation is to determine which markets, market rules, and types of contracts are beneficial. Another goal of this research is to provide training and an evaluation laboratory to pit computer against human in a complex multiple-

commodity environment. The recent failure of electric markets in the United Kingdom and California demonstrates the necessity of accurately evaluating market interactions over long time periods in order to determine improper play and the ability of a multiple market structure to sustain business.

Publications:
1. Cheng, H. Z., H. F. Zhu, M. L. Crow, and G. B. Sheblé. 2004. Flexible method for power network planning using the unascertained number. *Electric Power Systems Research* 68 (1, January): 41–6.
2. Berleant, D., M. P. Cheong, C. Chua, Y. Guan, A. Kamal, G. Sheblé, S. Ferson, and J. F. Peters. 2003. Dependable handling of uncertainty. *Reliable Computing* 9 (6): 407–18.
3. Sheblé, G. B., and V. Petrov. 2002. Simulation of energy auctions with virtual worlds of adaptive agents. In *22nd Annual North American Conference of the USAEE/IAEE (United States Association for Energy Economics, International Association for Energy Economics).* 6–8 October, Vancouver, British Columbia, Canada ("Energy markets turmoil: Making sense of it all"). (Under review as journal publication.)
4. Dekrajangpetch, S., G. B. Sheblé, and H. Wu. 2002. Multiple-class electric power auctions with specified strictness of guarantee. In *22nd Annual North American Conference of the USAEE/IAEE (United States Association for Energy Economics, International Association for Energy Economics).* 6–8 October, Vancouver, British Columbia, Canada ("Energy markets turmoil: Making sense of it all").
5. Gutiérrez, G., and G. B. Sheblé. 2002. Modeling of adaptive agents for auction simulation. In *International Systems Engineering Conference.* Las Vegas, Nevada.
6. Sheblé, G. B., and K. H. Ng. 2001. Economic lessons from the market evolution of present US power markets. In *IEE Proceedings* 148 (2, March): 185–8. (Invited.)
7. Dekrajangpetch, S., G. B. Sheblé, and H. Wu. 2000. Single-class electric power auctions with specified strictness of guarantee. In *Probability Methods Applied to Power Systems Conference (PMAPS).* Madeira, Portugal.
8. Lane, D., A. Kroujiline, V. Petrov, and G. Sheblé. 2000. Electricity market power: Marginal cost and relative capacity effects. In *Congress on Evolutionary Computations 2000.* San Diego, California.

RISK-BASED MAINTENANCE ALLOCATION AND SCHEDULING FOR BULK TRANSMISSION SYSTEM EQUIPMENT

This project addressed resource allocation needs associated with the asset management of electric power transmission equipment. A method was developed for selecting and
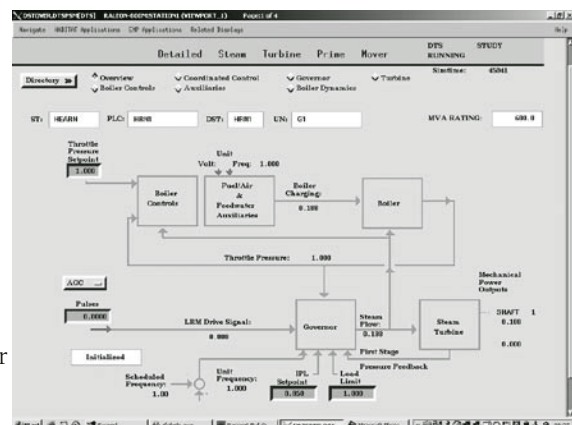
Detailed modeling of turbine governor

scheduling maintenance activities to minimize risks associated with network security problems (overloads, low voltages, cascading overloads, and voltage instability). The problem was solved using a combination of

Colombian Power
Grid (2003)

CASE DATA
System Load: 6000 MW
Generation Loss: 500 MW

FREQUENCY EVOLUTION
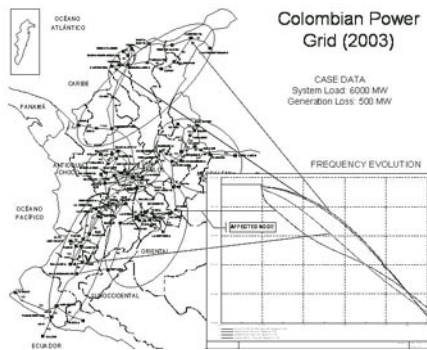
Frequency response of study system

relaxed linear programming and dynamic programming that maximizes maintenance-induced cumulative risk reduction under budget, labor, and outage-risk constraints.

PI: James McCalley
Collaborators: S. Meliopoulos, Timothy Van Voorhis
Student: Yong Jiang
Funding: Power Systems Engineering Research Center

Publications:

1. Jiang, Y., Z. Zhang, J. McCalley, and T. Van Voorhis. Submitted. Risk-based maintenance optimization for transmission equipment. *IEEE Transactions on Power Systems.*
2. Zhang, Z., Y. Jiang, and J. McCalley. 2003. Condition-based failure-rate estimation for transformers. In *Proceedings, 2003 North American Power Symposium.* October, Rolla, Missouri.
3. Jiang, Y., Z. Zhang, T. Van Voorhis, and J. McCalley. 2003. Risk-based maintenance optimization for transformers. In *Proceedings, 2003 North American Power Symposium.* October, Rolla, Missouri.
4. Jiang, Y., M. Ni, J. McCalley, and T. Van Voorhis. 2002. Risk-based maintenance allocation and scheduling for bulk electric power transmission system equipment. In *Proceedings, Fifteenth International Conference on Systems Engineering (ISENG 2002).* 6–8 August, Las Vegas, Nevada.

DEVELOPMENT OF DISTRIBUTED KNOWLEDGE NETWORKS TO PROVIDE DECISION-SUPPORT FOR SECURITY-ECONOMY DECISIONS IN OPERATING STRESSED POWER SYSTEMS

The PI and his collaborators developed a multi-agent system software infrastructure for supporting negotiated, multi-party decision making in electric power systems with access to heterogeneous data resources and multi-party negotiation capability. A software system called MASPower was developed to address communication and negotiation needs. MASPower is a platform-independent, Java-based API built on top of the commercially distributed computing platform Voyager to instantiate agents and multi-agent systems for eliciting coordinated and negotiated decision making from power system decision makers.

PI: James McCalley
Collaborator: Vasant Honavar
Student: Zhong Zhang
Funding: National Science Foundation

Publications:

1. Zhong, Z., J. McCalley, V. Vishwanathan, and V. Honavar. In press. Multiagent system solutions for distributed computing, communications, and data integration needs in the power industry. In *Proceedings, IEEE Summer Meeting.* June, Denver, Colorado.
2. McCalley, J., Z. Zhong, V. Vishwanathan, and V. Honavar. 2003. Multiagent negotiation models for power system applications. In *Autonomous Systems and Intelligent Agents in Power System Control and Operation*, 49–74. Ed. C. Rehtanz. Berlin, Germany: Springer-Verlag.
3. Zhong, Z., V. Vishwanathan, J. McCalley, and V. Honavar. 2002. A multiagent security-economy decision support infrastructure for deregulated electric power systems. In *Proceedings, 2002 Probabilistic Methods Applied to Power Systems.* September, Naples, Italy.
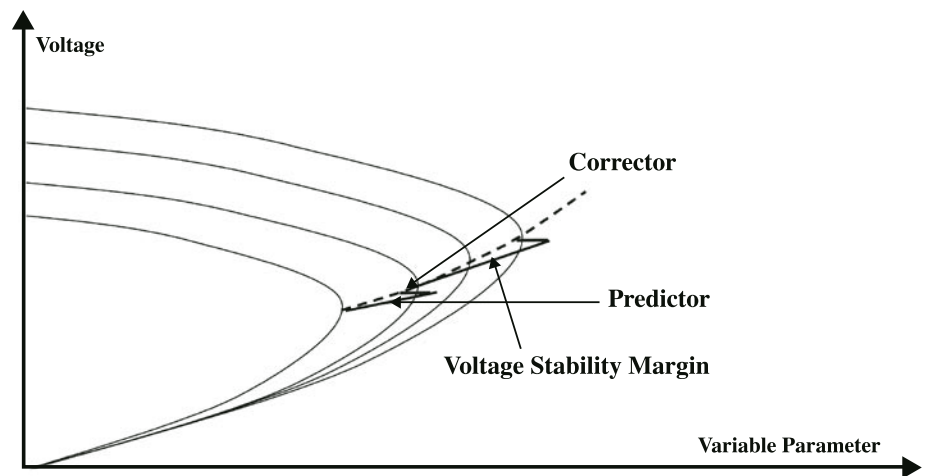
SECURITY MARGIN TRACING

Illustration of voltage stability boundary tracing

SECURITY MAPPING AND RELIABILITY INDEX EVALUATION

This project developed on-line security monitoring software for electric transmission control centers to provide operators with the ability to quantify, monitor, and track power system reliability and to facilitate control room decision making based on risk assessment.

PI: James McCalley
Collaborators: S. Greene, A. Phadke, Vijay Vittal
Students: Weihui Fu, Jian Pu
Funding: Electric Power Research Institute

Publications:

1. Ni, M., J. McCalley, V. Vittal, S. Greene, C. Ten, V. Gangula, and T. Tayyib. 2003. Software implementation of on-line risk-based security assessment. *IEEE Transactions on Power Systems* 18 (3, August): 1165–72.
2. Ni, M., J. McCalley, V. Vittal, and T. Tayyib. 2003. On-line risk-based security assessment. *IEEE Transactions on Power Systems* 18 (1, February): 258–65.
3. Fu, W., S. Zhao, J. McCalley, V. Vittal, and N. Abi-Samra. 2002. Risk-based assessment for special protection schemes. *IEEE Transactions on Power Systems* 17 (1, February): 63–72.
4. Zhang, J., J. Pu, J. McCalley, H. Stern, and W. Gallus. 2002. A Bayesian approach to short-term transmission line thermal overload risk assessment. *IEEE Transactions on Power Delivery* 17 (3, July): 770–8.
5. Chen, X., M. Ni, and J. McCalley. 2002. Use of multicriterion techniques for control-room security economy decision-making. In *Proceedings, 2002 Probabilistic Methods Applied to Power Systems.* September, Naples, Italy.
6. Pu, J., and J. McCalley. 2001. On-line analysis of high order contingencies. In *2001 North American Power Symposium.* October, College Station, Texas.
7. Fu, W., J. McCalley, and V. Vittal. 2001. Transformer risk assessment. *IEEE Transactions on Power Systems* 16 (3, August): 346–53.
8. Fu, W., and J. McCalley. 2001. Risk-based optimal power flow. In *Proceedings, IEEE Power Tech Conference.* September, Porto, Portugal.

PREVENTIVE AND CORRECTIVE CONTROL AGAINST VOLTAGE COLLAPSE

This project deals with a cost-effective control strategy to maintain the required power system voltage stability margin for changing system conditions. It not only includes explicit stability limits but also tracks these limits for changing system conditions. The maximum stability margin for any given control configuration can be derived while minimizing the corresponding control costs. The margin benefit and the corresponding optimal control costs are visualized along the margin boundary. This framework is flexible enough to adapt to various optimal power flow and parametric optimal flow applications. The methodology is demonstrated through a MidAmerican Energy Company test system.

PI: Venkataramana Ajjarapu
Student: Yuan Zhou
Funding: Electric Power Research Institute-TC
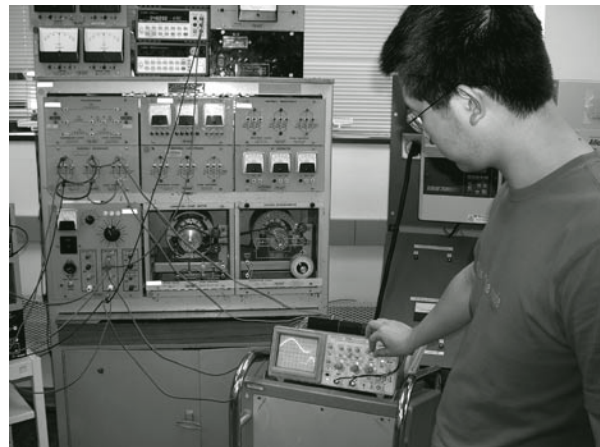
Analysis of motor drive system

Publications:

1. Zhou, Y., X. Wen, and V. Ajjarapu. 2003. Identifying and tracing of oscillatory stability margin boundaries. Invited paper at IEEE panel session on recent developments in linear analysis techniques for small signal stability analysis. Toronto.
2. Zhou, Y., and V. Ajjarapu. 2002. Optimal margin boundary tracing with continuation optimal power flow. In *Proceedings of 34th North American Power Symposium.* October, Tempe, Arizona.
3. Zhou, Y., and V. Ajjarapu. 2002. Local parameterization approach for unified time domain simulation of power system dynamics. In *02WM138, IEEE Winter Power Meeting, 02WM139.* January, New York.
4. Zhou, Y., and V. Ajjarapu. 2002. Identification and tracing of voltage and oscillatory stability margins. In *IEEE Winter Power Meeting, 02WM139.* January, New York.
5. Zhou, Y., and V. Ajjarapu. 2001. A unified voltage and oscillatory stability margin boundary tracing in multi control parameter space. In *Proceedings of 33rd North American Power Symposium.* October, Texas A&M University, College Station.

6. Zhou, Y., and V. Ajjarapu. 2001. Local parameterization based tracing for stability boundary, optimal margin control and time domain simulation. In *Proceedings of Bulk Power System Dynamics and Control V*. 26–31 August, Onomichi, Japan.

A NOVEL CONTINUATION-BASED, QUASI-STEADY-STATE ANALYSIS APPROACH TO MITIGATE LONG-TERM VOLTAGE INSTABILITY

This research deals with a novel continuation-based, quasi-steady-state analysis tool integrated with trajectory sensitivity. The team has used the system to develop a systematic and comprehensive control strategy to mitigate long-term voltage instability. The strategy includes issues of time, location, and quantity as it relates to load shedding.

PI: Venkataramana Ajjarapu
Student: Qin Wang
Funding: Electric Power Research Center/AEP

Publications:
1. Wang, Q., and V. Ajjarapu. 2001. Implementation of continuation method in quasi-steady state analysis. In *Proceedings of 33rd North American Power Symposium*. 15–16 October, Texas A&M University.
2. Wang, Q., and V. Ajjarapu. 2001. QSS analysis by using continuation method. In *Proceedings of IEEE Winter Power Meeting*. February.
3. Wang, Q., and V. Ajjarapu. 2001. A critical review on preventive and corrective control against voltage collapse. *Journal of Electrical Components and Systems* 29 (12, December): 1133–44.

INTERIOR POINT-BASED OPTIMA VOLTAGE STABILITY, OSCILLATORY STABILITY, AND ATC MARGIN BOUNDARY TRACING

This project presents a cost-effective control strategy to maintain the required power system voltage stability and oscillatory stability margins for changing system conditions. It can trace optimal margin boundaries for both voltage and oscillatory stability.

The optimal ATC tracing program can provide the optimal control configuration for any feasible ATC margin, which helps the ISO find the most effective way to avoid network congestion.

PI: Venkataramana Ajjarapu
Student: Zhou Zheng
Funding: Electric Power Research Center

Publications:
1. Zhou, Z., and V. Ajjarapu. 2004. A novel approach for cost based optimization with variable oscillatory stability limits. In *Proceedings of 36th North American Power Symposium*. August, University of Idaho, Moscow.
2. Zhou, Z., and V. Ajjarapu. 2003. A novel approach for cost based optimization with variable voltage stability limits. In *Proceedings of 35th North American Power Symposium*. 20–21 October, University of Missouri-Rolla.
3. Huang, J., S. S. Venkata, V. Ajjarapu, and Z. Zhou. 2003. Adaptive wide area protection to mitigate voltage collapse. In *Proceedings of 35th North American Power Symposium*. 20–21 October, University of Missouri-Rolla.
4. Zhou, Z., and V. Ajjarapu. 2001. A critical review on secondary voltage regulation. In *Proceedings of 33rd North American Power Symposium*. October, Texas A&M University, College Station.

Adaptive agent rule-based market solution through repeated experiments
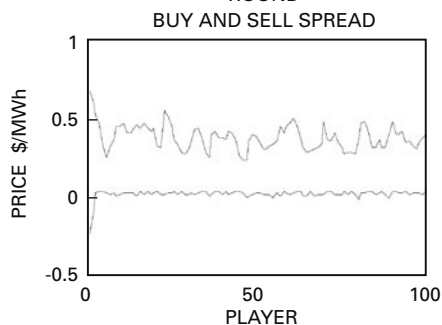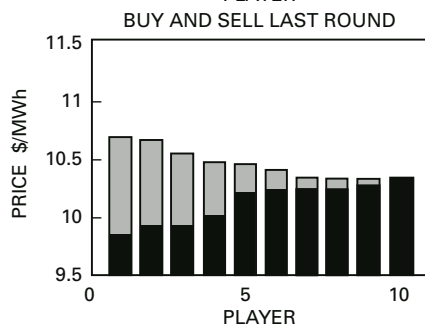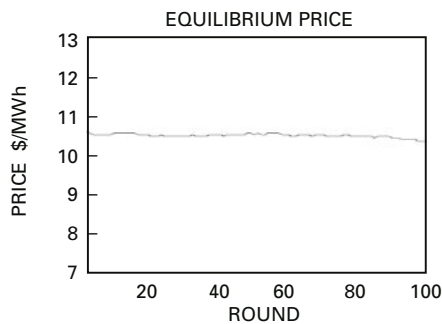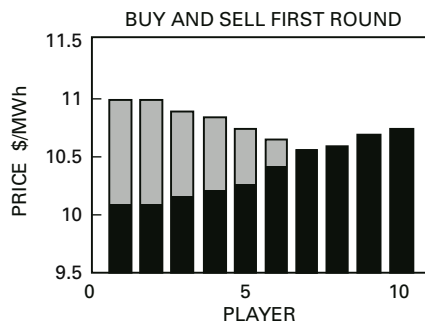
SECURE AND RELIABLE COMPUTING

The Secure and Reliable Computing group is a focal point for new and innovative research targeted at the problems in security and asset protection facing the world today. Major research areas supported by the group are intrusion detection, denial of service attacks, attack-tolerant networks, reliable networking, fault-tolerant systems, and computer security education. Diverse resources facilitate leading edge research in problem areas requiring scientific, engineering, and social expertise.

Doug Jacobson, Chair

Primary Members
    Tom Daniels
    Jennifer Davidson
    James Davis
    Richard Horton
    Steve Russell

Secondary Members
    Julie Dickerson
    Manimaran Govindarasu
    Yong Guan
    Diane Rover
    Arun Somani
    Akhilesh Tyagi
    Zhao Zhang

INTERNET-SCALE EVENT AND ATTACK-GENERATION ENVIRONMENT (ISEAGE)

The goal of ISEAGE (pronounced "ice age") is to provide a world-class research and education facility to enhance the current state of the art in information assurance. Dedicated to creating a virtual Internet for the purpose of researching, designing, and testing cyber-defense mechanisms, the proposed one-of-a-kind facility will be the catalyst for bringing together top researchers from several disciplines for a common goal of making computing safer. Unlike computer-based simulations, real attacks will be played out against real equipment. ISEAGE will also be used to test key components of the critical infrastructure.

PI: Doug Jacobson
Student: Noah Korba
Funding: National Institute of Justice

NSF INDUSTRY/UNIVERSITY COOPERATIVE RESEARCH CENTER

In collaboration with Mississippi State University and the University of Kansas, Iowa State University's Information Assurance Center (IAC) is in the process of forming an NSF Industry/University Cooperative Research Center (I/UCRC). This will be the only I/UCRC with the objective of protecting information systems.

The NSF Federal Cyber Service: Scholarship for Service program seeks to increase the number of qualified students entering the fields of information assurance and computer security and to increase the capacity of the U.S. higher education establishment to continue producing professionals in these fields.

PI: Doug Jacobson
Funding: National Science Foundation

DILON: DETECTION OF INTRUSION AT LAYER ONE

This project explores ways to detect intrusion based on measurements and characterization of signals from hardware (i.e., Ethernet cards). Research demonstrates that hardware can be uniquely identified, based on analog measurements of the physical layer ("layer one"). This significant finding allows researchers to provide network security based on the hardware signature of the users. In addition, research shows that methods of monitoring and classifying hardware will allow network managers to identify hardware problems before failure occurs, resulting in system assurance and enhanced security.

PI: Tom Daniels
Collaborators: Mani Mina, Steve Russell
Students: Mohammad Ali, Norm Anderson, Edward Jackson
Funding: ISU College of Engineering

ADVANCED ATTACK ATTRIBUTION (AAA) PROJECT

The AAA project is developing new technology and better understanding of methods for finding the sources of network attacks, despite the use of sophisticated evasion techniques. There are three primary areas of study in AAA: (1) limits of and extensions to packet marking based on network topology and deployment, (2) correlation of network data streams involved in complex stepping stones, and (3) enhanced mechanisms for integrating correlation information and higher-level data sources into an overall distributed attribution tool.

PIs: Tom Daniels, Yong Guan, Julie Dickerson
Funding: Advanced Research and Development Activity, U.S. Department of the Interior

Publication:
1. Al-Duwairi, B., and T. E. Daniels. To appear. Topology based packet marking. In *Proceedings of the 13th International Conference on Computer Communications and Networks (ICCCN'04)*.

DIGITAL FORENSICS

Our ability to investigate and understand computer incidents, whether past or ongoing, requires reliable, verifiable, and scientifically rigorous tools and methods. However, the new field of digital forensics (also known as computer and network forensics) has been plagued by various problems, including a lack of fundamental scientific knowledge, ad hoc and independent tool development, few formal and verifiable standards, ad hoc investigation processes, and the absence of rigorous education and training resources. The goal of this research is to build a scientific foundation for cyber forensics, developing both technologies and a theoretical framework for cyber-crime scene reconstruction sufficient to identify the genuine sources of incidents with confidence.

PI: Yong Guan
Funding: National Science Foundation

ADVANCED ATTACK ATTRIBUTION

The goal of this project is to advance the knowledge of techniques for attributing complex, multi-stage attacks to their earliest entry point into an organization's network. One major problem in apprehending and stopping network-based intrusions is that intruders can easily hide their identities and points of origin through readily available means such as stepping stones and fielded anonymity systems. It is highly challenging to trace and identify the origins of encrypted attacks, since such attacks make most trace-back schemes based on the examination of message content ineffective. This research studies the fundamental constraints and effectiveness of both
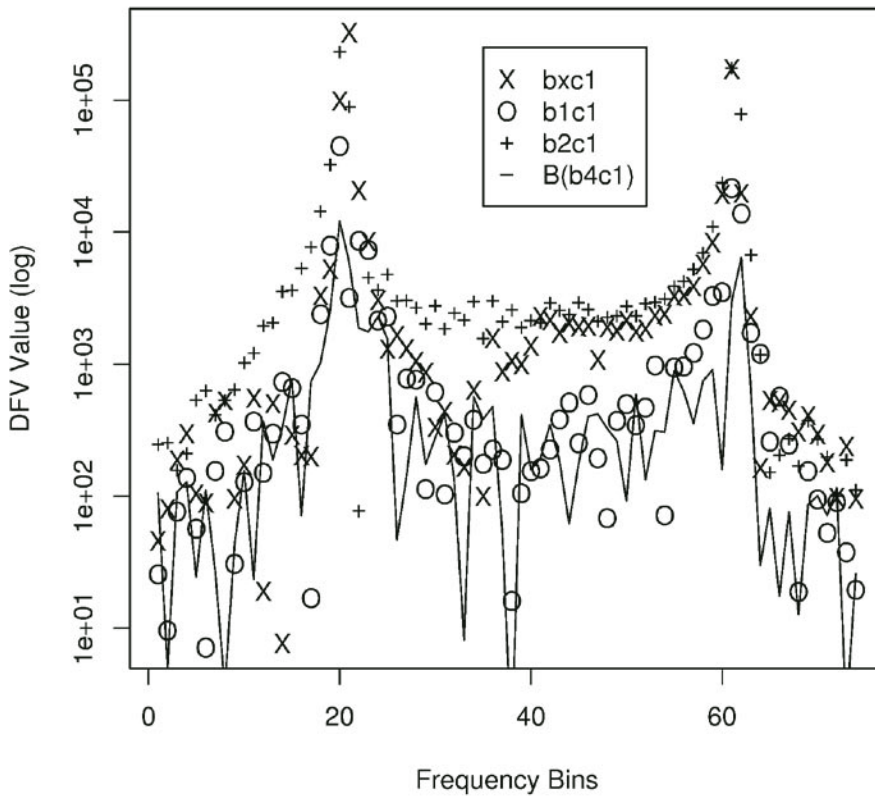
Spectral comparison of three different model ethernet cards to an expected card (line)

passive and active traffic analysis approaches in order to develop new schemes for tracing encrypted attack traffic through stepping stones.

PI: Yong Guan
Funding: Advanced Research and Development Activity

Publication:
1. Zhang, L., A. Persaud, A. Johnson, and Y. Guan. 2004. *Stepping Stone Attack Attribution in Non-cooperative IP Networks.* Technical report. June.

PRIVACY PROTECTION TECHNIQUES FOR THE INTERNET

With the rapid growth and public acceptance of the Internet as a means of communicating and disseminating information, concerns about privacy and security have grown. Privacy and/or anonymity become basic requirements for many on-line Internet applications such as voting, banking, auctions,

and other commercial transactions. The goal of this research is to study various theoretical and practical aspects of privacy technologies, as well as to conduct experimental studies of fielded systems for providing privacy and anti-censorship services for the Internet and other communication networks.

PI: Yong Guan
Funding: Defense Advanced Research Projects Agency

Publications:
1. Guan, Y., X. Fu, R. Bettati, and W. Zhao. 2004. A quantitative analysis of anonymous communications. *IEEE Transactions on Reliability* 53 (1, March): 103–16.
2. Fu, X., Y. Guan, R. Bettati, and W. Zhao. 2002. Hiding role assignment for mission critical collaborative systems, quality and reliability. *Engineering International Special Issue on Computer Network Security* 18 (3): 201–16.

3. Guan, Y., X. Fu, R. Bettati, and W. Zhao. 2002. An optimal strategy for anonymous communication protocols. In *Proceedings of the 22nd IEEE International Conference on Distributed Computing Systems (ICDCS 2002)*. July, Vienna, Austria.
4. Guan, Y., X. Fu, D. Xuan, P. Shenoy, R. Bettati, and W. Zhao. 2001. NetCamo: Camouflaging network traffic for QoS-guaranteed mission critical applications. *IEEE Transactions on System, Man, and Cybernetics, Special Issue on Information Assurance* 31 (4, July).

WIRELESS SECURITY

With increasing reliance on wireless networks in both business and personal life, issues related to secure and dependable operation of such networks are increasingly important. The goal of this research is to study authentication, key management, trust management, intrusion detection, privacy and anonymity, and secure and dependable wireless routing.

PI: Yong Guan
Funding: ECpE Research Initiation

Publications:
1. Wang, H., J. Cardo, and Y. Guan. 2004. A lightweight statistical authentication protocol for access control in wireless LANs. In *Proceedings of the 4th IEEE Workshop on Applications and Services in Wireless Networks (ASWN 2004)*. 8–11 August, Boston, Massachusetts.
2. Wang, H., A. Velayutham, and Y. Guan. 2003. A lightweight authentication protocol for access control in IEEE 802.11. In *Proceedings of IEEE Globecom 2003*. 1–5 December, San Francisco, California.

Suraj Kothari, Chair

Primary Members
Srinivas Aluru
Daniel Berleant
Brett Bode
Carolina Cruz-Neira
Manimaran Govindarasu
Yong Guan
Glenn Luecke (Mathematics)
Dirk Reiners
Diane Rover
Srikanta Tirthapura

Secondary Members
Viren Amin
Morris Chang
Tom Daniels
Julie Dickerson
Ahmed Kamal
Ratnesh Kumar
John Lamont
Daji Qiao
Gerald Sheblé

SOFTWARE SYSTEMS

The Software Systems group is engaged in research and educational activities in parallel computing, bioinformatics, software engineering, real-time and real-time embedded systems, multimedia systems and networks, distributed computing and security, and middleware. The group is involved in several interdisciplinary research projects that focus on computational science and computational biology. The group conducts leading edge research in software modeling, design, and verification; parallel and distributed computing; and automated software analysis and synthesis. This research provides enabling software technologies for important and diverse applications such as gene identification and controls for unmanned aerial vehicles. Group members also do significant work in the areas of text mining, virtual reality, and human-computer interaction.

PERFORMANCE ANALYSIS AND VISUALIZATION OF HIGH-PERFORMANCE COMPUTING SYSTEMS AND APPLICATIONS

New techniques have been developed for analyzing the performance of high-performance parallel and distributed computing systems and applications in both real-time and scientific computing domains. Uniform resource visualization (URV) is a new monitoring framework that focuses on the integration of performance information using visualizations. The goal of URV research is to systemize the visualization of resources with reusable and composable visualizations. URV supports services for connecting visualization to instrumentation, reusing visualization components, and creating system-level views dynamically. In the area of high-performance embedded computing, techniques have been developed for the following: (1) definition of an open software architecture for performance tools that enables domain specialization, (2) definition of multiple abstraction levels of performance data relevant to all system environments, and (3) data mining techniques that support field analysis. These techniques resulted in an architecture for performance data mining, a technique for analysis at multiple abstraction levels, and its path-based data model. A new methodology was developed for obtaining information about the relations emerging when compute-intensive applications are mapped onto advanced architectures. Analyses of the application itself were completed to determine the appropriate design of experiments for establishing relations between changes in high-level abstractions and performance outcomes. Feature subset selection was used to identify important system metrics. An evaluation of different statistical analysis alternatives was carried out to characterize the types of data obtained in performance studies.

Publications:
1. Santiago, N. G., D. T. Rover, and D. Rodriguez. In press. A statistical approach for the analysis of the relation between low-level performance information, the code, and the environment. *Special Issue of Parallel and Distributed Computing Practices.* Ed. L. Yang. NOVA Science Publishers.
2. Bakic, M., W. Mutka, and D. T. Rover. 2003. An on-line performance visualization technology. *Software—Practice and Experience* 33 (15, December): 1447–69. Wiley.
3. Rover, D. T., and K. Lee. 2003. Uniform resource visualization: Software and services. In *Performance Analysis and Grid Computing.* Ed. V. Getov, M. Gerndt, A. Hoisie, A. Malony, and B. Miller, (November): 145–59. Selected articles from the Workshop on Performance Analysis and Distributed Computing, 19–23 August 2002, Dagstuhl, Germany. Kluwer Academic Publishers.
4. Lee, K.-J., and D. T. Rover. 2001. A component-based framework for uniform resource visualization. In *Proc. IEEE Symposium on Information Visualization (InfoVis 2001)*. October, IEEE Visualization 2001, San Diego, California.
5. Rover, D. T., A. Bakic, M. Mutka, and A. Waheed. 2001. Performance optimization of distributed applications in an extensible, adaptive environment. *Future Generation Computer Systems Journal* 18 (1, September): 131–45. Elsevier.
6. Pierce, D., and D. Rover. 2001. Multiple abstraction level performance data mining. In *Proceedings of the 14th International Conference on Parallel and Distributed Computing Systems.* August.

AUTOMATION TOOLS TECHNOLOGY FOR SOFTWARE DEVELOPMENT

Software development consists largely of the creation of patterns based on the domain knowledge of specific applications. Creating and testing these patterns is the tedious but exacting process that makes software development so expensive. This tedium is precisely what must be automated to achieve efficiency in software development. We have developed this kind of automation technology for software development. It is not the first effort made in this area, but it is the first that has demonstrated dramatic productivity improvements in software development. We call this "knowledge-centric software" (KCS) technology because it incorporates high-level domain knowledge about the specific application into automated tools. The result is an interactive development process in which the human expert provides creative strategy while the KCS tools automate the arduous analytic processes.

The KCS technology incorporates an extensible common intermediate language (XCIL) and an extensible pattern specification language (XPSL). The XCIL makes it possible to develop a common core of tools for different programming languages. The XPSL makes it possible to incorporate domain-specific knowledge in the form of pattern catalogs that drive tools. The KCS technology has been applied in diverse areas, including a tool for automatic parallelization of climate-modeling software and a tool for quality inspection of safety-critical avionics software. Commercial applications of the KCS technology are being developed by EnSoft Corporation, a company located in the Iowa State University Research Park.

Publications:
1. Kothari, S. C., G. Daugherty, L. Bishop, and J. Sauceda. 2004. A pattern based framework for detecting software anomalies. *Journal of Software Quality* (January). (Invited paper.)
2. Deng, Y., and S. C. Kothari. 2002. Recovering conceptual roles of data in a program. In *Joint IEEE and ACM Conference on Software Maintenance.* October, Montreal, Canada.
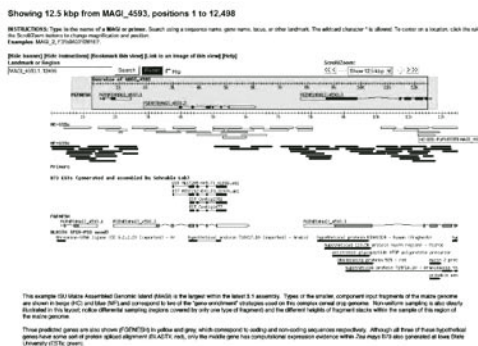
Maize genome assembly

PARALLEL COMPUTATIONAL METHODS FOR DNA SEQUENCE CLUSTERING AND GENOME ASSEMBLY

This project deals with parallel algorithms for solving a variety of problems related to large-scale clustering and assembly of DNA sequences. The algorithms can be applied to expressed sequence tag clustering and genome assembly, as well as other applications. A significant accomplishment of this project was assembly of the maize genome, which was carried out in less than two hours using a 64-processor commodity cluster. By comparison, traditional assembly methods require weeks of computational effort. This research was instrumental in making maize genome assembly available to researchers months in advance (see maize.ece.iastate.edu). The capabilities developed under this project are available as a software system named PaCE, which is currently used by more than 25 academic, research, and industrial institutions in ten nations.

PI: Srinivas Aluru
Collaborators: Volker Brendel, Suraj Kothari, Patrick Schnable
Students: Scott Emrich, Anantharaman Kalyanaraman, Mahesh Narayanan
Funding: National Science Foundation, IBM

Publications:
1. Emrich, S. J., S. Aluru, and P. Schnable. To appear. Status of maize genome project. *AgBiotechNet Journal.*
2. Emrich, S. J., S. Aluru, Y. Fu, T. J. Wen, M. Narayanan, L. Guo, D. A. Ashlock, and P. S. Schnable. 2004.

A strategy for assembling the maize (Zea mays L.) genome. *Bioinformatics* 20 (2): 140–7.
3. Rajko, S., and S. Aluru. 2004. Space and time optimal parallel sequence alignments. *IEEE Transactions on Parallel and Distributed Systems* 15 (11).
4. Huang, X., J. Wang, S. Aluru, S. P. Yang, and L. Hillier. 2003. PCAP: A whole-genome assembly program. *Genome Research* 13:2164–70.
5. Kalyanaraman, A., S. Aluru, V. Brendel, and S. Kothari. 2003. Space and time efficient parallel algorithms and software for EST clustering. *IEEE Transactions on Parallel and Distributed Systems* 14 (12): 1209–21.
6. Kalyanaraman, A., S. Aluru, S. Kothari, and V. Brendel. 2003. Efficient clustering of large EST data sets on parallel computers. *Nucleic Acids Research* 31 (11): 2963–74.

PARALLEL FAST MULTIPOLE-BASED METHODS FOR COMPUTATIONAL ELECTROMAGNETICS

The goal of this research is to develop efficient parallel methods based on fast multipole methods and to use them to solve a variety of problems in computational electromagnetics. Applications include electromagnetic scattering from two- and three-dimensional surfaces and problems of multi-region and time domains. The research focuses on developing scalable parallel algorithms and combining them with state-of-the-art numerical methods to solve large-scale problems. Applications include the design of antennas and circuits.

PI: Srinivas Aluru
Collaborator: Shanker Balasubramaniam (Michigan State University)
Students: Bhanu Hariharan, Sudip Seal, Fatih Sevilgen
Funding: National Science Foundation

Publications:
1. Aluru, S. To appear. Quadtrees and octrees. In *Handbook of Data Structures and Applications.* Ed. S. Sahni and D. P. Mehta. CRC Press.

2. Hariharan, B., and S. Aluru. In press. Efficient parallel algorithms and software for compressed octrees with applications to hierarchical methods. *Parallel Computing.*
3. Hariharan, B., S. Aluru, and B. Shanker. 2002. A scalable parallel fast multipole method for analysis of scattering from perfect electrical conducting surfaces. In *Proceeding of the IEEE/ACM Supercomputing Conference.*

THEORY AND APPLICATIONS OF SECOND-ORDER UNCERTAINTY

When stochastic uncertainty is combined with epistemic uncertainty (i.e., incomplete knowledge), bounds on cumulative distribution functions can result. A pair of such left and right bounds defines a family of distributions. Making inferences, conclusions, and decisions given such bounds as descriptions of input variables is a challenging problem and is important because often they describe the knowledge that is actually justifiable. By contrast, conventional methods require assumptions to be made in order to produce single distribution curves describing inputs, and such assumptions may not be justified by the information actually available. This research has both a theoretical and an applied dimension. Applications motivate theoretical advances, which are developed and implemented in software so that they can be used in the applications.

PI: Daniel Berleant
Collaborator: Gerry Sheblé
Students: Mei-Peng Cheong, Jianzhong Zhang
Funding: PSERC

Publications:
1. Berleant, D., and J. Zhang. In press. Bounding the times to failure of 2-component system. *IEEE Transactions on Reliability.*
2. Berleant, D., and J. Zhang. 2004. Using Pearson correlation to improve envelopes around the distributions of functions. *Reliable Computing* 10 (2): 139–61. (Reviewed.)

3. Berleant, D., and J. Zhang. 2004. Representation and problem solving with distribution envelope determination (DEnv). *Reliability Engineering and System Safety* 85 (1–3): 153–68.

4. Cheong, M.-P, D. Berleant, and G. Sheblé. 2004. Information gap decision theory as a tool for strategic bidding in competitive electricity markets. In *Proceedings, 8th Int. Conf. on Probabilistic Methods Applied to Power Systems.* 12–16 September, Ames, Iowa.

5. Berleant, D., M.-P. Cheong, C. Chu, Y. Guan, A. Kamal, G. Sheblé, S. Ferson, and J. F. Peters. 2003. Dependable handling of uncertainty. Reliable Computing 9 (6): 407–18. (Invited.)

6. Berleant, D., L. Xie, and J. Zhang. 2003. Statool: A tool for distribution envelope determination (D Env), an interval-based algorithm for arithmetic on random variables. *Reliable Computing* 9 (2): 91–108.

READER INTERACTION SYSTEMS

As it is often difficult to access the right information at the right time on the World Wide Web, there is a growing need for interfaces between Web users and the information they seek. One interfacing strategy is called information foraging. The PI and other project members are investigating this strategy with a system called MultiBrowser, which simultaneously presents views of several documents. The views are related by the fact that visible paragraphs are related, regardless of which documents they come from. MultiBrowser and other experimental multi-window displays are intended to enhance browsing by presenting users with information that is customized to their needs.

Publications:
1. Berleant, D., and J. Miao. Submitted. Head-tail display: A lightweight approach to query-dependent document display.

2. Miao, J., and D. Berleant. 2004. From paragraph networks to document networks In *Proceedings of the International Conference on Information Technology (ITCC 2004)*, 1:295–303. 5–7 April, Las Vegas, Nevada.

3. Berleant, D., J. Miao, Z. Gu, and D. Xu. 2004. Toward dialogues with documents: MultiBrowser. In *Proceedings of the International Conference on Information Technology (ITCC 2004)*, 1:2887–94. 5–7 April, Las Vegas, Nevada.

4. Miao, J., and D. Berleant. 2003. A graph based approach to comparing search engines. In *Proceedings, Fifth Russian Conference on Digital Libraries.* 29–31 October, St. Petersburg.

BIOINFORMATIC TEXT PROCESSING

The need to access bioscience literature is leading to the construction of automatic and semi-automatic databases containing facts drawn from the literature and to the automatic discovery of knowledge implicitly present in the literature but never specifically stated. As on-line access to this literature has become increasingly available in recent years, researchers worldwide have focused on the text processing of biological literature. Our work has focused on generating resources such as PathBinder (www.vrac.iastate.edu./ ~berleant/MedRep) and PathBinderH.

Publications:
1. Berleant, D., J. Ding, and D. Nettleton. In preparation. Corpus properties of protein interaction descriptions in MEDLINE.

2. Ding, J., K. Viswanathan, D. Berleant, D. Ashlock, J. Dickerson, A. Fulmer, E. Wurtele, and P. S. Schnable. In preparation. PathBinderH: A tool for mining the scientific literature for genome annotation.

3. Ding, J., and D. Berleant. Submitted. MedAid: A toolkit for working with MEDLINE/PubMed citations.

4. Dickerson, J., and D. Berleant. In press. Creating metabolic networks using text mining. In *Advances in Medical Informatics: Knowledge Management and Data Mining in Biomedicine.* Ed. S. Fuller, A. McCray, and H. Chen. Marcel Dekker.

5. Dickerson, J. A., D. Berleant, Z. Cox, W. Qi, D. Ashlock, E. S. Wurtele, and A. W. Fulmer. 2003. Creating and modeling metabolic and regulatory networks using text mining and fuzzy expert systems. In *Computational Biology and Genome Informatics.* Ed. J. T. L. Wang, C. H. Wu, and P. Wang, 207–38. World Scientific Publishing Company.

6. Ding, J., D. Berleant, J. Xu, and A. W. Fulmer. 2003. Extracting biochemical interactions from MEDLINE using a link grammar parser. In *Proceedings, Fifteenth IEEE Conference on Tools with Artificial Intelligence (ICTAI 2003)*, 467–71. 3–5 November, Sacramento, California.

7. Ding, J., D. Berleant, D. Nettleton, and E. Wurtele. 2002. Mining MEDLINE: Abstracts, sentences, or phrases? In *Pacific Symposium on Biocomputing* 7:326–37. 3–7 January, Kaua'i, Hawaii. (Acceptance rate for track was 6 of 17; international conference; Web site hosted by Stanford University at psb.stanford.edu.)

FAULT-TOLERANT AND SCALABLE DISTRIBUTED DATA STRUCTURES

In any distributed system, distributed and local data structures are necessary for processor coordination. As these systems get larger and span wide area networks, data structures are needed that can scale with system size and load and that can tolerate node and link failures. This project seeks to devise fault-tolerant and scalable data structures for fundamental coordination problems such as distributed counting (i.e., implementing a counter in a distributed system) and distributed queuing (i.e., implementing a shared queue).

The PI and his group have analyzed existing data structures and designed new data structures for queuing and counting. One research highlight is the demonstration that the performance of a well-known queuing protocol, the \emph{arrow protocol}, is 'competitive' with an optimal protocol for the same task, especially under conditions of high concurrency. Performance under concurrency is important, and this was the first such formal performance analysis of a distributed data structure.

Publications:
1. Herlihy, M., and S. Tirthapura. 2004. Randomized smoothing networks. In P*roceedings of the International Parallel and Distributed Processing Symposium (IPDPS).*
2. Herlihy, M., and S. Tirthapura. 2003. Self-stabilizing smoothing and counting. In *Proceedings of the 23rd IEEE International Conference on Distributed Computing Systems (ICDCS).*
3. Herlihy, M., and S. Tirthapura. 2001. Self-stabilizing distributed queuing. In *Proceedings of the 15th International Symposium on Distributed Computing (DISC).*
4. Herlihy, M., S. Tirthapura, and R. Wattenhofer. 2001. Competitive concurrent distributed queuing. In *Proceedings of the ACM Symposium on Principles of Distributed Computing (PODC).*

CONTROL AND DIAGNOSIS OF DISCRETE EVENT SYSTEMS WITH TEMPORAL LOGIC SPECIFICATIONS

This project is motivated from a comprehensive and formal study of the control and diagnosis of discrete event systems with temporal logic specifications. The supervisory control theory provides a formalism or synthesizing controllers for event-driven systems in order to enforce desired qualitative specifications. Such specifications are traditionally expressed as formal languages or, equivalently, as state machines. It is more practical, however, to express specifications in a language that is closer to naturally spoken language. Temporal logic is an attempt to bridge the gap between formal and natural languages. The PI and other project members will develop techniques for the control and diagnosis of discrete event systems when specifications are expressed in temporal logics. The logics used will be the computational tree logic and linear time logic proposed by Clarke, Emerson, and Sitsla, for which automated techniques exist for verifying system properties. The proposed research complements their work by developing automated techniques for synthesizing control and diagnostic mechanisms. Several problems in this context have been proposed, including control under complete observation, control under partial observation, modular control, failure modeling and diagnosis, and computation using the symbolic method. Initial work shows that there is no loss of computational complexity with the use of temporal logic, yet there is surely a gain of expressibility and user friendliness.

Publications:
1. Huang, Z., V. Chandra, S. Jiang, and R. Kumar. 2003. Modeling discrete event systems with faults using a rules based modeling formalism. *Mathematical and Computer Modeling of Dynamical Systems* 9 (3): 233–54.
2. Chandra, V., Z. Huang, W. Qiu, and R. Kumar. 2003. Prioritized composition with exclusion and generation for the interaction and control of discrete event systems. *Mathematical and Computer Modeling of Dynamical Systems* 9 (3): 255–80.
3. Balduzzi, F., and R. Kumar. 2003. Hybrid automata model of manufacturing systems and its optimal control subject to logical constraints. *International Journal of Hybrid Systems* 3 (1): 61–80.
4. Chandra, V., Z. Huang, and R. Kumar. 2003. Automated control synthesis for an assembly line using discrete event system control theory. *IEEE Transactions on Systems, Man, and Cybernetics Part C* 33 (2): 284–9.
5. Kumar, R., and Z. Luo. 2003. Optimizing the operation sequence of a chip placement machine using TSP model. *IEEE Transactions on Electronics Packaging Manufacturing* 26 (1): 14–21.
6. Jiang, S., R. Kumar, and H. E. Garcia. 2003. Diagnosis of repeated/intermittent failures in discrete event systems. *IEEE Transactions on Robotics and Automation* 19 (2, April): 310–23.
7. Jiang, S., R. Kumar, and H. E. Garcia. 2003. Optimal sensor selection for discrete event systems with partial observation. *IEEE Transactions on Automatic Control* 48 (3, March): 369–81.
8. Chandra, V., and R. Kumar. 2002. A event occurrence rules based compact modeling formalism for a class of discrete event systems. *Mathematical and Computer Modeling of Dynamical Systems* 8 (1): 49–73.
9. Jiang, S., and R. Kumar. 2002. Supervisory control of nondeterministic discrete event systems with driven events via masked prioritized synchronization. *IEEE Transactions on Automatic Control* 47 (9): 1438–4.

ALGORITHMS FOR MASSIVE DISTRIBUTED DATA STREAMS

Massive data sets often occur as physically distributed data streams. For example, a data set may include all the transactions conducted by Wal-Mart in a single day or measurements made by a number of sensors over time. It is important to estimate various aggregates and statistics (e.g., mean, variance, median, etc.) over such data streams, which requires algorithms that work under two extreme resource constraints. First, their workspace must be smaller than the size of the data set itself, and, second, they must perform all computations in only one

pass through the data. The group has designed algorithms to estimate various key aggregates over sequential and distributed data streams.

PI: Srikanta Tirthapura
Collaborator: Phillip Gibbons (Intel Research)
Funding: ECpE Research Initiation

Publications:
1. Gibbons, P., and S. Tirthapura. To appear. Distributed streams algorithms for sliding windows. *Theory of Computing Systems.* (Expanded and revised version of #2 below.)
2. Gibbons, P., and S. Tirthapura. 2002. Distributed streams algorithms for sliding windows. In *Proceedings of the ACM Symposium on Parallel Algorithms and Architectures (SPAA).*
3. Gibbons, P., and S. Tirthapura. 2001. Estimating simple functions on the union of data streams. In *Proceedings of the ACM Symposium on Parallel Algorithms and Architectures (SPAA).*

TEACHING TECHNOLOGY AT THE UNDERGRADUATE LEVEL

The goal of this project is to develop effective curriculum and teaching strategies to teach undergraduates technology, particularly in electrical engineering. The project has resulted in a number of ASEE conference publications and papers in progress for various international engineering education journals.

PI: Mani Mina
Students: Edward Jackson (MS'04), Kathleen Knott (MS'03)
Funding: Learning Communities and Provost Office

EMBEDDED SYSTEMS DESIGN AND EDUCATION

Research in embedded systems design has been coordinated with research in engineering education, resulting in course, laboratory, and curriculum development in electrical and computer engineering. The developments have spanned from lower-level to upper-level and graduate courses. New approaches to interdisciplinary teaching and learning have been investigated through course integration and Web-based resources such as an on-line design document to facilitate interaction and information exchange. The strategic use of the senior design course to transfer research concepts into undergraduate education has been used successfully at two universities. Moreover, the focus on embedded systems has been a successful approach for developing teamwork across the sub-disciplines within both computer and electrical engineering, as well as for meeting ABET Engineering Criteria 2000 outcomes. Embedded systems provides a problem-based learning context for curriculum development. An approach called "open your I's" (i.e., "Introduction, Instruction, Illustration, Investigation, and Implementation)" provides an innovative method for engaging in active teaching and learning.

PI: Diane Rover
Collaborators: Carolina Cruz-Neira, Julie Dickerson, Robert Weber
Student: Robert Walstrom
Funding: National Science Foundation

Publications:
1. Rover, D., J. Dickerson, C. Cruz-Neira, R. Weber, K. Lee, G. Faidley, J. Hero, R. Walstrom, B. Lwakabamba, and F. Che. 2004. CRCD: Low-power wireless communications for virtual environments—Design document. In *Proc. of 2004 ASEE Annual Conference.* June, Salt Lake City, Utah. (CD-ROM.)

2. Rover, D., J. Dickerson, C. Cruz-Neira, R. Weber, K. Lee, and Z. Min. 2003. Using a design document to support interdisciplinary learning. In *Proc. of 2003 IEEE/ASEE Frontiers in Education Conference*, S3A–12–17.CD-ROM/Online: http://fie.engrng.pitt.edu/fie2003/papers/1539.pdf. November.

3. Dickerson, J., D. Rover, R. Weber, C. Cruz-Neira, E. Eekhoff, B. Lwakabamba, F. Chen, Z. Min, and K. Lee. 2003. CRCD: Low-power wireless communications for virtual environments—Course integration. In *Proc. of 2003 ASEE Annual Conference*, CD-ROM/Online: http://www.asee.org/conferences/caps/document/2003-2508_Final.pdf. June, Nashville, Tennessee.

4. Rover, D., and A. Striegel. 2003. The PowerBox case study: A 32-bit microcontroller platform for introductory embedded programming. Workshop summary in *Proc. 2003 IEEE/ASEE Frontiers in Education Conference*, W3C-1.CD-ROM/Online: http://fie.engrng.pitt.edu/fie2003/papers/1546.pdf. November, Boulder, Colorado.

5. Striegel, A., and D. Rover. 2002. Enhancing student learning in an introductory embedded systems laboratory. In *Proc. 2002 IEEE/ASEE Frontiers in Education Conference.* November, Boston, Massachusetts. (CD-ROM.)

6. Rover, D., and A. Niemi. 2002. Senior design as an agent for change in engineering education. In *Proc. 2002 IEEE/ASEE Frontiers in Education Conference.* November, Boston, Massachusetts. (CD-ROM. One of ten finalists for Dasher Award, outstanding paper of the conference.)

7. Rover, D. T. 2002. Interdisciplinary teaching and learning: What, why, and how. *ASEE Journal of Engineering Education* 91 (4, October): 369–70. Academic Bookshelf.

YEAR	# OF BS DEGREES AWARDED
2000–01	237
2001–02	222
2002–03	277
2003–04	256

YEAR	# OF MS DEGREES AWARDED
2000–01	66
2001–02	51
2002–03	60
2003–04	54

YEAR	# OF PhD DEGREES AWARDED
2000–01	20
2001–02	22
2002–03	16
2003–04	18

YEAR	# OF UNDERGRAD STUDENTS
2000–01	1,402
2001–02	1,519
2002–03	1,497
2003–04	1,327

YEAR	# OF GRAD STUDENTS
2000–01	251
2001–02	263
2002–03	242
2003–04	244

YEAR	STATE BUDGET ($)
2000–01	$6,001,778
2001–02	$6,233,671
2002–03	$6,420,680
2003–04	$6,611,031

YEAR	RESEARCH EXPENDITURES
2000–01	$7,436,744
2001–02	$5,696,582
2002–03	$6,825,322
2003–04	not available

The primary location of the Department of Electrical and Computer Engineering is in Coover Hall in the northwest quadrant of the main campus of Iowa State University. The department also uses space in Durham Hall (3rd floor) and Town Engineering Building (3rd floor, north). Satellite and associated areas include space in Howe Hall (VRAC); the Office and Laboratory Building (Cyber Corps); and Applied Science I (MRC) & II (CNDE), located approximately two miles northwest of central campus off Ontario Street.

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