Advances in information technology are enabling scientists to study previously inaccessible phenomena and environments. The payoff of IT research in scientific and human terms may well be enormous, and it is just beginning.

The Coordinated Science Laboratory, one of the nation’s premier, multidisciplinary research laboratories, focuses on information technology at the crossroads of computing, control, and communications. With a rich history of nearly 60 years of innovation, CSL has developed and deployed new technologies that have achieved international scientific recognition and transformed society. At the laboratory, design, implementation, interaction, and evaluation take place at every level, from circuits to systems and networks, and from algorithms to complex, new-generation architectures, design tools and software.

CSL uses these innovations to explore critical issues in defense, medicine, environmental sciences, robotics, life-enhancement for the disabled, and aeronautics. The laboratory has made many important contributions to NASA, the Department of Defense and major manufacturers including Motorola, HP, IBM, Microsoft, and many others.

The laboratory is led by a faculty of about 100 world-renowned experts and researchers from 10 departments, and assisted by 50 senior professional researchers, post-docs, and adjunct faculty members. CSL also is home to about 330 graduate students and 60 undergraduate students. CSL is located primarily in its own building, with additional facilities in the Engineering Science Building, Beckman Institute, and the Frederick Seitz Materials Research Laboratory.

A selection of current efforts illustrates the laboratory’s breadth, including:

- Building next-generation air transportation systems.
- Enhancing multi-modal imaging and visualization for health care, animation, security, and surveillance.
- Designing pervasive and embedded technologies, from hand-held devises to large-scale systems.
- Creating telecommunications networks that are secure, available, safe, private, and survivable in the face of attacks and other disruptions.
- Building new parallel technologies for high-end computing applications.
- Constructing new wireless technologies for seamless, high-speed communications.
- Designing new architectures for the future power grid.

Underlying all advances in information technology must be a powerful and dynamic infrastructure—one that is fast, adaptive, responsive, highly reliable, and secure. CSL is building this infrastructure today.

*R. K. Iyer served as director during the reporting period.

CSL’s major research areas include:
• Computing and Networks
• Decision and Control
• Communications and Signal Processing
• Circuits, Electronics and Surface Science

Faculty associated with CSL are listed below:

Department of Aerospace Engineering
C. Langbort  
N. Neogi  
P. Voulgaris

Department of Civil and Environmental Engineering
L. Liu

Department of Computer Science
V. Adve  
G. Agha  
R. Campbell  
G. Dejong  
C. Gunter  
S. LaValle  
K. Nahrstedt  
L. Sha

Department of Electrical and Computer Engineering
I. Adesida  
N. Ahuja
Faculty and Their Interests

John R. Abelson
Plasma-assisted deposition of semiconductor, dielectric, and conductive thin-films for electronic applications; the physics and chemistry of film growth; fabrication of photovoltaic cells and thin-film transistors for macroelectronics

Ilesanmi Adesida
Electronic and transport properties of ultra-low dimensional semiconductor structures, advanced processing methods for electronic devices, high-speed optoelectronic devices and integrated circuits, radiation effects

Vikram Adve
Compilers, software reliability, performance analysis, computer architecture

Gul A. Agha
Developing new abstractions for building open distributed systems and reasoning about their behavior, parallelism, coordination, real-time behavior

Narendra Ahuja
Computer vision, robotics, image processing, sensors, pattern recognition, virtual environments, intelligent interfaces

Jont Allen
Speech recognition based on the articulation index and aspects of information theory, bioacoustics, circuits, communications, electromagnetics, signal and image processing

Leslie H. Allen
Thin-film physics, microelectronic processing, interfaces, nanoscale, size-dependent material properties, nanocalorimetry

Andrew G. Alleyne
Automotive systems, control systems

Tamer Basar
Information technology research; control over wired and wireless networks; usage-limited sensing, estimation, and control; robust identification and control; dynamic games and stochastic teams; nonlinear and adaptive robust control; decentralized and distributed detection and estimation; routing, pricing, and congestion control; modeling and control of communication networks; mobile and distributed computing; information security and intrusion detection; incentive mechanisms through pricing; neural networks-based identification and control; applications of control and game theory in economics

Carolyn L. Beck
Control systems, modeling and model reduction for the purposes of control, systems theory

Jennifer Bernhard
Reconfigurable active and passive antennas, phased array antennas, wireless sensor systems

Stephen G. Bishop
Optical and electrical characterization of crystalline and amorphous semiconductors and semiconductor nanostructures, compound semiconductors (GaAs, InP, AlGaAs, ZnSe, SiC), defects in semiconductors, isoelectronic defects, rare earth-doped chalcogenide glasses and GaN. Experimental techniques, including photoluminescence, nuclear magnetic resonance, electron spin resonance, magneto-optics, photoemission, infrared spectroscopy

Richard Blahut
Communications, signal processing, information theory, optical recording

Yoram Bresler
Biomedical imaging systems; statistical signal and image processing; inverse problems; statistical pattern recognition; sensor-array processing

Donna J. Brown
Asynchronous learning technologies and environments; WWW-based education; VLSI placement and routing; parallel and distributed algorithms and architectures; analysis and design of algorithms, with a particular interest in approximation algorithms; graph theory

David Cahill
Epitaxial growth, scanning tunneling microscopy, ion-surface interactions, thermal properties of thin films, strained layer heterostructures
Roy H. Campbell
Security, distributed operating systems, ubiquitous computing

Andreas Cangellaris
Numerical techniques for electromagnetic modeling and simulation, microwave circuit design, speed VLSI interconnects, electronic packaging, electromagnetic computer-aided design for high-speed digital and RF/microwave electronics, antenna modeling, optoelectronic interconnects, electromagnetic modeling for nonlinear optics

Scott Carney
Optical physics, including imaging, near-field microscopy, classical and quantum coherence theory, beam propagation, fundamental issues of energy conservation, mathematical methods in inverse scattering and the propagation of light

Nicholas Carter
Architectures that combine programmable processors and reconfigurable logic, computing using nanotech devices, design techniques to integrate computation and sensing

Deming Chen
Synthesis and architecture exploration for programmable logic devices; CAD for multicore and SoC under process variation; reconfigurable computing; nanoscale IC design and CAD; high-level synthesis with physical planning; design space exploration for SoC; algorithmic design and applications

Keh-Yung Cheng
Molecular beam epitaxy technology, optoelectronic integrated circuits, high speed devices, in situ fabrication of nanostructures, quantum wire lasers, vertical cavity surface emitting lasers, Sb-based IR detectors and electronic devices

Yun Chiu
Integrated circuits, VLSI signal processing, device modeling and CAD, wire-line and wireless communications

Todd P. Coleman
Wireless networks, information theory, operations, research, computational neuroscience

Gerald DeJong
Artificial intelligence

Minh Do
Image and multidimensional signal processing, wavelets, imaging, multiscale geometric analysis, visual information representation

Geir E. Dullerud
Control systems, dynamic systems

J. Gary Eden
Ultraviolet and visible lasers and laser spectroscopy, microcavity plasma devices and arrays, micro- and nanophotonic resonators; optical physics, including femtosecond laser spectroscopy and technology, and the interaction of intense optical fields with matter, laser magnetometry

Milton Feng
High-speed devices and ICs for wireless and light emitting transistors for optoelectronics (optoelectronic IC), monolithic microwave and millimeter-wave IC, digital IC, high field transport properties, RF-MEMS for wireless communications, advanced Si-CMOS device physics

Matthew Frank
Computer system architecture, parallel computing, program analysis, concurrency control, online algorithms

Steven J. Franke
Development and application of radar and signal processing techniques for remote sensing in the middle and upper atmosphere; application of tomographic imaging to the middle and upper atmosphere using arrays of ground-based sensors and low-earth orbit satellites; low-power wireless RF communications; high efficiency linear power amplifiers for RF communications and radar applications

Chester S. Gardner
Optical communication, laser altimetry, laser remote sensing and ranging, laser remote sensing and ranging, adaptive optics

Carl A. Gunter
Security, networks, software engineering, programming languages

Christoforos Hadjicostis
Systems and control, error control coding, fault diagnosis and tolerance in dynamic systems, testing and verification, discrete event systems, algebraic systems, coding and graph theory
Bruce Hajek  
Communication networks information theory, computer networks stochastic analysis, optimization wireless communication

Mark Hasegawa-Johnson  
Acoustic phonetics, audio signal processing and speech recognition, speech and auditory physiology

Thomas S. Huang  
Image processing, image compression, computer vision, human computer interaction, image and video databases

Seth Hutchinson  
Robotics, computer vision, artificial intelligence

Wen-Mei Hwu  
Architecture, compilation, and microarchitecture of high performance parallel computer systems

Ravishankar K. Iyer  
Design and evaluation of reliable and secure networks and systems, computer measurement and modeling, dependability and security validation and benchmarking

Douglas L. Jones  
Digital signal processing, time-varying and time-frequency analysis, signal processing for communications, binaural hearing aids, signal processing for MEMS

Farzad Kamalabadi  
Remote sensing and imaging, multidimensional signal and image processing, signal reconstruction and tomography, ionospheric and space physics

Ralf Koetter  
Practical and theoretical aspects of coding theory, complexity, algorithms, communication systems, networks

Philip T. Krein  
Power electronics, electric machinery and electromechanics, electric and hybrid vehicle systems

Erhan Kudeki  
Radar remote sensing; atmospheric winds, waves, and turbulence; ionospheric plasma instabilities; incoherent scatter electric field measurements; midlatitude field aligned irregularities and meteor trails

P. R. Kumar  
Wireless networks, sensor networks, convergence of control, communication and computation, semiconductor manufacturing, manufacturing systems, machine learning, adaptive systems, control, stochastic systems

Jean-Pierre Leburton  
Theory of semiconductor devices, modeling and simulation of nanostructures, electronic and optical properties of heterostructures and low dimensional systems, transport in quantum structures, electronic properties, charging effects in quantum dots and nanocrystals, spin effects in nanostructures, quantum computation and quantum information processing, nanoelectronics

Stephen Levinson  
Speech processing, language acquisition, natural language understanding, speech synthesis

Zhi-Pei Liang  
Magnetic resonance imaging, pattern recognition, statistical learning, bioinformatics

Daniel Liberzon  
Nonlinear control theory, analysis and synthesis of hybrid dynamical systems, systems with imprecise measurements and/or modeling uncertainty, stochastic differential equations and control

Liang Y. Liu  
Construction project controls, productivity analysis and improvements, information technology, sensors and field data collection, construction modeling and simulation

Michael C. Loui  
Computational complexity theory, ethics in engineering and computing, scholarship of teaching and learning

Steven Lumetta  
Optical network architecture, computer architecture, cluster computing, parallel computing, user-level communication, validation and reliability
Joseph W. Lyding
Scanning tunneling microscopy and spectroscopy, STM-based nanolithography and nanofabrication, silicon-based molecular electronics, carbon nanotubes and carbon-based nanotechnology merged with silicon, growth of 3-D silicon nanostructures, deuterium processing and hot electron degradation in semiconductor devices, atomically precise dopant mapping, cross-sectional STM of semiconductor heterostructures, oxide silicon interface mapping, carbon nanotube purification

Yi Ma
Computer vision, including multiple view geometry, structure from motion, dynamic vision, real-time tracking, and active vision; systems theory, including geometric nonlinear control, hybrid systems, vision-based robotic control and navigation

Jonathan Makela
Ionospheric physics, especially irregularities at low- and mid-latitudes and their effects on trans-ionospheric satellite signals, response of the Earth's ionosphere to geomagnetic storms; optical and radio remote sensing techniques from ground- and satellite-based platforms

Sean Meyn
Optimal control, Markov processes (with or without control), stochastic approximation and adaptive control, reinforcement learning and simulation, spectral theory and large deviations, information theory, stochastic networks

Pierre Moulin
Image and video processing, compression, statistical signal processing, information hiding, information theory

Klara Nahrstedt
Quality-of-Service (QoS) management, integration of guaranteed and best effort services for audio/video/DATA traffic, QoS-aware resource management, QoS routing, multimedia security, soft real-time scheduling, middleware support for distributed multimedia applications

Natasha Neogi
Aerospace software, hazard elimination using backwards reachability techniques in discrete and hybrid models

David Nicol
Cyber-security, modeling and analysis of computer and communications systems, high performance simulation, parallel processing

Michael L. Oelze
Ultrasound, including backscatter microscopy, quantitative imaging, computed tomography; use of ultrasound for cancer diagnosis and therapy; bioeffects of ultrasound; sonoporation; coded excitation and ultrasound

Sanjay Patel
Computer architecture, microarchitecture, high-performance and reliable computer systems, the implications of future generation applications and implementation technologies on systems design

Janak H. Patel
VLSI testing and testability, VLSI design automation

Constantine D. Polychronopoulos
Parallelizing/optimizing compilers for multithreaded architectures, program restructuring and optimization; code generation and optimization for superscalar processors; parallel programming languages; environments for parallel programming; partitioning, scheduling, and run-time environments for parallel computers; multiprocessor operating systems with multithreading support; parallel computer architectures; performance evaluation of parallel architectures

Umberto Ravaioli
Monte Carlo simulation of high speed electronic devices; numerical methods for semiconductor device simulation; quantum devices; supercomputation and visualization; reliability of MOS devices; micro- and nano-electromechanical systems (MEMS and NEMS); charge transport in biological systems (ionic channels); properties of carbon nanotubes

Angus A. Rockett
IV, III–V, and chalcogenide semiconductors, materials for solar cells, theory of crystal growth, defects in semiconductors, contact metallurgies, solid phase reaction kinetics, surface science, microelectromechanical systems

Elyse Rosenbaum
Design of ESD-protected RFICs, modeling and simulation of ESD protection circuits, latch-up, design of very high speed I/Os, gate oxide reliability

William Sanders
Dependability, security, and performance evaluation; intrusion- and fault-tolerant systems; reliable and secure distributed systems

Dilip V. Sarwate
Communications
Peter W. Sauer  
Electric machinery modeling, analysis and control, power system dynamic modeling and simulation, power system stability

Jose Schutt-Aine  
Electronic packaging, microwave theory and measurements, and digital circuit modeling, including integration of modeling and simulation tools, high-performance computation for simulation of packages, applications of V-shaped transmission lines

Lui Sha  
Distributed real-time computing systems, dynamic real-time architecture, Quality-of-Service (QoS) driven resource management, security and fault tolerance in networked embedded systems

Naresh Shanbhag  
Design and VLSI implementation of low-power, high-performance multimedia digital signal processing and communications systems, noise-tolerant deep submicron VLSI systems, fundamental bounds on efficiency of VLSI information processing systems, power-aware reconfigurable DSP systems, low-power DSP and circuits, DSP and communication system design, digital ASIC design

Andrew Singer  
Statistical signal processing, communications, machine learning, data compression, sonar/lidar/optical signal processing

Mark W. Spong  
Nonlinear control theory, robotics, mechatronics, networked control systems, teleoperation, bipedal locomotion

R. S. Sreenivas  
Discrete-state/discrete-event systems, approximate algorithms, on-line algorithms

Rayadurgam Srikant  
Internet, wireless networks, sensor networks, game theory, queueing theory, information theory

Gary Swenson  
Remote sensing of the atmosphere from ground-based, aircraft, and spacecraft using optical methods; space environment issues with a particular emphasis on spacecraft glows

John Tucker  
Metal silicide source/drain MOS transistors at ~10nm gate length, atom-scale electron devices made by STM patterning of donors in silicon, nanoscale architectures

Nitin Vaidya  
Wireless networking, mobile computing, fault-tolerant computing

Venu Veeravalli  
Sensor networks, wireless communication, detection and estimation theory, information theory

Pramod Viswanath  
Communication theory, wireless communication, information theory, communication networks

Petros G. Voulgaris  
Robust control, time-varying and nonlinear systems, general systems theory, estimation and identification, distributed control of complex systems and networks, emphases on aerospace applications

Benjamin W. Wah  
Nonlinear optimization, parallel processing, distributed processing, artificial intelligence, computer networks, multimedia signal processing

Martin Wong  
Computer-aided design of VLSI, design for manufacturing, routing for high-speed packaging, field-programmable systems, design and analysis of algorithms, combinatorial optimization

Advanced Automation

Acquisition, Compression and Interpolation of Panoramic Stereo Images of a Scene for Remote Walkthroughs

N. Ahuja,* Y. Shinagawa,* M. Maitre, A. Jagmohan  
n-ahuja@uiuc.edu

National Science Foundation, ECS 02-25523

Conducted in the Coordinated Science Laboratory

This project is aimed at producing novel images of a scene from arbitrary new viewpoints using a sparse set of panoramic snapshots or sample images of the scene. The samples are taken from a relatively small number of strategically placed cameras. A major application and evaluation testbed of the proposed work is to enable walkthroughs of a 3-D scene by generating the images of

* Denotes principal investigator.
the scene along a trajectory chosen by a remote user dynamically.

Automated Visual Learning of Safety Appliances on Railcars
N. Ahuja,* C. Barkan,* J. M. Hart, C. B. Liu
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American Association for Railroads

This project is aimed at the development of visual learning techniques and their implementation for automatic checking of the state of safety appliances on a moving train. This consists of the following stages: acquisition of images of railcars for inspection of the safety appliances located on the railcar sides; identification of image characteristics associated with the health of the safety appliances; identification of types of models useful to represent the railcar appearance when the safety appliances are in satisfactory condition, and if necessary, to represent unsatisfactory condition as well; application of models to learn the descriptions of safe and unsafe appliances; and application of the results of learning to railcar classification.

Globally Coordinated Locally Linear Models
N. Ahuja,* H. Arora, A. Briassouli
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Office of Naval Research

This project is aimed at modeling spatiotemporal variations in video sequences such as variations in raw color values, as well as certain functions computed on these values. Since an arbitrary scene consists of distinct objects occupying different parts at different times, making video sequences nonstationary, the goal is local rather than global spatiotemporal modeling. The applicability of the models being developed extends beyond video, to a variety of multivariate, multidimensional data encountered in everyday life.

Machine Vision for Improved Safety Inspection of Railcars
N. Ahuja,* C. Barkan,* A. Kumar
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Transportation Research Board

It is vital to rail safety to ensure that critical mechanical components are in good working order at all times. However, currently much of inspectors’ time is expended inspecting items that are in good working order. This project is aimed at the development of a machine vision system for wayside automatic inspection of railcars, using an advanced camera system that images each railcar truck as a train passes by, and then using machine vision algorithms to analyze these images for detecting worn or defective components.

Machine-Vision Based Assessment of Intermodal Railroad Loading Patterns
N. Ahuja,* C. Barkan,* J. M. Hart, S. Todorovic, P. Vemuru
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Burlington Northern Santa Fe

This project is the design and implementation of a computer vision system for automatic assessment of the loading pattern of trains passing by a wayside monitoring station. The research is concerned with the following major areas: development of algorithms for automatic inspection of double stack railcars, identification of advanced imaging sensors to enhance algorithm performance, field testing of the algorithms and sensors, and the development of a field deployable wayside system to demonstrate a proof of concept. The system needs to have the following capabilities: to image parts of a moving train, to identify specific double stack cards in the train, to analyze key portions of these images to detect the presence or absence of loaded containers, and to detect occurrences of double stack loading.

Next-Generation RFID Systems: People and Object Tracking for Homeland Security Applications
N. Ahuja,* J. Bernard,* G. Horn, R. Jachne,* V. Kindratenko,* S. Patel,* N. Vaidya,* T. Yu, B. Ghanem
n-ahuja@uiuc.edu
University of Illinois

This project is aimed at developing methods for tracking and localization of people in buildings. A central feature of the proposed work is the use of Radio Frequency Identification (RFID) tags. Current RFID technology has inadequate reliability, particularly for homeland security applications. The goal of this project to pursue research on next-generation RFID systems, in collaboration with application domain experts at the Illinois Fire Service Institute, e.g., to help firefighters and other first responders do their jobs more effectively.

Recognition and Contents-Based Retrieval of Hand Gestures from Video
N. Ahuja,* A. Briassouli, A. Sehgal
n-ahuja@uiuc.edu
U.S. Office of Naval Research, N00014-03-1-0107

This project is concerned with recognition of scenes from the spatiotemporal structure of the video data. Trajectories of scene contents seen in the video sequence are used as

* Denotes principal investigator.
the basis for this purpose. Objects are characterized by their spectral properties as well as temporal behavior. Such representations are used for information access as well as for recognition using such methods as support vector machines.

Scale Dependent Processing of Clustered Sensory Signals
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n-ahuja@uiuc.edu  
National Science Foundation, NSF IBN 04-22073

The broad objective of this proposal is to understand the computational algorithms used by animals to extract individual signals that are embedded in a cluster of similar signals. Our major hypotheses are: that characteristics of the received signal and the separability of individual components will vary as a function of distance from the cluster; that computational algorithms for detection, localization, and identification should reflect these scale-dependent changes; and that motor strategies and sensory filtering properties should be adaptively adjusted when processing sensory signals at different distance scales.

Real-Time Path Planning in Changing Environments
S. Hutchinson*  
National Science Foundation

Conducted in the Coordinated Science Laboratory

New methods are proposed to generate collision-free paths for robots that operate in environments that change over time. The proposed approach is related to recent probabilistic roadmap approaches. These planners use preprocessing and query stages and are aimed at planning many times in the same environment. In contrast, the preprocessing stage for this research creates a representation of the configuration space that can be easily modified in real-time to account for changes in the environment. As with previous approaches, the proposed approach began by constructing a roadmap in the configuration space, but this roadmap is not constructed for a specific workspace. Instead, it is constructed for an obstacle-free workspace, and the mapping from workspace cells to nodes and arcs in the roadmap is encoded. When the environment changes, this mapping is used to make the appropriate modifications to the roadmap, and plans can be generated by searching the modified roadmap. At the heart of the method is the encoding for mapping workspace obstacles to configuration space obstacles. To make the proposed approach truly viable, a major component of the proposed research will focus on robustness and complexity issues. These issues will be addressed by using tools from the fields of image processing, information theory, computational geometry, and incremental algorithms.

Advanced Processing and Circuits

AlGaN/GaN HFET Fabrication and Characterization
I. Adesida,* V. Kumar, A. Kuliev  
Triquint Corporation

Conducted in the Micro and Nanotechnology Laboratory

This project involves a collaboration with Triquint Corporation on the fabrication of AlGaN/GaN HFETs. Technologies for the fabrication of the HFETs will be developed.

Gallium Nitride Optoelectronics
I. Adesida,* L. Zhou  

Conducted in the Micro and Nanotechnology Laboratory

This project focuses on experimental issues for the fabrication of novel optoelectronic devices and circuits in gallium nitride and related materials. UV detectors, field effect transistors, and heterojunction bipolar transistors will be investigated. Methods for integrating these devices will also be explored.

Porous GaN: Production, Characterization, and Applications
I. Adesida,* P. Bohn,* X. Li,* S. Kim  
U.S. Office of Naval Research, N00014-01-1

Conducted in the Micro and Nanotechnology Laboratory

This program involves the generation and characterization of porous GaN and SiC for applications in growth of high quality epitaxial layers. Matrices with dimensions down to 50 nm are to be achieved for the porous materials.

Processing of Gallium Nitride and Related Compounds
I. Adesida,* L. Zhou, F. Khan  
ATMI/Air Force

Conducted in the Micro and Nanotechnology Laboratory

This program consists of the development of viable processing methods for gallium nitride and related compounds. A systematic study of etching techniques, ohmic contact formation, and other metallizations will be conducted and applied to devices.

* Denotes principal investigator.
Resonant Enhanced Modulators
I. Adesida,* S. Rommel
Air Force; Sarnoff Corporation
Conducted in the Micro and Nanotechnology Laboratory
This is a collaborative program with Sarnoff Corporation on resonant enhanced modulators in InP-based heterostructures. Waveguides with coupling rings are to be fabricated and characterized in InP-heterostructures. High precision patterning using inductively coupled plasma reactive ion etching and electron beam lithography will be used in fabricating the modulators.

Silicon-Germanium Modulation-doped Field Effect Transistors
I. Adesida,* K. Ismail*
National Science Foundation, ECS 97-10418
Conducted in the Micro and Nanotechnology Laboratory
This collaborative program with IBM Corp. is intended to significantly advance the growth and fabrication technologies for SiGe/Si modulation-doped field effect transistors (MODFETs) needed for low-power, high-speed microwave and digital applications. Specific goals are to study the physics of short gate-length p-type, n-type, and complementary MODFETs and to demonstrate simple circuits.

Ultra-High-Power GaN Power Amplifier at X-Band
I. Adesida,* W. Lu, D. Selvanathan
Air Force; TRW Corporation
Conducted in the Micro and Nanotechnology Laboratory
This collaborative project with TRW Corporation is to fabricate an ultra-high-power GaN-based HFET amplifier on SiC at X-Band. Various processing techniques for GaN will be developed as part of this project.

Aeronomy

Engineering Services and Utilities for ST Radar Operation at the Sidney Field Station
E. Kudeki,* S. Henson
National Science Foundation; SBC Utah State University
This grant concerns the operation of an ST radar at the university's Sidney Field Station. Tropospheric and stratospheric wind, reflectivity, and aspect sensitivity measurements to be conducted with the Sidney radar will complement similar measurements conducted by similar radars operated at the Urbana Atmospheric Observatory and Bondville Field Station. The three-radar network will be used in correlative studies of atmospheric gravity wave propagation in the troposphere and the lower stratosphere as well as phenomena associated with the evolution and dynamics of weather fronts.

Engineering Services and Utilities for the Bondville Field Station
E. Kudeki,* S. Henson
National Oceanic and Atmospheric Administration, 52 RANR 100075
Continuous operation of the FLATLAND ST (stratosphere-mesosphere) radar administered by NOAA is maintained at the Bondville Field Station. The FLATLAND radar, operating at a frequency of 50 MHz, has been designed to investigate the dynamics of the atmosphere above a plain area with insignificant orographical forcing. The routinely measured reflectivity profiles and Doppler spectra are collected in a NOAA database. Joint measurements with the Urbana Field Station MST radar are performed to investigate the horizontal scale lengths of atmospheric gravity waves and to follow the transit of weather fronts.

Radar Studies of the Equatorial Ionosphere
E. Kudeki,* E. Chapin, S. Bhattacharyya, J. Urbina
National Science Foundation, ATM 90-22400
The 50 MHz Jicamarca Radio Observatory located near Lima, Peru, is used to investigate the structure and dynamics of the equatorial ionosphere. In the mesosphere ionospheric D region, investigations aim to resolve the internal structure of narrow echoing layers and determine the relevant scattering/reflection mechanisms. In the higher ionosphere, E- and F-region plasma drifts, instabilities, and turbulence are under study. Current projects include efforts to quantify the anisotropies of equatorial plasma turbulence, obtain interferometric images of plasma irregularity structures, and measure the component of ionospheric drifts in the geomagnetic field direction. Major research effort is dedicated to the refinement of radar techniques suitable for these studies.

Artificial Intelligence: Machine Learning, Vision, and Robotics

Domain Knowledge, Explanation-Based Control, and Reinforcement Learning
G. DeJong,* A. Laud, Q. Sun, V. Moskovich
Office of Naval Research, N00014-01-1-0063
Prior research has shown that complex skill-like decision policies can be acquired by combining an inferential
symbolic reasoning with a numeric component. The approach is called Explanation-Based Control. Reinforcement Learning (RL) is a popular machine learning approach that also automatically acquires skill-like policies. However, it is difficult or impossible to exploit a domain expert’s knowledge. This means that RL cannot learn complex policies in an example-efficient manner. This research explores combining the two approaches to achieve greater example efficiency on the practical side and a clearer conceptual foundation theoretically.

The Role of Experience in Natural Language
D. Roth,* K. Bock, J. Cole, G. Dell, C. Fisher, S. Garnsey, A. Goldberg, S. Levinson National Science Foundation, KDI SBR 98-73450

An integrated multiparadigm approach to the study of learning mechanism in language production and comprehension is studied. The language processing system is constantly changing. It adapts quickly to recent experience while continuing to reflect the accumulated experience of a lifetime of speaking, listening, reading, and writing. This project integrates research efforts in psycholinguistics, linguistics theory, and computational models of learning in an attempt to address the mechanisms that enable the language processor to adapt to experience. In addition, the research will suggest learning mechanisms for language processing technology, particularly for rapid adaptation to changing linguistic environments.

Bioacoustics

Biomaterials Characterization with High-Frequency Ultrasound Computed Tomography
M. L. Oelze* oelze@uiuc.edu 3M Corporation

Conducted in the Beckman Institute for Advanced Science and Technology

The objective is to evaluate diffraction tomography algorithms applicable to soft tissue scattering, construct a high-frequency ultrasound computed tomography scanning device, and evaluate model biological systems for scanning. An ultrasound frequency of up to 100 MHz yielding resolution of 12 to 15 micrometers will be used. Elastic properties of cell models, other kinds of tissues, and synthetic biomaterials will be imaged and quantified. The high-resolution, quantitative information that the high-frequency ultrasound computed tomography device can yield will be beneficial for many kinds of research into properties and functioning of materials.

Tumor Diagnosis through Enhanced Ultrasound Imaging
M. L. Oelze,* J. F. Zachary (Vet. Pathobiol.), W. D. O'Brien, Jr. oelze@uiuc.edu National Institutes of Health, National Cancer Institute, F32CA96419

Conducted in the Beckman Institute for Advanced Science and Technology

The objective is to develop and refine a fundamentally new approach to enhance ultrasound imaging of biological tissues by the quantification of tissue microstructure through acoustic backscatter. This enhanced imaging technique will then be adapted for real-time in situ clinical diagnosis of solid tumors with the expectation of producing acoustic images that will provide an accurate diagnosis of cancer. Use of enhanced ultrasound imaging is medically significant because it offers a quick and noninvasive means of detecting and classifying tumor types.

Bioengineering

Fluid Power Assistive Orthoses
E. T. Hsiao-Wecksler,* A. G. Alleyne, E. Loth ethw@uiuc.edu National Science Foundation

In the United States alone, there are over 800,000 individuals affected by gait disabilities caused by weakness of muscle groups below the knee. This project, which is a testbed project for the National Science Foundation funded Engineering Research Center for Compact and Efficient Fluid Power, will design novel ankle foot orthoses (AFOs) with embedded fluid power control and actuation that assist a person's functional gait. Each design iteration will address progressively more complex gait pathologies, thus allowing for an evolution of advanced fluid power concepts, such as power harvesting and fast-response sensing. Initial designs will utilize fluid-controlled (adaptive-passive) systems to correct for toe drop and foot slap, helping to lift the foot during swing and initial foot contact during walking. Later advanced designs will use fluid-powered (active) systems to provide torque assistance during the propulsive late-stance phase of the gait cycle. The testbed will demonstrate and integrate compact, efficient, and effective fluid power concepts in a challenging, untethered, human-scale device. The long-term goal is to develop and test a series of

* Denotes principal investigator.
prototype devices that will incorporate current thrust area projects, as well as drive new enabling and systems technologies within the center. These technologies will follow an evolutionary roadmap addressing the highest priority aspects of the overall testbed first, and then integrating developments from other center projects as they come available over the lifetime of the center. This testbed will culminate with prototypes supplied to health care professionals and patients for testing and evaluation.

**Fluid Power Assistive Orthoses**
E. T. Hsiao-Wecksler,* A. G. Alleyne, E. Loth ethw@uiuc.edu

*National Science Foundation*

In the United States alone, there are over 800,000 individuals affected by gait disabilities caused by weakness of muscle groups below the knee. This project, which is a testbed project for the National Science Foundation funded Engineering Research Center for Compact and Efficient Fluid Power, will design novel ankle foot orthoses (AFOs) with embedded fluid power control and actuation that assist a person's functional gait. Each design iteration will address progressively more complex gait pathologies, thus allowing for an evolution of advanced fluid power concepts, such as power harvesting and fast-response sensing. Initial designs will utilize fluid-controlled (adaptive-passive) systems to correct for toe drop and foot slap, helping to lift the foot during swing and initial foot contact during walking. Later advanced designs will use fluid-powered (active) systems to provide torque assistance during the propulsive late-stance phase of the gait cycle. The testbed will demonstrate and integrate compact, efficient, and effective fluid power concepts in a challenging, untethered, human-scale device. The long-term goal is to develop and test a series of prototype devices that will incorporate current thrust area projects, as well as drive new enabling and systems technologies within the center. These technologies will follow an evolutionary roadmap addressing the highest priority aspects of the overall testbed first, and then integrating developments from other center projects as they come available over the lifetime of the center. This testbed will culminate with prototypes supplied to health care professionals and patients for testing and evaluation.

**Biomaterials**

**Development of Nanoliter Calorimetry for Biomaterials**
L. H. Allen,* T. Siaf, M. Wheeler

*National Science Foundation, EF 0304149*

Miniaturized measurement instruments have been developed in the field of MEMS. Their use in biological studies will add a whole new dimension for investigations in microbiology and protein research. The goal of this project is to measure processes in biology, such as those for protein folding and for ultrasmall volumes on short time scales, with a new technique made possible via MEMS membrane technology. Our group has developed the most sensitive scanning calorimetry device to date for materials characterization in metals and polymers: nanocalorimetry.

**Circuits**

**CAREER: Nano-Centric Design Methodology for Nanoscale FPGAs**
D. Chen*

*National Science Foundation*

Conducted in the Coordinated Science Laboratory

This project proposes a fundamental, systematic, and nano-centric design methodology for nanoscale FPGAs. The proposal includes the following four integrated design aspects: patterning, designs of novel and reliable architecture patterns; modeling, development of new device/wire/circuit models considering nanomaterial-specific characteristics; synthesizing, focuses on novel nano-centric synthesis techniques; and evaluating, building a new parameterized nanoFPGA evaluation/exploration engine called the NanoEngine.

**High-Performance Reliable Computing Addressing the Parameter-Variation Challenge through a Cross-Disciplinary Architecture, CAD, and Compiler Approach**
D. Chen,* J. Torrellas, C. Zilles

*National Science Foundation*

Conducted in the Coordinated Science Laboratory

This project proposes to combine microarchitectural, CAD, and compiler innovations to enable reliable, high-performance, gigascale multicore chips built out of unreliable components. We treat frequency, power, and error rate as dynamically tradable quantities that are the subject of multilevel optimization.
Modeling, Mitigating, and Tolerating Faults Due to Parameter Variation in Multicores: A Microarchitecture and CAD Approach
D. Chen,* J. Torrellas
Semiconductor Research Corporation

Conducted in both Coordinated Science Laboratory and the Siebel Center

This project proposes novel microarchitecture and CAD techniques for the mitigation, detection, and tolerance of variation-induced errors—in an environment where such errors may happen frequently during normal multicore execution. The approach can be applied to both high-performance and low-power environments.

New Techniques in Synthesis and Physical Design for FPGAs
D. Chen,* M. Wong
Altera Corporation, USA

Conducted in the Coordinated Science Laboratory

This project investigates the following FPGA synthesis topics: synthesis with multiclue constraints, synthesis for FPGA power reduction, and the design of new academic benchmark circuits.

SOS: A Nanotube-Based Configurable Logic Fabric
D. Chen,* E. Pop
Research Board, University of Illinois at Urbana-Champaign

Conducted in the Coordinated Science Laboratory

This project will design and build a new SWCNT-based logic fabric, named SOS (Sea-of-SWCNTs), targeting high performance and logic density. This prototyping chip is configurable through a burn-in process.

An Integrated Design Methodology for Low-Power DSP and Communications Systems
I. N. Hajj,* N. R. Shanbhag,* S. Bobba
National Science Foundation, MIP-9710235

The goal of this project is to develop an integrated computer-aided design (CAD) approach for the design of low-power hardware for digital signal processing (DSP) and communications applications. The approach incorporates high-level (algorithmic) and low-level (circuit) parameters and includes novel capabilities for design exploration and low-power circuit synthesis. The design exploration will be done by developing low-power constrained algorithm design procedures that employ an analytic relation between word-level and bit-level signal statistics. The synthesis effort will incorporate signal statistics, high-level hardware models, and algorithm transformations to generate low-power dedicated implementation of DSP algorithms.

Compact, Scalable SCR Model
E. Rosenbaum,* J. Di Sarro
elyse@uiuc.edu
National Semiconductor

Conducted in Coordinated Science Laboratory

SCR devices may be used for on-chip ESD protection. The turn-on delay and holding voltage are highly layout dependent. We are developing a compact, scalable model of the SCR for circuit simulation purposes.

Electrical Overstress Protection for System-in-a-Package
E. Rosenbaum,* N. Olson, N. Jack
National Science Foundation

Conducted in the Coordinated Science Laboratory

The objective of this research is to explore the response of system-in-a-package to electrical overstress events, and to develop the know-how to protect against these without compromising the system performance.

ESD Reliability of 3-D System-in-a-Package
E. Rosenbaum,* J. Lee, N. Jack
Micron Technology Foundation

Conducted in the Coordinated Science Laboratory

This research project focuses on the development of strategies for protecting 3-D SiP against electrostatic discharge (ESD). Of particular interest are SiP in which the die are connected to each other by wafer interconnects (TWI). The various die are not necessarily fabricated using the same technology, nor are their ESD networks necessarily designed together.

Full-Chip Simulation of Charged Device Model ESD
E. Rosenbaum,* J. Lee, F. Farbiz
elyse@uiuc.edu
UMC

The capability to perform circuit simulation of ESD events increases the number of parts that pass ESD qualification on the first try. The charged device model (CDM) best represents yield reducing events that occur in modern factories. The CDM represents the single pin discharge of a packaged chip that is at a potential hundreds of volts above ground. We are investigating whether sufficiently accurate CDM simulation results can be obtained using only a small simulation netlist that contains macro-models of the multiple discharge paths. The various power

* Denotes principal investigator.
domains are linked through the substrate, and an appropriate model of it must be developed.

**Highly Reliable Receiver Circuits for High-Speed IO Links**
E. Rosenbaum,* N. Shanbhag,* A. Srivastava, A. Faust, K. Bhatia, R. L. Narasimha
eelyse@uiuc.edu
Semiconductor Research Corp.

We are applying communication theory to design ESD-protected, high-speed serial links. Links are expected to provide data rates in excess of 10 Gb/s at a BER less than $10^{-15}$, per-channel power consumption less than 100 mW, and a 3-KV HBM-ESD protection level.

**Simultaneous Reduction of Substrate Noise Coupling and Latchup Hazards**
E. Rosenbaum,* F. Farbiz
Semiconductor Research Corp.
Conducted in the Coordinated Science Laboratory

The objective of this project is to develop compact models and design guidelines for the simultaneous mitigation of substrate coupling and latchup hazards. Substrate coupling and latchup both are the result of current injection into the silicon substrate beneath the active circuitry. Substrate coupling compromises signal integrity; latchup can cause catastrophic permanent failure of an integrated circuit.

**Stacked Packaging and CDM-ESD Reliability**
E. Rosenbaum,* V. Shukla
Semiconductor Research Corp.
Conducted in the Coordinated Science Laboratory

For applications in which the microelectronic components must have a minimum footprint, stacked packaging is the preferred way to integrate multiple die. This project focuses on development of ESD protection strategies for stacked chip-sized packages (CSP). The use of stacked packaging will tend to increase the ESD hazard. In stacked packaging, the static charge may have to travel through protection circuits located on multiple die, as well as one or more bond wires. Thus, one expects to observe a larger voltage drop along the discharge path in a stacked package, and this will present a hazard to gate dielectric integrity.

**Algorithms and VLSI Architectures for Joint Equalization and Decoding**
N. R. Shanbhag,* A. C. Singer, S. J. Lee
CCR-9979381; CCR-00-85929

This project explores efficient algorithms and architectures for joint equalization and decoding in high data-rate communications systems. Such systems suffer from intersymbol interference (ISI) and noise. Conventional approaches separate the two functions of equalization and decoding for historical reasons. Significant improvements in bit-error rates are feasible if the two functions are executed jointly. Techniques such as turbo equalization are being explored where the equalizer and the decoder exchange soft information to enhance performance. Application of these new receiver techniques to broadband communication systems such as very high-speed digital subscriber lines (VDSL) and wireless is being studied.

**Fluid IP Core Generators**
N. R. Shanbhag, B. Lam, M. Zhang, B. Shim
Defense Advanced Research Projects Agency

This project seeks to develop design techniques and tools for realizing custom-quality VLSI designs in synthesis quality design cycle times for DOD applications. The focus of our research is on datapath intensive broadband communication subsystems, such as filters and FFT. The design methodology includes an architecture optimizer and a layout synthesizer bypassing logic synthesis. Techniques such as device sizing, noise-tolerance (both at the circuit and algorithmic level), algorithm transforms, power, and delay models are being incorporated into the core generator. The resulting circuit layouts are targeted to meet power, delay, and reliability specifications.

**High-Speed Architectures for Iterative Decoders**
N. R. Shanbhag,* M. Mansour
CCR-9979381; CCR-0085929

This research focuses on the design of high-speed iterative decoders. Recently, turbo codes, low-density parity check (LDPC) codes, and related concatenated codes have been proven to be extraordinarily effective in improving the bit-error rates on noisy communication links. Decoders for such codes are iterative and block-based, making high data-rates difficult to achieve. These decoders are also memory intensive. Our research explores alternative decoding algorithms that might be appropriate for low-power and high-performance VLSI implementations.

**High-Speed IO Signaling**
N. R. Shanbhag,* G. Balamurugan, H. M. Bae, S. Sridhara
Intel

The goal of this project is to investigate solutions for data transmission in the range of 5Gb/s–10Gb/s for inter-chip communications. The project involves the application of communications and signal processing theory and techniques to analyze high-speed I/O links. Until recently,
design efforts have been focused primarily on transceiver electronics without comprehension of the communication channel. In addition, no rigorous, comprehensive analysis techniques exist to analyze and predict the performance of I/O signaling systems. By viewing the I/O link as a noisy communication channel over which reliable information transfer needs to take place, the project proposes to develop analysis methods and explore design possibilities to accomplish reliable energy-efficient high-speed data transfer over inter-chip links.

**Noise-Tolerant DSP in the Deep Submicron Era**  
N. R. Shanbhag,* R. Hegde, L. Wang, G. Balamurugan  
*National Science Foundation, CCR-9902745*

This research addresses the design of reliable and energy-efficient DSP systems in deep submicron (DSM) SMOS technology in a unified manner via the development of noise-tolerant algorithmic and circuit design techniques. In particular, circuit design techniques that tolerate leakage, crosstalk, ground bounce, and process variations are being developed. Algorithmic approaches that exploit the statistical structure of multimedia signals to combat DSM noise are also being studied. A design methodology is being formulated that jointly applies circuit and algorithmic noise-tolerance techniques to achieve an overall level of system reliability while minimizing energy.

**VLSI Architectures for Soft Decoding of Reed–Solomon Codes**  
N. R. Shanbhag,* R. Koetter, R. Blahut, A. Ahmed  
CCR-0073490

This project investigates high-performance architectures for soft decoding of Reed–Solomon codes. Reed–Solomon codes are commonly employed to enhance the reliability of broadband communications links. Reed–Solomon decoders used in practice today employ hard-decision decoding. Soft decision decoding of Reed–Solomon codes can provide significant coding gains over hard-decision decoders. Soft decision decoding algorithms are computationally complex and hard to implement in VLSI. This research explores algorithmic and architectural techniques to design soft decision Reed–Solomon decoders for high-data rate communication systems.

**CAD for VLSI Manufacturability and Reliability**  
M. D. Wong*  
*National Science Foundation*

In nanometer-design technologies, computer-aided design software must consider manufacturability and reliability. In this project, we focus on the development of theories and prototype systems for solving problems in the design for manufacturability and reliability area. Research topics include lithography-aware design tools, fast reticle enhancement techniques (OPC, PSM, OAI, and such), and layout optimization for CMP.

**Routing for High-Performance VLSI Packaging**  
M. D. Wong*  
*IBM*

In this project, we develop a complete routing system for high-performance circuit boards. The type of high-end boards targeted in this project is generally completed using manual methods because of the complexity or density of the design. The goal is to create a system that will either completely remove the need of manual routing or significantly reduce the effort of manual routing. Such a system will dramatically reduce the design time for state-of-the-art, high-performance complex boards.

**Communications**

**Fair Scheduling and Admission Control for Shared-Channel Wireless Packet Networks**  
V. Bharghavan,* R. Srikant,* S. Shakkottai, A. Eryilmaz  
*National Science Foundation*

Fair scheduling of traffic sources in wireless networks is difficult due to bursty channel errors and location-dependent channel capacity. In this project, researchers study MAC, scheduling and admission control algorithms for indoor and outdoor wireless networks that allocate the available bandwidth in a fair manner to competing sources.

**High-Performance Decoding of Algebraic Codes Beyond their Packing Radii**  
R. Blahut,* N. Shanbhag, R. Koetter  
*National Science Foundation, CCR-0073490*

Conducted in the Coordinated Science Laboratory

The objective of this research is to investigate practical and theoretical aspects of interpolation/factorization algorithms that were pioneered by M. Sudan for decoding beyond half the minimum distance of Reed–Solomon, Bose–Chaudhuri–Hocquenghem (BCH), and algebraic geometry codes. The research has two main thrusts. The first is the characterization of the decoding algorithm and its complexity or performance trade-off, together with subsequent improvements in the decoding of BCH and algebraic geometry codes; these are at the theoretical core of this proposal. The second main thrust is the development of efficient computational architectures for implementing the algorithms and the demonstration of the feasibility and practicality of very large scale integrated circuit (VLSI)

* Denotes principal investigator.
implementation of decoders that will dramatically outperform the decoding algorithms used in current commercial communications and storage systems.

**Codes on Graphs, Factor Graphs, and Iterative Algorithms**  
R. Koetter*  
*National Science Foundation Career Award, CCR 99-84515*

The primary focus of this research is the investigation of creative new methods for reliable transmission of information in the context of modern error-control techniques. Error-correcting codes are an essential part of modern communication and storage systems and much of today's technology would not be possible without them. This study is focused on graph-based, iterative decoding algorithms, which, without doubt, are one of the most significant coding-theoretic developments of the last decade. The goal of the investigator's research is to develop a broad, analytical, and constructive approach to research and education, unifying graphical models, coding theory, and iterative algorithms. The interplay between codes on graphs and other areas, like iterative graph-based algorithms, system theory, and network information theory, is in the focus of this investigation with the goal of discovering and utilizing fundamental connections between these fields.

**High-Performance Short Iterative Codes**  
R. Koetter*  
*Motorola, Inc.*

This project aims at developing excellent codes for application requiring short- to moderate-length (64 bits to <1,000 bits) codes. Traditional coding schemes for these lengths rely typically on algebraic constructions or convolutional codes. Researchers strive to make the tremendous gains achievable for long blocklengths (>10,000 bits) by turbo and other iteratively decodable codes available for much shorter code length.

**Unwrapping Phase Images: Theory and Applications Using Probabilistic Inference Techniques**  
R. Koetter,* B. Frey, D. Munson  
*National Science Foundation, CCR 01-05719*

Phase unwrapping in two-dimensional topologies is a signal processing problem that has been studied extensively over the past 20 years and has important applications, such as medical imaging and synthetic aperture radar. However, despite its importance in science and engineering, to date, phase unwrapping in two-dimensional grids has remained an essentially unsolved problem. This research takes a fresh approach to the problem using methods from probabilistic inference. The work not only holds the promise of resulting in powerful phase unwrapping schemes based on the sum-product algorithm and structured variational methods, but also has the potential to provide deep theoretical insight into the ill-posed nature and solvability of the phase unwrapping problem. Such an insight is extremely important for guiding the development of practical algorithms.

**Communication over Dispersive Wireless Channels: Theory and Methods Based on Physical Principles**  
V. V. Veeravalli,* J. Chen, C. Lin, V. Raghavan, V. Annapureddy  
*National Science Foundation, CCF0431088*

*Conducted in the Coordinated Science Laboratory*

The research in this project is aimed at exploiting an angular (virtual) representation of multi-input multi-output (MIMO) wireless channels to design and analyze new communication schemes for these channels. The project has three broad thrusts: accurate statistical channel characterization in the spatial, temporal, and spectral dimensions, and reliable estimation of the essential channel parameters in the angular domain; exploitation of virtual channel structure in determining the channel capacity of dispersive wireless channels, and in designing coherent and noncoherent coding and modulation schemes; and leveraging the virtual representation for efficient sharing of signal dimensions in time-frequency-space among multiple users.

**Design and Analysis of Sensor Networks for Statistical Inference Applications**  
V. V. Veeravalli,* J. Fuemmeler, S. R. Srinivasan  
*Motorola Communications Center, RPS-28*

*Conducted in the Coordinated Science Laboratory*

This goal of this project is to explore applications of sensor networks in the following areas of interest to Motorola: early warning and prediction of failures in machines and other large structures; government and enterprise mobility solutions (GEMS) applications such as fire-fighting and rescue operations; industrial process monitoring; and industrial work in progress (WIP) tracking for assembly lines.

* Denotes principal investigator.
Communications Networks

**ITR: Diagnosis and Assessment of Faults, Misbehaviors, and Threats in Distributed Systems and Networks**

C. Hadjicostis,* R. S. Sreenivas, K. Thulasiraman, C. Beck

*National Science Foundation*

The proposed research develops theory and techniques for monitoring and diagnosing faults, hazards, or more generally, functional changes in dynamic systems and networks, under limited and possibly corrupted information. We present a unifying and multifaceted approach to this problem that decomposes the large body of fault diagnosis research into six topics: deterministic fault diagnosis, model-based probabilistic diagnosis, adaptive and sequential diagnosis, distributed system-level diagnosis with communication constraints in wired/wireless networks, fault diagnosis via distributed belief propagation algorithms, and model-independent diagnosis. The research involves a synergy of several areas, including fault diagnosis, sequential detection, system-level diagnosis, distributed control, modeling, analysis and performance evaluation, applied probability, graph theory, belief propagation and model reduction to the problem of detecting, and identifying and localizing faults and abnormalities in dynamically evolving environments.

Computer Architecture and Compilers

**Compiler Support for Performance Modeling of Parallel and Distributed Programs**

V. Adve*

*Defense Advanced Research Projects Agency, N66001-97-C-8533*

*Conducted in the Digital Computer Laboratory*

Researchers are developing compiler techniques that enable fast, accurate, and automatic performance modeling of highly scalable applications. One focus of this effort is a compiler-generated program representation that allows one to automate a wide range of analytical, simulation, and hybrid models of parallel programs. A second focus is to use additional compiler analysis, together with this representation, to enable efficient simulation of highly scalable applications. One such compiler technique achieved 10-2000x reduction in memory usage and 2-10x reduction in simulation time for the simulation of large message-passing programs. This work is part of a broader collaboration with five other universities.

* Denotes principal investigator.

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New Techniques for Optimizing the Quality and Capacity of Wireless Communication Systems

V. V. Veeravalli,* J. F. Chamberland, Y. Liang, N. Wang

*National Science Foundation, Faculty Early Career Development, Presidential Early Career Award for Scientists and Engineers, CCR-0049089*

The research in this project is directed toward the development of future generation multimedia wireless communication systems. Specifically, the research spans the following four areas: wireless channel modeling and analysis; information theory for wireless systems; wireless CDMA systems; and dynamic radio resource management.

New Techniques for Optimizing the Quality and Capacity of Wireless Communication Systems


*National Science Foundation, Faculty Early Career Development, Presidential Early Career Award for Scientists and Engineers, CCF0049089*

Conducted in the Coordinated Science Laboratory

The research in this project is directed toward the development of future generation multimedia wireless communication systems. Specifically, the research spans the following five areas: wireless channel modeling and analysis; information theory for wireless systems; wireless CDMA systems; dynamic radio resource management, and sensor networks.

Spatial-Temporal Nonlinear Filtering with Applications to Information Assurance and Counterterrorism

V. V. Veeravalli,* V. Raghavan, J. Fuemmeler

*DOD Army Research Office FY06 MURI Program on Spatial-Temporal Event Pattern Recognition, W911NF-06-1-0094*

Conducted in the Coordinated Science Laboratory

The objective of this project is to develop new statistical methods for spatial-temporal event and pattern recognition with applications to information assurance and counterterrorism. Specific problems of interest include quickest change detection and energy-efficient tracking in distributed sensor networks.
S. Adve,* A. F. Harris, C. J. Hughes, D. L. Jones, R. H. Kravets, K. Nahrstedt, D. G. Sachs, V. Vardhan, W. Yuan
AMD Corp.; National Science Foundation, CCR-02-05638, EIA-02-24453

Conducted in the Digital Computer Laboratory
Mobile devices that primarily process multimedia data are expected to become a dominant computing platform for a variety of application domains. Their design must consider demanding, dynamic, and multiple resource constraints, with energy as a first-class resource. However, the ability of multimedia applications to trade off output quality for system resources offers an opportunity for the design of systems where each system layer can adapt in response to resource or application changes. Reaping the full benefits of a system with multiple adaptive layers, however, requires a careful coordination of those adaptations. This project is developing a cross-layer adaptive system and framework to reduce energy consumption while preserving application quality within available computation and bandwidth resources. The final system prototype will integrate adaptations in the hardware, network, operating system, and application layers, opening up sources of energy savings not possible before.

SAFECode: A Compiler System for Enforcing Memory Safety in C Programs
V. Adve,* D. Dhurjati, S. Kowshik
National Science Foundation, EIA-00-93426, CCR-02-09202, and CNS-04-06351; SRC MARCO/DARPA consortium

Programming errors that lead to illegal memory accesses are a dominant source of vulnerabilities that lead to security violations in modern computer systems. Such errors can include buffer overruns, dangling pointer errors, and others. The SAFECode compiler automatically transforms programs to prevent all kinds of memory errors in production code, through a combination of static and runtime checking. For safety techniques used in production code, the run-time checking introduces very low overheads. These low overheads are made possible by a novel approach for making hard-to-find errors harmless, without actually eliminating those errors. The compiler also ensures that a specific approach to program analysis can be made sound, despite the presence of hard-to-detect errors, enabling static checking and verification tools to give guarantees of soundness for the properties they claim to prove. SAFECode also provides additional techniques for debugging difficult-to-find errors like dangling pointers, through more expensive but complete techniques.

Secure Virtual Architecture (SVA): Compiler Techniques for Operating System Security and Reliability
V. Adve,* A. Lenharth,* J. Criswell, D. Dhurjati
National Science Foundation, EIA-00-93426, CNS-04-06351, CCF-04-29561; DARPA/MARCO Gigascale Systems Research Center (GSRC)

Despite major developments in technologies for system security and reliability, today's operating systems and user processes remain vulnerable to an extensive range of attacks. At the root cause of such vulnerabilities is an important class of bugs: implementation errors, e.g., memory access errors or missing security checks. These are not addressed even by powerful, security-conscious design approaches like security kernels or virtual machine monitors. Moreover, design weaknesses in legacy kernels can magnify the potential risk when a successful exploit occurs, e.g., allowing device drivers or other kernel extensions to operate with full privilege within the kernel address space. This project is developing a compiler-based virtual machine (Safe LLVA) that is capable of hosting a standard C/C++-based operating system and all its applications, and exploring how this organization can improve overall system security and provide new security capabilities. Such a virtual machine can apply a range of compiler-based safety checking techniques on legacy kernel code. The immediate goal of this work is to apply compiler-based techniques for memory safety from the SAFECode project to kernel code to prevent attacks via memory access errors. More broadly, the combined system will also address techniques for reducing kernel implementation errors, improving application security by enforcing least-privilege, and protecting critical application data from the kernel even if it is compromised.

Virtual Instruction Set Computers (VISC)
V. Adve,* R. Bocchino, J. Criswell, D. Dhurjati, T. Lattner,
National Science Foundation, EIA-00-93426, CCF 04-29561; DARPA/MARCO Gigascale Systems Research Center (GSRC)

Virtual Instruction Set Computer (VISC) architectures define two separate instruction sets (one to serve as the representation of stored programs, and another to control the hardware), and use a hardware-specific translation layer to optimize and execute code on the hardware. This approach lends great flexibility to hardware and compiler design, enabling close cooperation between the translator

* Denotes principal investigator.
and the microarchitecture on each individual chip (since each distinct processor design has its own specific translator). This is because the hardware instruction set can expose microarchitecture details to the translator and, conversely, can rely on the translator to produce code with predefined assumptions. This project is defining a novel virtual instruction set for VISC architectures called Low Level Virtual Architecture (LLVA) and a translation strategy that permits both offline and online translation or a combination thereof. The project is also exploring compiler and architecture techniques to exploit the VISC framework with the rich virtual instruction set for improved processor performance and reliability.

**The LLVM Compiler System**


*National Science Foundation, EIA-00-93426, CCR-02-09202, CNS-04-06351, CCF 04-29561; DARPA/MARCO Gigascale Systems Research Center (GSRC)*

Modern applications are increasing in size, change their behavior significantly during execution, support dynamic extensions and upgrades, and often have components written in multiple different languages. While some applications have small hot spots, others spread their execution time evenly throughout the application. In order to maximize the efficiency of all of these programs, program optimization must be performed throughout the lifetime of a program, including compile-time, link-time, install-time, run-time, and "idle-time" profile-guided optimization between runs. The LLVM compiler project provides a framework to make "lifelong" program analysis and transformation available for arbitrary software, and in a manner that is transparent to programmers. The LLVM system retains key program information in a language-independent format that can be used for lifelong compilation, and exploits this representation to provide a unique combination of capabilities. LLVM is available freely in open-source form and has attracted a large community of active users and contributors in industry, academia, and the open-source community.

**Macrosopic Data Structure Analyses and Transformations**

V. Adve,* Q. Yi, K. Kennedy (Rice Univ.)

*U.S. Department of Energy ASCI Academic Strategic Alliances Program, B347884*

Conducted in the Digital Computer Laboratory

Managing performance on deep memory hierarchies is widely considered to be a critical open problem for high-performance systems. This research team is exploring a novel class of compiler transformations that provides improved locality at multiple levels of memory hierarchy simultaneously. The transformations exploit the property that recursive algorithms have identical reuse patterns at each level of recursion, providing a hierarchy of working sets. Researchers are developing compiler algorithms to transform existing loop-based codes into efficient recursive form automatically. Such a transformation has wide applicability, including automatic blocking for multiple levels of cache hierarchy and improving communication locality in shared memory codes.

**Computer Engineering**

**Ad Hoc Wireless Networks Utilizing Multirate and Power-Save Capabilities**

N. Vaidya*

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*National Science Foundation, ANI 01-25859*

Wireless communication technology has gained widespread acceptance in recent years. Wireless local area networks have come into greater use, with the advent of the IEEE 802.11 standard and availability of several commercial products based on this standard. An ad hoc network can be formed by wireless, potentially mobile hosts, without requiring the use of any fixed infrastructure, such as base stations. Such networks have many applications, including home networking, personal area networking, sensor networking, search-and-rescue missions in remote areas, and other civilian as well as military operations. Modern wireless devices are often designed with the capability to transmit at different bit rates using different modulation schemes and to operate in a power-save mode to conserve energy. While such wireless devices can be built, there is not adequate research on performance of ad hoc networks utilizing such devices. This project will, therefore, attempt to answer two broad questions: How do we design wireless medium access control (MAC) protocols that exploit multirate and power-save capabilities in ad hoc networks? While there has been

* Denotes principal investigator.
some work on such protocols, this project is expected to
develop new techniques to utilize multirate and power-
save capabilities. What is the impact of multirate and
power-save capabilities on performance on network layer
and transport layer? The project will study the interaction
between wireless device capabilities and upper layer
performance, and develop mechanisms to improve
performance of the various layers.

**Wireless Wind Tunnel: A Testbed for Experimental Evaluation of Wireless Networks**

N. H. Vaidya,* J. T. Bernhard, V. V. Veeravalli,
R. K. Iyer, P. R. Kumar

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* Denotes principal investigator.

This project, evaluating protocols for wireless networks
and developing scaling techniques for physical environments, aims at deploying an anechoic chamber for interference control, forming a testbed, referred to as the wireless wind tunnel (WWT). The uses of the testbed focus on: evaluation of wireless protocols (WP) in controlled environments, development of channel models suitable for simulation-based evaluation of WPs, and evaluation of techniques for scaling the physical environment to facilitate realistic wireless experiments. The WWT addresses some of the limitations based on computer evaluations resulting from the present insufficient understanding of channel and system models for wireless networks. These are not well understood and brute force accurate simulation of the wireless environment are at present too complex. Existing hardware testbeds suffer from one or both of the following shortcomings: experiments often cannot be repeated due to interference by other wireless devices operating in the same frequency range, and the parameters of the experiment (such as the mobility patterns of the mobiles and scatterers in the environment) are not fully controllable. This work impacts the education mission, including coursework, laboratories, and student projects. The testbed will serve as a demonstration tool. New educational opportunities will open involving experimental research providing better training and motivation. Facilities will be made available to a larger pool of researchers. Additional impact is expected on communications systems in practice.

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**Construction Management**

**Nighttime Construction: Evaluation of Lighting Glare for Highway Construction**

K. El-Rayes,* L. Liu, I. Odeh

* Illinois Department of Transportation, ICT R27-2

An increasing amount of highway repair and construction work in Illinois is being performed during the off-peak nighttime hours. Nighttime construction is advocated as a way to mitigate the impact of construction operations on the traveling public, shorten the duration of construction operations, and reduce the potential for work zone-accidents. However, nighttime construction operations may in fact be more hazardous for both drivers and construction personnel. Drivers often find difficulty in adjusting to the extreme changes in lighting levels when entering a construction zone from a relatively dark roadway environment. The utilization and placement of lighting equipment to illuminate the work zone may cause glare for drivers and/or equipment operators. To address these challenges, the main objectives of this project are to survey existing types of glare measurement practices currently being used in the industry; develop practical tools for evaluating glare at nighttime construction sites and evaluate their performance with selected lighting arrangements that are common to nighttime construction; and evaluate and recommend acceptable levels of glare that take into account construction workers, the traveling public, and overall light reflection from the work zone. The results of this study will provide the Illinois Department of Transportation with a scientific and objective approach for specifying the required lighting standards in nighttime highway construction projects.

**Web-Based Management of Multiple Interdisciplinary and Geographically Distributed Research Projects**

K. El-Rayes,* L. Liu, F. Pena-Mora, W. Orabi

elrayes@uiuc.edu

* Denotes principal investigator.

Conducted in the Newmark Civil Engineering Laboratory

The main objective of this project is to develop a robust IT-based management system for engineering research centers to ensure the accomplishment of their research and educational and outreach goals on time and within budget. To this end, a web-based system is being developed to enable remote and effective management of multiple interdisciplinary research projects that are located in different geographic regions.
Automated Productivity and Progress Assessments Using Digital Close-Range Photogrammetry
L. Y. Liu,* T. Trupp
lliu1@uiuc.edu
University of Illinois; Hewlett Packard; National Science Foundation

Conducted in the Newmark Civil Engineering Laboratory

Construction productivity and progress assessments are among the most challenging tasks of a construction project. Accurate measurements of productivity and progress play a critical role in the success of a construction project. This research project integrates digital close-range photogrammetry, computer vision, image reasoning, 3D-CADD, and computer databases to provide an automated system for measuring construction productivity and progress.

This research will impact how we manage construction projects in the future.

Building Blackbox System for Emergency Response
L. Y. Liu,* F. Pena-Mora, M. Tsai
National Science Foundation

This project explores the design and development of a building blackbox system that collects data from building systems to support urban rescue in manmade or natural disasters. This research will lead to smart buildings and structures for construction diagnostics and inspection in addition to information services during emergency response.

Construction Object-oriented Process Simulation
L. Y. Liu*
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University of Illinois

Conducted in the Newmark Civil Engineering Laboratory

Simulation provides a practical means of analyzing construction processes to identify resource utilization and idleness, operation bottlenecks, productivity, and operational costs. This research uses object-oriented programming to design a network-based discrete-event simulation system for construction process modeling. All modeling elements are implemented as objects with integrated functionality of interactive computer graphics and simulation. Models are constructed through a friendly graphical user interface. Simulation is accomplished by having active objects send messages to one another. This paradigm of simulation system design can provide many advantages over traditional design, such as realistic resource tracking, precise simulation control, and linkage with other knowledge-based expert systems.

This research will impact how we manage construction projects in the future.

Construction Project Productivity Time-Series Monitoring and Predictions
L. Y. Liu,* S. Hwang
University of Illinois

This project investigates new applications of time-series techniques to better predict future productivity performance and trends. By fusing historical and actual data and factors from on-going projects, project managers can better predict future performance and manage resources more efficiently for construction projects.

Construction Site Digital Data Collection Devices
L. Y. Liu*
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University of Illinois

Conducted in the Newmark Civil Engineering Laboratory

This project develops a hardhat-mounted device that collects multimedia information, including video and sound, for construction inspection and documentation. The device uses voice-activated control and allows construction inspectors to walk hands-free at the project site to document site conditions or problems. Narration, pictures, and videos can be taken and stored digitally into the device and can be ported later into a database that supports project control and documentation. A heads-up display is used for synchronizing the camera direction with the eyes. This device allows wireless, two-way communications where images can be transmitted to and from the host computer.

The project will lead to intelligent field automation in the future.

Construction Time–Cost Trade-Off Decision Support
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Conducted in the Newmark Civil Engineering Laboratory

Construction engineers face the challenge of selecting the most effective construction methods for tasks within a project. Different methods, equipment, and crew sizes can be chosen for tasks depending upon the contract time limit and budget. Not all tasks are of equal importance in a project. Some tasks carry floats and can be delayed without impacting the project duration. Some tasks are critical because any delay on those tasks delays the project.

* Denotes principal investigator.
Construction engineers may choose alternative construction methods, smaller crew sizes, and less productive equipment at lower costs while maintaining the same project duration. The purpose of this research is to develop a generic algorithm for assisting construction engineers in selecting optimal time–cost strategies to complete a project.

This new algorithm will support analyses of construction planning and controls, by lowering overall construction costs.

**Real-Time Geometrical Tracking and Productivity Analyses**
L. Y. Liu,* Y. Su
*University of Illinois

This project utilizes the real-time location data, via a wireless communication network, from construction equipment, materials, and personnel to support productivity analyses. The geometrical (x,y,z) and time data are analyzed to automatically obtain insight into resource bottlenecks and productivity problems.

**Sensor-Based Construction Quality Control and Monitoring**
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*University of Illinois

Conducted in the Newmark Civil Engineering Laboratory

This project investigates new applications of sensor devices (electrical, micro-electrical-mechanical, and fiber-optic) in construction quality control and monitoring. These sensors are imbedded in infrastructure components to collect data for monitoring the conditions and other properties relevant to safety and performance of a structure, such as a bridge, tunnel, or building.

The potential impacts of this research include a new and better approach to conduct construction inspections, more timely responses to repair needs, and lower costs for structure maintenance.

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**Control Systems**

**Advanced Dynamic Modeling and Control of Air Conditioning and Refrigeration Systems**
A. G. Alleyne,* N. Jain, B. Li, T. McKinley, V. Chandan
30 Company Consortium: Air Conditioning and Refrigeration Center; National Science Foundation

Conducted in the Mechanical Engineering Building

This project develops a dynamic simulation-modeling environment that is suitable for closed loop control of stationary and mobile a/c and refrigeration systems. The focus is on controlling quasi-steady transitions between operating states, instead of startup and shutdown transients, by modulating flow rates of both air and refrigerant. It builds upon previous models by making more extensive use of physical parameters, based on results from other research projects. The model development is supported by a parallel set of experiments conducted in a flexible test facility.

**Control of Fluid Power Systems**
A. G. Alleyne,* S. Manwaring, S. Tyson, B. Hencey, T. Deppen
*University of Illinois at Urbana-Champaign; National Science Foundation; Caterpillar, Inc.; U.S. Army Research Office

Conducted in the Mechanical Engineering Building

The modeling and control of fluid power systems includes electrical, mechanical, hydraulic, and pneumatic subsystems. Various types of advanced controllers are applied to these complex nonlinear systems. Applications of these systems range from automotive systems to earth-moving vehicles to high-speed machine tool drives.

**Control of Nonlinear Systems**
A. G. Alleyne,* B. Hencey
*University of Illinois at Urbana-Champaign

Conducted in the Mechanical Engineering Building

The control of various nonlinear mechanical and electromechanical devices is studied. The techniques applied vary from standard linearization (Jacobian) to gain scheduling to nonlinear transformations (feedback linearization). The structure of the particular systems being controlled is exploited to facilitate control. The application of this is directed to the control of various mechanical systems.

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* Denotes principal investigator.
Control of Systems in a Dimensionless Framework
A. G. Alleyne*
University of Illinois Research Board; National Science Foundation

Conducted in the Mechanical Engineering Building

This project examines the benefits of using dimensionless system representations for control system design. Dimensionless system representations afford benefits for parameter identification as well as dynamic uncertainty representation. These benefits translate into better adaptive control and robust control designs. Current investigations examine engineered systems, such as vehicles, as well as individual subsystems and components.

Dynamic Simulation of Transport Refrigeration: Baseline Model
A. G. Alleyne,* N. Jain
alleyne@uiuc.edu

Ingersoll Rand

This project develops a dynamic simulation-modeling environment that is suitable for closed loop control of mobile a/c and refrigeration systems. The project consists of developing baseline dynamic models to be tested against data from our industrial partners. Additionally, real-time systems will be developed to enable hardware in the loop setups to test OEM controller hardware.

Dynamic Simulation of Transport Refrigeration: Baseline Model
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Microscale Robotic Deposition
A. G. Alleyne,* P. M. Ferreira,* J. Lewis, D. Bristow, K. Barton, D. Mukhopadhyay, D. Hoelzle
National Science Foundation, DMI-0140466

Conducted in the Mechanical Engineering Building

The objective is to develop new materials systems, manufacturing systems, control, and planning algorithms required for microscale robotic deposition (m-RD) of colloidal gels. An integrated approach will be directed toward the fabrication of 3-D periodic structures (feature sizes less than 10 mm) required for emerging photonic applications. Such novel structures provide the optical analogues to semiconductor materials at length scales relevant for optical communication and computing technologies.

Nano-CEMMS Systems Integration Testbeds for the Micro- and Macroscale
A. G. Alleyne,* P. M. Ferreira, D. Mukhopadhyay, K. Barton, K. Khanapure, B. Helfrich, X. Xiao
National Science Foundation, Nanoscale Science and Engineering Center, DMI-0328162

Conducted in the Mechanical Engineering Building

This work relates to the Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems (Nano-CEMMS). We are developing systems integration tools and testbeds for rapidly identifying potential bottlenecks in the confluence of different core technologies associated with our nanoscale manufacturing efforts. The tangible results of this project will be the development of the earliest testbeds that are representative of the fully functional Nano-CEMMS system as it is currently envisioned. Additionally, this project will provide systems-level planning and guidelines for the development of the overall research plan. The ability to provide planning input will grow throughout the project as better knowledge and understanding of the overall systems-level issues are developed.

A Dynamic Simulation Model for the Environmental Control Systems (ECS) on Combat Vehicles
A. G. Alleyne,* T. McKinley
alleyne@uiuc.edu

General Dynamics Land Systems

This project develops a dynamic simulation-modeling environment that is specifically targeted for high performance military cooling applications.

A Dynamic Simulation Model for the Environmental Control Systems (ECS) on Combat Vehicles
A. G. Alleyne,* T. McKinley
alleyne@uiuc.edu

General Dynamics Land Systems

This project develops a dynamic simulation-modeling environment that is specifically targeted for high performance military cooling applications.

* Denotes principal investigator.
Hierarchical and Reconfigurable Schemes for Distributed Control over Heterogeneous Networks
National Science Foundation, ITR 0085917
The research project deals with issues arising in controlling geographically distributed complex real-time systems over a heterogeneous communication network. It is aimed at developing the foundations of network-based control, from theory to applications. The overall objectives are the following: the design, analysis, implementation, and performance characterization of hierarchical and heterogeneous distributed control algorithms and middleware that are affected through hierarchical heterogeneous networks comprised of wired and wireless subnets; and specification and implementation of network services and support required for the development and deployment of distributed control algorithms over hierarchical heterogeneous networks.

Cooperative Networked Control of Dynamical Peer-to-Peer Vehicle Systems
U.S. Air Force Office of Scientific Research; Defense Advanced Research Projects, Multidisciplinary Research Programs of the University Research Initiative, F49620-02-1-0325
The proliferation of computing and wireless communication technology has opened up tremendous possibilities for deploying large cooperative networks of smart vehicles to perform intricate and complex missions. It is evident that collaborative teams of aerial and ground vehicles can perform a plethora of highly beneficial tasks for achieving military objectives and civilian security. The major objective of our consortium is the development of a rigorous theoretical foundation, and scalable analytical tools and paradigms, so that systems can be systematically constructed and their performance formally verified. More generally, the activity of this program can be expected to have a dramatic impact on understanding and designing large-scale, robust, real-time distributed systems. Our goals are to make use of recent algorithmic developments to provide hard performance guarantees and bounds for systems performing sophisticated tasks in uncertain and dynamic physical situations.

Control of Automata-Switched Distributed Systems
G. E. Dullerud*
National Science Foundation
This project aims at developing computational algorithms and theory for control of dynamical systems using distributed architectures, where a combination of continuous and logical dynamics are present. This situation results from the coupling of physical, communications, and computer processes. The proposed work has a very broad set of associated applications, and in this project we particularly emphasize its use in networked robotics. The specific approach and techniques pursued stem mainly from semidefinite programming, graph theory, and robust control methods (e.g., operator theory, quadratic cost functions and Hamilton-Jacobi inequalities, IQCs, parameter variation), providing a unified framework in which to deal with and consider computer-based rules, communication latency and packet loss, obstacles in an uncertain environment, trajectory tracking, and nonlinear dynamics, using a distributed architecture. The project, in addition to fundamental research, will also produce reusable software to be made publicly available to the wider academic community and industry.

Architectures for Secure and Robust Distributed Infrastructures
S. Lall* (Stanford Univ.); C. Beck (Indus. & Enter. Syst. Engr.); S. Boyd (Stanford Univ.); J. Doyle (California Technical Univ.); G. E. Dullerud*; C. Hadjicostis (Elect. & Comput. Engr.); B. Lesieutre, M. Medard (MIT); B. Prabhakar (Stanford Univ.); R. Srikant (Indus. & Enter. Syst. Engr.); C. Tomlin (Stanford Univ.); G. Verghese (MIT); V. Vladimerou, D. King
U.S. Air Force Office of Scientific Research, F49620-01-1-0365
The major barrier constraining the successful management and design of large-scale distributed infrastructures is the conspicuous lack of knowledge about their dynamical features and behaviors. Until very recently, analysis of systems has primarily relied on the use of nondynamical models. These traditional approaches have enjoyed considerable success while systems are run in predominately cooperative and “friendly” environments and provided that their performance boundaries are not approached. With the current proliferation of applications...
using and relying on such infrastructures, these infrastructures are becoming increasingly stressed, and the incentives for malicious attacks are heightening.

**A Normative Theory for the Design of Discrete Event Dynamic Systems**
R. S. Sreenivas*
National Science Foundation, CNS-0437415

The goal of the project is to identify tractable synthesis of supervisory policies that control discrete event dynamic systems such as: air-traffic control systems; automated manufacturing systems; computer networks; integrated command, control, communication and information (C3I) systems; and operations-management of multicomponent organizations with event-driven dynamics like shipyards, airports, hospitals, and so forth. Despite the myriad and diverse applications for DEDS, advances in core aspects of supervisory control of DEDS have not found application beyond academia, primarily due to the fact that synthesis procedures require complete specification of the desired behavior of the system, a difficult, if not impossible task. Even when complete specifications are available, the synthesis of the appropriate supervisory policy can be intractable. This project develops a normative theory of how DEDS should be structured so that, starting from a supervisory policy that enforces an incompletely specified behavior, progressive supervisory corrections can be applied such that the (complete) desired specification is eventually enforced. The supervisory policy advocated by this project is based on analysis of observed "desirable" and "undesirable" states of a system. This project focuses on three areas of DEDS. First is a learning phase: the development of learning algorithms for supervisory systems where desired behavior can be easily learned/identified using examples/counter-examples. Second is a supervisory policy synthesis phase: the identification of DEDS structures where learning is tractable. A third area of DEDS is the progressive improvement phase: the development of methods for improving learned behavior that can be progressively improved with computations effort as additional information is made available.

**Decision and Control**

**Dynamic Team and Game Theory for Congestion Control in High-Speed Networks**
T. Basar,* R. Srikant,* D. Wiedenheft
* Denotes principal investigator.
National Science Foundation, ANI 98-13710

This project is related to NSF 98-13710, and involves research for undergraduate students on various aspects of communication networks, particularly in the area of congestion control.

**Objective-Oriented Model Heterogeneous Sensor Networks for Coordinated Control**
T. Basar,* T. Alpcan, C. Tang, S. Yuksel
National Science Foundation, ECS 02-25481

This is a multi-university research effort that focuses on a comprehensive study of large, mobile ad-hoc reconfigurable networks for coordinated control. It draws on elements from coordinated control, dynamic state estimation, ad-hoc network management, resource assignment, and fault tolerance. Its aim is to provide a formalism in which the methods of sensor networking may be integrated as part of a systematic design process focused on achieving a specific control objective. Particular topics of study at the present are robust H-infinity and risk-sensitive control and filtering in a receding horizon framework, performance-and utility-driven resource allocation in networks, and control over networks using decentralized and distributed sensor information.

**Reliable and Robust Control of Formations of Unmanned Vehicles**
D. M. Stipanović,* M. W. Spong*
dusan@uiuc.edu
Boeing

This project is to develop reliable and robust control architectures and algorithms for networks of autonomous aerial and ground vehicles. The aim is to develop control laws that have low sensitivity to noisy and lossy data communication among vehicles, that are scalable in terms of number of vehicles, and that have the ability to handle discrete transitions in the network, such as formation reconfiguration, addition or loss of vehicles from the formation, and so forth. Applications of this work include undersea and planetary exploration, search and rescue, air traffic control, and control of sensor networks. Both theoretical and experimental issues are being investigated.

**Smart Icing Systems**
T. Basar,* W. R. Perkins,* P. Voulgaris,* J. Melody, V. Sharma
* Denotes principal investigator.
NASA Glenn Research Center, NAG3-2135

This part of the larger interdisciplinary/interdepartmental research program addresses the identification and control research required to develop a smart icing system for aircraft. A smart icing system would sense the effect of ice accretion on the aircraft performance and handling qualities and provide information to the flight crew, operate ice protection systems, provide envelope...
protection, and possibly adapt the flight controls. The research conducted here involves in-flight parameter identification of aircraft flight dynamics utilizing excitation generated by only natural (and not forced) maneuvers of the aircraft and turbulence. Subsequently, this information would be fed (along with other sensor-based data) into an appropriate neural network that would, in turn, lead to an accurate detection of the level of severity of ice accretion on the flight surfaces of the aircraft. The ultimate goal of this effort is to provide both the pilot and the autopilot with needed information to improve the safety of aircraft operating in icing conditions.

**Architectures for Secure and Robust Distributed Infrastructures**
C. Hadjicostis,* G. Takos
chadjic@uiuc.edu

*U.S. Air Force Office of Scientific Research; Department of Defense, URI Award F49620-01-1-0365URI (subcontracted from Stanford University)*

Within the context of a much larger project, this work focuses on addressing the challenges that arise in regards to distributed or hierarchical coordination, fault tolerance, safety, and scalability in emerging dynamic systems and networks. The initial goal of this project has been to develop distributed estimation algorithms that can be used in network monitoring.

**Designs of Robust Encoded Dynamic Systems**
C. N. Hadjicostis,* G. Takos
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*Air Force Office of Scientific Research, DoD URI Award F49620-01-1-0365URI*

This work analyzes the effects of roundoff noise on our ability to nonconcurrently detect and identify transient faults that corrupt state variables during the operation of a fault-tolerant discrete-time LTI dynamic system. The analysis provides insights that allow us to evaluate the performance of established decoding algorithms using analytical techniques. It also leads to explicit bounds on the precision needed in order to guarantee the correct identification of the number of faults that have affected the system.

**Diagnosis and Assessment of Faults, Misbehavior, and Threats in Distributed Systems and Networks**
C. N. Hadjicostis,* Y. Ru
chadjic@uiuc.edu

*National Science Foundation, ECS 04-26831 ITR*

This project addresses the problem of state estimation in discrete event systems (DES) that are modeled by labeled Petri nets that may have both nondeterministic transitions (i.e., transitions that share the same label) and unobservable transitions (i.e., transitions that are associated with the empty label). These techniques are promising because they show that one can compute the set of consistent markings with complexity that is at most polynomial in the length of the observed label sequence.

**Enabling Diagnosis of Faults and Misbehavior in Heterogeneous Networked Systems via Structured Redundancy**
C. N. Hadjicostis,* T. Le
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*Boeing*

This project aims to evaluate how the use of redundant sensors, actuators or, more generally, redundant information can enable efficient and gracefully degradable diagnosis algorithms for large networked systems. Instead of focusing on how diagnosis can be performed for a given system or network, this project is interested in finding out how small modifications in the system structure (e.g., sensor or actuator allocation) or the communication links and protocols can result in more efficient and robust diagnosis algorithms.

**Enabling Novel Digital Sequential Circuit Designs through Error Control and Noise Tolerance Techniques**
C. Hadjicostis,* S. Sundaram
chadjic@uiuc.edu

*National Science Foundation, ECS 02-18939 ITR*

Conducted in the Coordinated Science Laboratory

This project is developing a framework for fault-tolerant convolution using a polynomial residue number system with non-coprime moduli. These techniques are promising in terms of the simplicity of the corresponding error detecting and correcting mechanisms. We are specifically investigating how these techniques, together with nonconcurrent error detection and correction techniques, can offer advantages in terms of hardware and time complexity.

**Error Control in Switched Linear Controllers**
C. Hadjicostis,* S. Sundaram
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*National Science Foundation, ECS 02-18939 ITR*

This project develops protection schemes for linear time-invariant (LTI) controllers in switched systems. Tolerance against internal controller faults is achieved via embeddings that preserve the state evolution of the original controller in some encoded form, but enable error detection.

* Denotes principal investigator.
and correction through nonconcurrent (e.g. periodic) checks.

**Operation and Control of Energy Processing Systems: Economic and Environmental Considerations**
C. N. Hadjicostis,* G. Deltas*
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*National Science Foundation, ECS 02-24729 EPNES*

The goal of the proposed research project is to develop a comprehensive framework for studying reliability and sustainable operation of energy processing systems in regulated economic markets. The successful completion of this project can have potentially significant implications in characterizing and evaluating the economic and environmental consequences of reliable designs for future commercial power generation and distribution systems.

**Operation and Control of Energy Processing Systems: Fault Tolerance Considerations**
C. N. Hadjicostis,* L. Li
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*National Science Foundation, ECS 02-24729 EPNES*

The main goal of this research project is to develop a comprehensive framework for dynamical state estimation, fault detection, and fault accommodation in energy processing systems. This includes terrestrial and autonomous power systems, as well as electric drives and power electronic systems, as found in civilian and military sectors. In particular, this project aims at making connections with traditional fault tolerance techniques by developing distributed monitoring/correcting schemes and by explicitly accounting for the system dynamics before overcoming faults that affect the functionality of the system.

C. N. Hadjicostis,* H. Mo
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*National Science Foundation, ITR 02-24729 EPNES*

This research project deals with issues arising in controlling and monitoring real-time systems over heterogeneous communication networks. The project aims at studying the performance of variants of state feedback control schemes in a network setup where packets can be lost or delayed due to deteriorating network performance. In particular, the project studies the tradeoffs that arise between system instability, noise level, link delay, and packet dropping probability.

**Operation and Control of Energy Processing Systems: State Estimation in Switched Linear Systems**
C. N. Hadjicostis,* S. Sundaram
chadjic@uiuc.edu
*National Science Foundation, ITR 02-24729 EPNES*

This project develops observer methodologies for switched linear systems that are driven by unknown inputs. The methodologies are based on using (possibly delayed) outputs, and knowledge of the switching sequence and the system dynamics in order to decouple the unknown inputs from the observer error.

**An Integrated Approach to Fault Tolerance in Discrete-Time Dynamic Systems**
C. Hadjicostis,* E. Athanasopoulou
chadjic@uiuc.edu
*National Science Foundation, ECS 00-92696 CAREER*

This project develops systematic approaches for modeling, detecting, identifying, and correcting faults in order to ensure the proper functionality of discrete-time dynamic systems or networks. The project takes a system-theoretic viewpoint and aims to characterize the fundamental limitations of fault-tolerant designs by jointly exploiting system-, coding-, and information-theoretic techniques.

**A Robust Control Approach to Digital Communications**
C. Hadjicostis,* P. Voulgaris,* R. Touri
chadjic@uiuc.edu
*National Science Foundation, CCR 00-85917 ITR*

This project develops a deterministic worst-case framework for reconstruction of discrete (source) data transmissions through dispersive communication channels. This framework can be explored based on robust control ideas and formulations and serves as a complement to existing approaches that reconstruct data by optimizing probabilistic criteria.

**Adaptive Optimized Cross-Layer Protocols**
P. R. Kumar*
Rockwell-Collins
*Conducted in the Coordinated Science Laboratory*

The goal is to research, model, and simulate power control protocols for wireless networks.

* Denotes principal investigator.
Channel Aware Distributed Scheduling for Optimal Throughput and Latency: A Unified PHY/MAC Approach
P. R. Kumar*
National Science Foundation
Conducted in the Coordinated Science Laboratory
The goal of this project is to build a theoretical foundation for channel aware distributed scheduling in wireless ad-hoc networks.

Designing Reliable and Secure Tactical MANETS
P. R. Kumar*
U. S. Army Research Office
Conducted in the Coordinated Science Laboratory
The goal is to develop algorithms for secure wireless networks.

Efficient Resource Management for Controlled Mobility Wireless Networks
P. R. Kumar*
National Science Foundation
This project addresses the design, development and operation of networks that are mobile.

Supporting Temporal Coordination in Wirelessly Networked Control Systems: Fundamental Theory, Algorithms, and Experimentation
P. R. Kumar*
National Science Foundation
Conducted in the Coordinated Science Laboratory
This project addresses how to achieve temporal coordination over wirelessly networked control systems of sensors, actuators, and computational nodes.

Toward Building a Performance Predictable Wireless Mesh Network
P. R. Kumar*
National Science Foundation
Conducted in the Coordinated Science Laboratory
The goal is to study how to build wireless mesh networks.

Towards a Theory of In-Network Computation for Surveillance and Monitoring in Wireless Sensor Networks
P. R. Kumar*
National Science Foundation
This project addresses the development of a theoretical foundation for sensor networks.

Scalable Multilayer Control of Joint Battlespace Networks
P. R. Kumar*
U.S. Air Force Office of Scientific Research, F49620-02-1-0217
This project addresses issues relating to communication networks, both wireless radio and free-space optical.

Verification of Probabilistic Hybrid Systems: Stability and Beyond
D. M. Liberzon*
National Science Foundation, CNS-0614993
In collaboration with MIT; Conducted in the Coordinated Science Laboratory
This collaborative project studies dynamical systems characterized by a combination of hybrid and probabilistic behavior. Hybrid behavior is characterized by discrete switching between system modes and continuous evolution within a mode. Such systems frequently arise in a wide range of applications, from power electronics and communication networks to economics and biology. In this research, a new modeling framework for such systems is developed, which supports external variables, compositional reasoning, and nondeterministic as well as probabilistic transitions. New stability criteria for such probabilistic hybrid systems are obtained. In contrast with existing results, they are formulated in terms of two independent components: a family of Lyapunov functions (one for each continuous mode) and a slow-switching condition of an average-dwell-time type. This modularity has the benefit of decoupling the search for Lyapunov functions from the verification of the desired properties of the discrete dynamics. The latter task is the focus of the project, and is treated using two complementary methods: one based on proving an invariant property, and another based on solving an optimization problem. These theoretical results are supported by development of new software tools.

Hybrid Control of Nonlinear Systems
D. Liberzon*
liberzon@uiuc.edu
National Science Foundation, ECS-0134115
The research and educational development plan proposed here is aimed at designing hybrid control algorithms. In this framework, a continuous-time process is controlled by means of logic-based switching among a family of regulators. The closed-loop system is then called hybrid because it combines continuous and discrete dynamics. We study several situations in which such a control paradigm

* Denotes principal investigator.
is natural and helps overcome various shortcomings of more traditional control methodologies. The primary focus of this research is on systematic development of tools for hybrid control design, applicable to general and useful classes of nonlinear dynamical systems.

**Multiple View Geometry**
Y. Ma*
University of Illinois

The goal of this project is to unify the study of geometry of multiple images into a simple and clean mathematical framework where efficient algorithms and systems can be developed for applications in computer vision, robot vision, computer graphics, cognitive science, and so forth.

**Adaptive Methods for Heterogeneous Wireless Services**
S. Meyn,* M. Medard, J. Huang
National Science Foundation, NSF CCR 99-79381, NSF ITR 00-85929

With communication and computing systems becoming increasingly pervasive, future systems will require the ability to accommodate, in real time, wireless services to support a variety of applications ranging from traditional voice and paging services to nomadic computing applications. Different services such as voice, or data, may have vastly different requirements in terms of burstiness, or rate and quality of service (QoS) requirements. We consider coding, routing, and traffic rate mechanisms to provide smooth heterogeneous services to a variety of users via wireless access to a network.

**Control Techniques for Complex Networks**
S. Meyn*
meyn@uiuc.edu
National Science Foundation, ECE-02-17836

In many application areas and in many scientific disciplines, one seeks methods for managing complexity of man-made or real-world systems. Famous application areas include network management in production systems and wireless networks; analysis of the stability of candidate pharmaceutical compounds; and the relationship between chromosomal and protein structure. This project concerns several interrelated approaches to managing complexity in large interconnected systems. Specific application areas addressed in the proposal include phase transitions in molecular models and resource allocation in large network models.

**Large-Scale Simulation of Manufacturing and Communication Systems**
S. Meyn,* S. Henderson (Cornell University)
National Science Foundation, DMI-0085165

In the past decade, we have seen astonishing growth in both the theory and application of queuing networks. Industry is driving research in communication and data networks, computer systems, and manufacturing systems. Semiconductor manufacturing plants and the Internet are two infamous examples of networks of almost unimaginable complexity. A powerful need exists for methods for deriving and evaluating operational policies that may be used to effectively drive these systems. This project sets out to develop methods for control synthesis and evaluation for truly complex networks.

**Visualization and Optimization Techniques for Analysis and Design of Complex Systems**
S. Meyn*
National Science Foundation, ECS-0228251

This project concerns several interrelated approaches to managing complexity in large interconnected systems. The focus of this project is resource allocation in large network models. A related project concerns phase transitions in molecular models. This research will provide new design methodologies and efficient approaches to simulation and online tuning of control algorithms.

**An Integrated Exploration of Wireless Network Communication**
S. Meyn*
meyn@uiuc.edu
National Science Foundation, ITR-00-85929

This research studies the design of agile wireless networks that accommodate time variations in the communication channels, the information sources, and the network topology. The research will lead to design principles that, in addition to enabling more efficient use of the current cellular and PCS bands, will allow exploitation of frequency bands in the 10-100 GHz range to provide high-speed multimedia services for both indoor and outdoor applications.

**Passivity-Based Control in Bipedal Locomotion**
M. W. Spong,* J. Holm, D. Herring, J.-S. Moon, A. Block, T. Filipiak
National Science Foundation Grant 0510119

The project explores bipedal locomotion in the context of passivity based hybrid nonlinear control. We are investigating speed regulation, the use of alternate potential functions to increase the basins of attraction of

* Denotes principal investigator.
stable limit cycles, the effect of control saturation and underactuation in passivity based control, and the efficiency of passivity based control methods compared to true energy optimal control. The goal is to help solidify the foundations of the field through analysis, development of new concepts, and the design of provably correct control algorithms.

Telemanipulation in Multi-Robot Networks
Office of Naval Research, Grant N00014-05-1-0186

In this project, we are addressing fundamental issues in communication, coordination, and teleoperated control of multiple agents in coordinated manipulation tasks. While multiagent coordination and control problems such as swarming, flocking, and rendezvous have been studied by several researchers, much less work has gone into the teleoperated control of multirobot networks, especially when the multirobot network is expected to engage in tasks involving both manipulation and motion coordination. Manipulation tasks require haptic and force feedback that introduce significant stability and transparency problems with respect to communication delay, packet loss, and other communication effects.

U.S.-France Cooperative Research: Passivity Based Control of Networked Control Systems
M. W. Spong,* R. Ortega (CNRS, France)
National Science Foundation Grant 0128656

This award supports U.S.-France collaboration in control systems between Mark W. Spong of the University of Illinois and Romeo Ortega of the Signal and Systems Laboratory at SUPELEC, a French center for research in electrical engineering. The objective is to investigate passive nonlinear control of networked control systems, in particular, systems involving bilateral remote operation (teleoperation) over unreliable communication networks. The problem is motivated by interest in wireless communication in imbedded real time control systems and the use of the Internet as a communication medium in teleoperated and networked control systems.

Reliable and Robust Control of Formations of Unmanned Vehicles
D. Stipanovic,* M. W. Spong,* P. Hokayem, C. Burns, J. Mejia
Boeing

This project is to develop reliable and robust control architectures for networks of autonomous aerial and ground vehicles. The aim is to develop control laws that have low sensitivity to noisy and lossy data communication among vehicles, that are scalable in terms of number of vehicles, and that have the ability to handle discrete transitions in the network, such as formation reconfiguration, addition or loss of vehicles from the formation, and so forth. Applications of this work include undersea and planetary exploration, search and rescue, air traffic control, and control of sensor networks. Both theoretical and experimental issues are being investigated.

Protocols for Mobile Ad Hoc Networks
N. Vaidya*
nhv@uiuc.edu
National Science Foundation, ANI 01-96410

Mobile ad hoc networks are multihop wireless networks, with dynamically changing network topology. In this project, we investigate several protocol design issues corresponding to routing, medium-access control, and transport layers in mobile ad hoc networks. The focus is on performance issues related to individual layers as well as interlayer interactions.

TCP-Unaware Approaches to Improve Performance of TCP Over Wireless Links
N. Vaidya*
nhv@uiuc.edu
National Science Foundation, ANI-01-96413

The focus of this project is on TCP-unaware techniques to improve TCP performance over paths that include wireless links. The path from a TCP sender to a TCP receiver usually includes several intermediate nodes that may drop TCP packets if congestion occurs. TCP makes the implicit assumption that all packet losses are due to congestion. Since wireless links are prone to transmission errors, this assumption is not accurate for TCP over wireless links. Nevertheless, TCP reduces its congestion window when packet losses due to transmission errors occur. This phenomenon is known to result in poor throughput for TCP over wireless links. This project investigates TCP-unaware mechanisms to avoid such TCP performance degradation.
Design Theory and Methodology

Integrating Electrical, Economic, and Environmental Factors into Flexible Power System Engineering
P. Krein, P. Chapman, M. Pai, P. Sauer (Elect. & Comput. Engr.); D. Thurston*
National Science Foundation

A flexible power system is one in which redundancy and reliability are managed through localized control, distribution of energy sources, shifting among available sources, treating loads as a potential resource for operations and control purposes, and directing energy to the most critical needs. This project seeks to establish a firm science-based framework for integrating electrical, economic, and environmental factors into flexible power system design.

Digital Signal and Imaging Processing

Efficient Algorithms for Lossless Data and Image Compression
Y. Bresler,* D. Baron
National Science Foundation, CCR-0122293

In spite of the focus in recent years on lossy compression of audio, images, and video, lossless data compression remains crucial in applications such as text files, facsimiles, software executables, and medical imaging. Universal source coding algorithms, which deal with sources whose statistics are unknown, are of particular importance. The main goal of this research is to develop algorithms featuring fast computation and low memory use, while providing compression quality near the fundamental theoretical bounds. The resulting algorithms will have linear complexity and will be better than any current algorithm with comparable asymptotic compression performance, in terms of computation and/or memory use. Some versions of these algorithms will also have simple structure, admitting fast hardware implementations. A special focus of this research is also on parallel algorithms that allow arbitrary speedup while maintaining the same compression quality.

Fast Algorithms for 3-D Cone-Beam Tomography
Y. Bresler,* J. Brokish, A. George
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National Science Foundation, CCR-0209203

In cone-beam tomography, projections are acquired by an area detector, using a source of divergent rays traveling on one of several possible trajectories. It is already used in current PET and SPECT scanners and in nondestructive evaluation (NDE) in manufacturing, and it will be the basis for the next generation of diagnostic CT scanners. This will allow use of CT as a dynamic imaging modality for cardiac imaging, or for real-time surgical guidance in medicine, or as a high-throughput NDE system in manufacturing, or as a high-accuracy security baggage scanner in airports. Unfortunately, the high computational cost of current cone-beam reconstruction algorithms constitutes a major barrier to their applications. We are developing new image reconstruction techniques that require only computations for an image. These techniques can be 100 times faster than current methods for typical images and promise to overcome the computational bottleneck in 3-D cone-beam CT, helping to make it a feasible and commercially viable technology for wide use.

Fast Algorithms for Tomography
Y. Bresler,* S. Basu, F. Charpentier, J. Brokish, A. George
National Science Foundation, CCR-9972980

Computerized Tomography (CT) is the principle underlying most of the key diagnostic imaging modalities and many other imaging techniques, including synthetic aperture radar. We are developing new image reconstruction techniques that require only computations for an image, as compared to computations for the current method of choice, the filtered backprojection (FBP). These techniques are orders of magnitude faster than FBP for typical images and promise to overcome the computational bottleneck created by new imaging technologies that acquire large quantities of data in real time. Similar developments are pursued for iterative and for 3-D reconstruction.

Minimum-Redundancy Spatiotemporal MRI
Y. Bresler,* Z. P. Liang,* N. Aggarwal
National Science Foundation, BES-0201876

Since its inception in the early 1970s, magnetic resonance imaging (MRI) has become a premier diagnostic imaging tool. Although its early applications were largely limited to stationary objects, MRI has also proven extremely useful in recent years for dynamic imaging applications, such as cardiac, functional, or interventional imaging. An important challenge confronting dynamic MRI (D-MRI) is to obtain both high spatial and high temporal resolution, with three dimensional imaging capability. The goal of this research is to develop, implement, and test rigorously a new unified theoretical framework for minimum-redundancy D-MRI data acquisition and image reconstruction. In this framework, dynamic imaging is
treated as a higher-dimensional image reconstruction problem, with time being an independent axis. Instead of attempting to freeze all motion by sufficiently fast acquisition, time variation during acquisition is explicitly accounted for in the steps of MRI sequence design, data acquisition, and image reconstruction. The approach draws on and extends theories and algorithms introduced by the researchers over the past few years and offers the potential for significant speedups of the imaging process. Furthermore, combination of the theory and techniques developed in this project with fast-scan methods and with methods based on phased-array RF coils will produce combined speedups, greater than any one of the individual approaches.

Unwrapping Phase Images
R. Koetter,* D. C. Munson,* Z. P. Liang*
National Science Foundation, CCR 01-05719

The primary goal of the project is to develop optimal algorithms for the long-standing problem of unwrapping phase images from various imaging modalities such as SAR and MRI. Probabilistic inference algorithms will be developed and tested using SAR and MRI as testbeds. Prof. Liang is responsible for phase unwrapping of MRI data.

Brain Image Segmentation by Integrated Multiscale Analysis and Shape Deformation
Z. P. Liang,* S. Wang
NEC Research Lab; University of Illinois Research Board
Conducted in the Beckman Institute for Advanced Science and Technology

Brain image segmentation is an important and challenging engineering problem confronting brain mapping. By accurately segmenting gray-scale brain images into various brain structures, we will be able to effectively visualize three-dimensional brain structures and carry out meaningful neuromorphometric studies. The long-term goal of this project is to develop and implement a unified processing software platform to effectively support various information processing tasks in neuroimaging or brain mapping. The specific aim of the project is to capitalize on our recent, novel work on graph-based multiscale image analysis and shape deformation to produce an efficient, accurate, and reliable algorithm for identifying brain structures from MR images. We expect to accomplish three specific tasks during the project period: complete the development of a novel graph-theoretic algorithm for multiscale analysis of MR brain images; further develop, perfect, and validate a topology-preserving shape deformation algorithm so that prior shape information of brain structures can be incorporated into the image segmentation process effectively; and integrate multiscale analysis with shape deformation for accurate segmentation of brain images and develop a prototype software system to facilitate the application of the developed algorithms for practical applications in brain mapping.

Model-Based Tomographic Imaging Methods
Z. P. Liang,* J. Ji, Y. Bresler*
National Institutes of Health, R21 HL62336

The mathematical basis of tomographic imaging is conventionally rooted in the well-established Fourier or radon transform theories, so that image quality is mainly dependent on how the data space is sampled. In practice, physical and temporal constraints often prevent a sufficient coverage of the data space, resulting in various image artifacts, such as Gibbs ringing, resolution degradation, and various motion effects. This project is aimed at overcoming these problems by developing new model-based imaging techniques that can incorporate a priori information into the imaging process effectively. Application of these techniques to cardiac imaging and functional brain mapping is also addressed.

Multisensor Information Fusion
Z. P. Liang, H. Pan, K.-Y. Cheng*
kycheng@uiuc.edu
Defense Advanced Research Projects Agency, MDA972-00-1-0020
Conducted in the Micro and Nanotechnology Laboratory

This project is a component of research conducted in the Center for Bio-Optoelectronic Sensor Systems (BOSS). The primary mission of this center is to develop sensor and processing technology for detection of biochemical agents in battlefield situations. Prof. Liang is responsible for developing statistical algorithms for multisensor information fusion.

Statistical Image Reconstruction
Z. P. Liang,* C. Potter, B. Carragher
National Institutes of Health, RO1 GM61939
Conducted in the Beckman Institute for Advanced Science and Technology

The primary goal of the project is to develop practical image reconstruction methods for high-resolution imaging from electron microscopy data, particularly in the presence of uncertainties in data acquisition parameters (a projection angle for example). We formulate the problem as a statistical parameter estimation problem by introducing a proper model for the object (for instance, a virus) to be imaged. This research effort promises to provide a brand-
new solution to the long-standing problem in electron microscopy.

Electromagnetic Communication and Electronics Packaging

**CAD Tools for Communications Microsystems**  
J. Schutt-Ainé,* D. Lambalot, L. Jiang  
*Defense Advanced Research Projects Agency, AF ECE0849*

Recent developments in the area of wireless communication systems and microelectromechanical systems (MEMS) have enabled the networking of distributed transducers in a wireless mode. It is now possible to integrate monolithic microwave integrated circuit (MMIC) front-end modules with MEMS components such as antennas, switches, and filters. Our objective is to supply the necessary CAD tools to improve first-pass success and reduce design iterations for such systems. In particular, electromagnetic techniques are used to model various MEMS switch structures. These are combined with simulation techniques to predict the transient and steady state response of these components. The goal is to reduce the design cycle from several years to one week in the successful implementation of these MEMS structures.

**Design and Fabrication of MEMS Probe Station**  
J. Schutt-Ainé,* C. Liu, D. Lambalot  
*University of Illinois Research Board*

Recent advances in microelectronics have led to considerable reduction in size of components in integrated circuits (ICs). Typical VLSI circuits have dimensions in the submicron range and feature size that can be as low as 0.25 microns. This reduction is a result of several requirements for higher density and shorter interconnection delays. Future state-of-the-art microprocessors will accommodate more than a million transistors in an area of a few hundred squared millimeters. Along with these trends, several issues related to signal integrity and testing have moved to the forefront. With submicron dimensions, interconnect resistance has become a major bottleneck in circuit performance, leading to signal degradation and delays. In addition, measurement and testing in submicron geometries, which allows for determining the performance of the structure, is a challenging task. Nowadays, the methods employed consist of fabricating special-purpose test vehicles for evaluation, which often require expensive mask processes and complex de-embedding schemes. This investigation proposes to implement a nondestructive testing methodology for submicron integrated circuits using the recent advances in microelectromechanical systems (MEMS). More specifically, we intend to fabricate and test a microprobe structure that will permit the high-frequency characterization of submicron interconnects and devices in integrated circuits.

**Development and Modeling of Flip Chip and Interconnect Package Technology for Ka and W Band**  
J. Schutt-Ainé,* F. Liu  
*National Science Foundation, E-21-N50-G5*

In collaboration with the *National Science Foundation Package Research Center, Georgia Institute of Technology*

The electrical performance of mixed-signal integrated circuits strongly depends on the electromagnetic behavior of the components within the system. Future wireless and personal communication links will be strongly influenced by these considerations. Currently, millimeter-wave monolithic ICs (MMICs) chip sets are under development in the 24-94 GHz range. In recent years, power distribution and parasitic noise control have become critical issues in the design of these MMICs. Nowadays, with increased frequencies, interconnect schemes, layout, and power distribution have become mainstream design issues. It is now recognized in the CAD community that electromagnetic effects will generally take place at the forefront and will represent the critical limiting factor of MMICs performance. The collaborative effort between Georgia Institute of Technology and the University of Illinois focuses on developing the technology support for the implementation of low-cost packaging solutions for MMICs. This is to be achieved by harnessing the modeling, simulation, design, fabrication, and measurement infrastructure built over the past decade at these two institutions.

**Hardware Acceleration of Newton Solver**  
J. Schutt-Ainé,* M. Das Gupta, D. Prasanna, R. Gao, Y. Mekonnen  
*Demaco/SAIC*

In this project, we plan to demonstrate the effectiveness of implementing a Newton solver in hardware on a PCI bus card. The effort focuses on the use of the TI-TMS320C family of digital signal processor for the implementation of the solver. The implementation of fast Newton solver is to be first realized and tested before being implemented into a digital signal processor. We plan to provide documentation and interface requirements to allow users to install the hardware card and utilize it from programs.

* Denotes principal investigator.
High-Frequency Measurements and Validation of Electromagnetic Models in Scattering, Interconnects, and Optoelectronics
J. Schutt-Ainé*
U.S. Air Force Office of Scientific Research, AF JS 1660

There is tremendous demand for increased capacity in high-speed communication networks and novel applications in optical control of antenna phased arrays. With clock rates in the GHz range, interconnect considerations and electromagnetic phenomena have moved to the forefront in the design of high-speed computers. Microwave modulation of optoelectronic devices, such as semiconductor lasers and modulators, plays an important role in determining the high-speed performance of these devices. Continuing development of high-speed optical communication systems is contingent upon advances in high-speed sources and wavelength conversion devices. While numerous theoretical models have been developed to predict ways to improve these devices, much experimental work remains in order to verify these models and characterize devices based on new designs. This project proposes the experimental validation of various computational models in inverse scattering, wave propagation, interconnects, and optoelectronics. Most of the emphasis will be on the higher frequency range where measurement information is nonexistent. In recent years, computational electromagnetics has received growing interest due to the availability of fast computers and the recent development of fast algorithms. Models that allow the prediction of the most complex problems in scattering and wave propagation have been implemented. Unfortunately, the experimental verification of these models is seriously lagging, especially at higher frequencies where measurement accuracy and repeatability are more difficult to achieve. This project will allow us to determine the frequency range of validity of the computational models and generate useful information for high-frequency operation of radiating, optoelectronics, and waveguiding systems.

High-Performance Computing for the Electromagnetic Modeling of Interconnects and Packages
J. Schutt-Ainé,* D. Prasanna, R. Gao
Demaco/SAIC

The electromagnetic modeling of packages and interconnects plays a very important role in the design of high-speed digital circuits and is most efficiently performed by using computer-aided design algorithms. In the past two decades, researchers in the electromagnetic and microwave areas have worked to extend the knowledge of interconnection properties. Their efforts have resulted in models and analytical methods without which the development of reliable design tools would be impossible. Packaging and interconnects nowadays represent a critical area for the design of high-performance digital systems. State-of-the-art computational electromagnetic techniques necessitate large processing power and memory requirements. As the speed of high performance digital circuits increases, the full-wave characteristics of interconnects becomes important. The feasibility of using the finite difference time domain (FDTD) method for interconnect parameter extraction had been demonstrated earlier. The main advantage of the FDTD technique is its ability to model complicated structures and to account for the frequency dependence of the parameters. However, the computational efficiency and memory requirements seriously limit the practicality of FDTD, especially for three-dimensional problems. Recent advances in distributed and parallel computing require one to address the hardware-dependent aspects of these computational issues. The Orion Project takes advantage of the availability of low-cost PC components. Presently, mini-supercomputers can be built at a moderate cost by using fast communication networks. Moreover, the availability of software libraries for distributed computing, such as the parallel virtual machine (PVM) and the message passing interface (MPI), have rendered the software development within these environments easier.

Low-Cost Fully Monolithic RF Integrated Circuits for Wireless Applications
J. Schutt-Ainé*
National Science Foundation, ECS-9979292

The performance of radio frequency (RF) integrated circuits will strongly influence the versatility and portability of future wireless communication systems. With the ever-increasing demands for higher bandwidth and capacity as well as reductions in size, weight, and cost, the need for more robust and efficient RF circuits is expected to increase. Currently, millimeter-wave monolithic ICs (MMICs) chip sets are under development in the 24-94 GHz range and will represent the platform for the RF components of most wireless systems. With the recent advent of microelectromechanical systems (MEMS), new potentials are being discovered for applications in the RF/millimeter wave ranges. In order to implement RFICs for future wireless communication systems, several fundamental issues must be resolved. First, a design methodology must be devised and tested. Next, a low-cost solution for the integration of MEMS technology into existing MMIC processes must be developed as well as a reliable packaging scheme. Finally,
a robust platform of design guidelines, tools, and characterization techniques must be made available to ensure reliable implementation of these communication systems. More specifically, the effort will focus on these tasks: developing a computer-aided design environment for the robust implementation of MMICs and MEMS as well as the generation of reliable design guidelines; implementing a robust MEMS process for the fabrication of switches, filters, and tunable capacitors; integration of MEMS components into a reliable and well-established MMIC process; devising a low-cost and reliable packaging solution for RFICs. Executions of these tasks will make use of the existing infrastructure and expertise of the principal investigators in the related areas. These will define several design-build-test cycles that will be optimized through several iterations during the course of the project. Special attention will be devoted to demonstrating the feasibility of these various tasks. Moreover, a testbed prototype will be implemented to validate the proposed flow and assess the hardware advantages of the designed RFICs.

**Measurement and Test of Components for Optical Communication Applications**

J. Schutt-Ainé,* M. Angert, Z. Deng

*Xindium Technologies, Inc.*

High-speed optical communication systems are presently improving in speed in response to ever-increasing bandwidth requirements of users. Demand for high-speed digital access will dramatically increase in the future, leading to many opportunities in this area. In order to economically meet the needs of future high bit rate systems, significant changes to component and system architectures will be required. Current commercial systems operating at 2.5 Gb/s (OC-48) data rates are implemented at present using discrete InGaAs photodetectors wirebonded to electronic integrated circuits for signal processing. At bit rates of up to 2.5 Gb/s, an InGaAs photodetector or APD is coupled to sophisticated Si-based electronics with high levels of functional integration to realize photoreceiver modules that incorporate logic thresholding, clock and data timing recovery, and demultiplexing functions in a single package. Advanced signal processing, including coding and decoding for error correction is also implemented in the transceiver circuitry. The objective of this project is the measurement of high-speed components to 50 GHz. The measurements are performed in the Electromagnetics Laboratory, where high-frequency and high-speed testing instruments are available.

**Modeling and Simulation of Embedded Transmission Line Structures**

J. Schutt-Ainé,* F. Liu

*Raytheon Systems*

Embedded transmission line (ETL) structures have become very commonplace in many high-frequency and high-speed electronic systems; however, the analysis and design tools needed for their design are not readily available. The objective of this effort is the modeling, extraction, and simulation of three-dimensional complex interconnect structures embedded in multilayer structures. The focus of the work will be on the development of software tools that facilitate and automate the designer's task. The tools will be based on recently developed electromagnetic parameter extraction techniques to determine the electrical parasitic capacitance and inductance coefficients of these structures. These parameters can next be used with efficient simulation algorithms to predict the signal response of ETL structures and provide information about noise immunity and high-speed performance. This will permit the generation of reliable design guidelines as well as a significant reduction in the time to market.

**National Course in Signal Integrity**

J. Schutt-Ainé*

*IEEE CPMT; National Science Foundation*

Signal integrity has become a critical area in the design of high-speed communications systems and fast computers. Many research areas have emerged from industry and universities to address issues related to electrical performance. However, the educational infrastructure is seriously lagging. The goal of the National Course in Signal Integrity project (http://natcsi.ece.uiuc.edu) project is to establish a web-based educational platform that will provide the education necessary for aggressive packaging schemes in the area of signal integrity. This is achieved by providing a better understanding of electromagnetics problems and through the use of modeling and simulation tools. With the emergence of visualization tools and online simulation packages, access to both qualitative and quantitative answers is immediate. In addition to the standard components of web-based courses, we have focused our attention on two major components. In the first part of the project, a Movie Creator was implemented to allow the incorporation of taped lectures into a website with synchronization between the audio and video components. In the second part of the project, an efficient Perl/Java interface was created that permits the execution of signal integrity modeling and simulation CAD tools in the web server. The study of signal integrity issues is

* Denotes principal investigator.
strongly dependent on the ability to simulate and model signal propagation. This task seeks to supply circuit modeling and simulation capabilities using state-of-the-art techniques and analysis tools that were previously developed. A combination of visualization tools and the ability to perform online simulations can provide students with immediate access to both qualitative and quantitative answers. Using our newly developed tool, simulation results can be displayed and examined in a web browser shortly after execution. This unique feature of executing CAD software via the Web will be a major asset in learning environment.

Electromagnetics

Antennas for Wireless Sensors
J. T. Bernhard*
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U.S. Office of Naval Research through the NCASSR Program/NCSA

The emergence of wireless sensor systems promises to change the way we control our environments, make decisions, and promote health and safety. While numerous research projects on wireless sensors exist, very few address the critical technology of antennas that enable wireless communication. Several projects in this area propose to use standard off-the-shelf antennas, but this choice often limits the capabilities of the system by ignoring the unique requirements and environment of the application. In this project, we are developing both a general methodology for the development of antennas for wireless sensor systems as well as several designs for specific applications.

Electromagnetic Study of Integrated Hearing Aid Antennas
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Phonak Communications

Coordinated signal processing between hearing aids allows hearing-impaired individuals to focus on conversations without having to listen to background noise. A wired connection between the hearing aids and a central processing unit makes the system more obtrusive than traditional hearing aids. This research project clarifies and predicts performance with both in-the-ear and behind-the-ear hearing aid antennas.

Intelligent Portable Antenna Systems for High-Speed Wireless Communication
J. T. Bernhard*
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National Science Foundation CAREER Award, ECS 99-83460

High-speed wireless data communication faces two challenges: high error rates caused by interference and unpredictable environments, and limited functionality and battery life at the portable unit. "Intelligent" or "smart" antenna systems that respond to changing operating conditions can help meet these challenges. This research develops intelligent portable antenna systems to improve the reliability, throughput, and noise immunity of high-speed wireless communication networks. Specifically, this project implements new compact radiation-tunable antennas with a performance-driven fuzzy controller. This novel approach views portable antennas as dynamic components of the communication system, creating a new paradigm for antenna design and control.

Low-Profile Radiators in Aperiodic Wideband Arrays
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jbernhar@uiuc.edu
U.S. Army Research Office, DAAD 19-02-1-0398

This project develops a family of low-profile antennas and associated array methodologies for wideband applications where traditional periodic patch arrays severely limit performance. The work includes the development of specialized simulation tools as well as extensive measurements to characterize both individual and arrayed elements.

Miniaturized Antennas in Random Sensor Arrays for Planetary Surface and Atmosphere Exploration
J. T. Bernhard,* A. C. Singer, P. E. Mayes, E. Michielssen
jbernhar@uiuc.edu
National Aeronautics and Space Administration, NAG3-2840

In this project, we are developing size-appropriate, electrically small (miniaturized) antennas with moderate bandwidths for such sensors as well as processing algorithms for random arrays that enable the sensors to work together to communicate their data to remote collection sites regardless of their relative positions or orientations. The array will configure itself to form a beam in a general direction that can be intercepted by a passing orbiter or directed to a particular satellite- or surface-based receiver. The project will culminate with a testbed

* Denotes principal investigator.
demonstration using the developed antennas and processing algorithms.

**Reconfigurable Antennas for High Data Rate Multibeam Communication Systems**
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*National Aeronautics and Space Administration, NAG3-2555

This research develops new, individually reconfigurable planar antenna array elements that can be adjusted to provide multiple beams while providing increased scan angles and higher aperture efficiencies than traditional diffraction-limited arrays. With the help of powerful simulation capabilities developed under the project, these antennas will be potential candidates for use in both large and small arrays for forward inter-satellite communication as well as tracking of multiple mobile surface-based units.

**Wideband Conformal Antennas and Arrays**
J. T. Bernhard*
jbernhar@uiuc.edu
*U.S. Air Force Research Laboratory, FA8718-04-C-0060

This project investigates the fundamental characterization of suitable wideband conformal microstrip-based antennas as single elements and in arrays and explores possible approaches to expand the operating frequency bands and performance of planar and conformal arrays. These approaches encompass the use of novel substrates and antenna designs, array designs that allow wideband performance, such as random and connected array topologies, and implementation of antenna reconfiguration to enable wideband operation of planar and conformal arrays.

**A Wireless Embedded Sensor System to Monitor and Assess Corrosion in the Tendons of Prestressed Concrete Girders**
J. T. Bernhard,* D. A. Kuchma, H. Reis
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*National Science Foundation, CMS 02-01305

A multidisciplinary team of three researchers with expertise in the areas of nondestructive evaluation, wireless communication, and structural modeling are developing a wireless embedded sensor system to examine corrosion of tendons in prestressed concrete girders. The project illustrates the importance of integrating technologies and expertise from several fields in solving complex information flow problems.

**Environmental Design and Manufacturing**

**Integrating Electrical, Economic, and Environmental Factors into Flexible Power System Engineering**
P. Krein,* P. Chapman, M. Pai, P. Sauer, D. Thurston
*National Science Foundation

A flexible power system is one in which redundancy and reliability are managed through localized control, distribution of energy sources, shifting among available sources, treating loads as a potential resource for operation and control purposes, and directing energy to the most critical needs. This project seeks to establish a firm science-based framework for integrating electrical, economic, and environmental factors into flexible power system design.

**Fluid Dynamics**

**High Performance Turbulence Simulations on Graphical Processors (GPU)**
*University of Illinois at Urbana-Champaign; NASA Glenn Research Center

Graphical processors can provide significant speedups of scientific computations over CPUs that are conventionally used. We are implementing a fractional step turbulent flow simulation code on the graphical processor using the language CUDA developed by NVIDIA. The code will eventually be applied to a variety of reacting and nonreacting flows.

**High Frequency Devices**

**38-GHz Ion Implantation GaAs MESFET Technology Transfer Program**
M. Feng,* J. Middleton, S. K. Hsia
*Northrop Grumman Corp.; M/A-Com/Amp

**Conducted in the Micro and Nanotechnology Laboratory**

This project is aimed at the technology transfer of the University of Illinois 0.25 µm gate GaAs MESFET for 24-GHz and 38-GHz MMICs for LNA and VCO to M/A-Com. for low-cost production.

* Denotes principal investigator.
50-GHz Ion Implanted GaAs MESFET
TriQuint Semiconductor
Conducted in the Micro and Nanotechnology Laboratory
This program is to study the 50 GHz to 100 GHz ion implanted GaAs MESFET for millimeter-wave integrated circuit application.

50-GHz Ion-implanted Enhanced/Depletion/Power GaAs MESFETs
M. Feng,* H. Hsia, D. Becher, Z. Tang, J. J. Hwang, S. Shen
Network Device Inc.
Conducted in the Micro and Nanotechnology Laboratory
This project is to develop enhancement mode, depletion mode, and power mode (E/D/P) GaAs MESFETs operated at 50 GHz.

50-GHz Self-Aligned Gate MESFETs
M. Feng,* D. Becher, D. Caruth
Vitesse Semiconductor Corp.
Conducted in the Micro and Nanotechnology Laboratory
We have investigate Vitesse self-aligned gate MESFET for the analog applications in term of noise gain and power. We have compare performance with the University of Illinois realigned gate FET with Vitesse and to understand device improvement issues.

ADC Circuit Design on a Sigma-Delta Modulator
M. Feng,* M. Heins, D. Barlage
U.S. Army Research Office, DAAH04-96-0218 (Intel Fellowship)
Conducted in the Micro and Nanotechnology Laboratory
This project is aimed at design of 3 Gbit/s for an 8-bit ADC. Our first goal is to design the subcircuits library of comparator, sample, and hold circuit and OA design of an ADC.

AlGaAs/GaAs HBT Modeling
M. Feng,* P. Mares, M. Hein
Rockwell Microelectronics, Inc.
Conducted in the Micro and Nanotechnology Laboratory
This project aims to establish a useful SPICE model for HBT integrated circuits application. Our approach is based on 45-MHz to 50-GHz bias-dependent microwave data collection on an HBT device using HP-ICCAP. Temperature-dependent microwave data collection will be included in the model.

CAD Design Tools for an Integrated Millimeter-Wave Wireless Communication Microsystem
M. Feng,* S. C. Shen, J. J. Hwang, M. Heins
Defense Advanced Research Projects Agency, F30602-97-2-0328
In collaboration with C. Liu. Conducted in the Micro and Nanotechnology Laboratory.
We are developing CAD capabilities for a gigahertz wireless communication and distribution microsystems. We are also developing scalable MMIC modules with integrated MEMS components.

Center of Hyper Uniform Nanophotonic Technologies for Ultrafast Optoelectronic Systems
M. Feng,* R. Chan, K. Cimino, W. Hafez, F. Dixon
mfeng@uiuc.edu
Defense Advanced Research Project Agency HUNT Program
Conducted in the Micro and Nanotechnology Laboratory
The goal of this project is to develop new optical source laser and LED using light emitting transistors modified by quantum well base and DBR to achieve high speed modulation of optical interconnect.

Development Materials for GaN-Based Minority-Carrier Power Electronic Devices for Advanced DoD Systems
M. Feng,* J. Lai, K. Price
Defense Advanced Research Projects Agency, GaN Power Program (under UTA team-Prof. Russel Dupuis)
Conducted in the Micro and Nanotechnology Laboratory
This program is to study material interface of heterjunction, minority carrier transport property in GaN HBT system, since HBT provides high linearity and high efficiency power amplification.

Digital Radar Receiver
M. Feng,* J. Fendrich
Mayo Foundation; Defense Advanced Research Projects Agency
Conducted in the Micro and Nanotechnology Laboratory
This project performs the design and fabrication of an RF front end (400-700 MHz) fully tunable receiver system. We are working closely with the Mayo Foundation MIT-Lincoln Lab and Defense Advanced Research Projects Agency to build two brassboard RF receiver front ends for digital radar applications.

* Denotes principal investigator.
Direct Ion Implantation GaAs MESFETs
M. Feng,* H. Hsia, Z. Tang, D. Becher, S. Shen
GaAstronics Co.

Conducted in the Micro and Nanotechnology Laboratory
This project is to develop low-cost ion-implanted GaAs MESFETs for 5.8-GHz MMICs.

GaAs- and InP-Based HBT Reliability
M. Feng,* D. Barlage, M. Heins
U.S. Army Research Office, DAAH04-94-0369

Conducted in the Micro and Nanotechnology Laboratory
This project is to set up an HBT reliability test. HBT reliability has become a major issue because of heterostructure interface and fast diffuse p-type impurities in both InP- and GaAs-based HBTs. We will test HBT devices from Rockwell, Hughes, and TRW for the basic failure mechanism.

GaN HBT Technology
M. Feng,* J. J. Huang
U.S. Navy, UTA 99-0302

Conducted in the Micro and Nanotechnology Laboratory
GaN has great potential to be a power source in millimeter wave ICs and high-speed electronics due to its large breakdown voltage and higher saturation velocity. In collaborate with Prof. Dupuis at the University of Texas at Austin, we have fabricated GaN HBT with beta >100. There are many problems to be solved in terms of current and power efficiency issues at millimeter wave frequency.

High-Frequency Measurement Project on High-Tc Superconductor
M. Feng,* J. Fendrich, H. S. K. Hsia
National Science Foundation, DMR 89-20539

In conjunction with the Science and Technology Center for Superconductivity. Conducted in the Micro and Nanotechnology Laboratory.
This project has contributed to the study of BKBO and YBCO film characterization at microwave and terahertz frequencies. A parallel-plate resonator (10 GHz) was built to characterize sheet resistance in the microwave frequency. A noncontact coherent time-domain spectroscopy (THz) was used to characterize real and imaginary parts of conductivity. An on-wafer cryogenic microwave probing technique (1-40 GHz, 15-300K) is employed to establish patterned film scattering parameter. This work also aims to develop engineering model parameters using a GHz on-wafer probe technique.

Hybrid and Monolithic OEIC Receivers
M. Feng*
Defense Advanced Research Projects Agency, Center for Optoelectronics Science and Technology

Conducted in the Micro and Nanotechnology Laboratory
This project is aimed at hybrid integration of a PIN/GaAs transimpedance amplifier at 20 GHz operation. The monolithic IC is involved in design and fabrication of 4-channel OEIC receivers using GaAs MESFET technology.

InGaAs/InP BiFET for ADC Applications
M. Feng,* D. W. Seo, H. Hsia, Z. Tang
Defense Advanced Research Projects Agency, N66001-97-C-8618

Conducted in the Micro and Nanotechnology Laboratory
We have developed a 200-GHz InGaAs/InP HFET and integrated it with a 200-GHz HBT. Using this technology, we will construct a fifth-order Sigma-Delta ADC for a 16-bit and 3 FDR > 100 dbc.

InGaP HBT for ADC Applications
M. Feng,* D. W. Seo, J. Mu, M. Heins
Defense Advanced Research Projects Agency, N66001-96-C-8615

Conducted in the Micro and Nanotechnology Laboratory
We are developing an InGaP HBT device model (thermal and electrical model) for implantation into MDS and HSPICs. The second-order Sigma-Delta ADCs with 5 Gbits and 8-bit resolution has been designed, simulated, and fabricated.

Intelligent Vehicle Highway System Chip Sets (II) (IVHS)
M. Feng,* H. Hsia
Northrop Grumman Corp.

Conducted in the Micro and Nanotechnology Laboratory
This project is a follow-up of the TRP/DARPA contract based on the success of the University of Illinois 24-GHz and 38-GHz GaAs MESFET MMIC for LNA and VCO. The new contract is aimed at low-cost implementation of a 0.1 μm gate GaAs MESFET and MMIC by direct ion implantation for 77-GHz LNA and VCO collision avoidance radar.
Intelligent Vehicle Highway System Chip Sets (IVHS)
M. Feng,* P. Apostolakis, J. Middleton
Northrop Grumman Corp.

Conducted in the Micro and Nanotechnology Laboratory
This project is a joint development effort between the University of Illinois and Northrop Grumman Corp. on millimeter-wave IC chip sets for IVHS. We will design transmitter, receiver, mixer, and oscillator millimeter-wave ICs using co-planar technology. The mask and fabrication will use University of Illinois ion implanted, super-low-noise GaAs MESFETs, and a monolithic IC process.

Millimeter Wave Technology HBT and HFET
M. Feng*
Sumitomo Chemical America, Inc.

Conducted in the Micro and Nanotechnology Laboratory
We will design and fabricate MOCVD-grown, doped channel HFETs and InGaP and AlGaAs HBTs. We will characterize these devices and optimize their performance for 24- to 77-GHz applications.

Millimeter-Wave ICs and Packages
M. Feng*
Georgia Institute of Technology, NSF Package Research Center

Conducted in the Micro and Nanotechnology Laboratory
This project is to develop 38-GHz and 77-GHz coplanar MMICs for flip chip packages.

MOCVD HEMT Technology
M. Feng,* Z. Tang
Sumitomo Chemical America, Inc.

Conducted in the Micro and Nanotechnology Laboratory
We will investigate the performance of MOCVD grown P-HEMT and HEMT technology and its performance comparison between MESFETs and MBE-grown HEMTs.

Modeling of Flip Chip Interconnects for RF/Wireless
M. Feng,* J. Schutt-Aine
Georgia Institute of Technology, NSF ERC Package Research Center, SBC GIT E21-N50-G5

Conducted in the Micro and Nanotechnology Laboratory
The next generation of wireless personal communication links and wireless LAN and WAN will be focused in the millimeter wave range due to wide bandwidths and less interference effects. This work is to develop a low-cost solution of millimeter-wave MMICs flip chip technology. This work will provide the design, simulation, and process of MMICs operating at 38 GHz for a real application in point-to-point communication links. The Georgia Tech PRC will provide the flip chip package technology.

Monolithic Millimeter-Wave Integrated Circuits Technology
M. Feng*
Northrop Grumman Corp.

Conducted in the Micro and Nanotechnology Laboratory
This project is a joint effort with Northrop Grumman Corp. for developing 0.25 μm gate and 0.1 μm gate GaAs FET-based technology for the application in monolithic millimeter wave ICs (MMWICs). Based on the high-frequency device characterization, an equivalent circuit model will be generated. This model will then be used for MMWIC design. The fabrication of the MMWICs will be demonstrated.

Noise Characterization of Self-Aligned Gate GaAs MESFETs
M. Feng*
ITT Corp.

Conducted in the Micro and Nanotechnology Laboratory
This project aims to reduce the minimum noise figure on the direct ion-implanted self-aligned GaAs MESFETs based on the design of experiments in terms of dose and gate overlay.

Novel Giga Sampling Analog-to-Digital Conversion for Direct Digital Receiver
M. Feng,* D. W. Seo
National Science Foundation, ECS-9979341

Conducted in the Micro and Nanotechnology Laboratory
We proposed novel GHz ADC architecture, the folding and interpolation-based 15-bit subrange A/D converter, will reduce the transistor count by one-third and the area by 60%. The subrange ADC requires a very precise and wide-band track and hold amplifier to maximize input bandwidth to greater than 2 GHz and converter resolution to greater than 15 bits.

Optical Correlation Spectroscopy Using Reconfigurable Diffraction Grating
M. Feng,* Q. He, K. F. Chen, J. J. Huang
Defense Advanced Research Projects Agency Center (DARPA) BOSS Program, MDA972-00-1-0020

Wavefunction Engineering of Individual Donors for Si-Based Quantum Computers
M. Feng,* R. Chan, C. Chuang
Defense Advanced Research Projects Agency, Quantum Computer Program, DAAD19-01-1-0324

In collaboration with John Tucker. Conducted in the Micro and Nanotechnology Laboratory.

The goal is to place individual phosphorus donors into silicon with atomic precision, demonstrate electronic control over wavefunction overlap, and characterize the spin singlet and triplet states of the two-electron system on couple donor pairs.

YBCO Superconducting Transmission Line Characterization
M. Feng,* J. Fendrich
Superconductor Technology Inc.

Conducted in the Micro and Nanotechnology Laboratory

This project studies the design rule of MCM using a superconductor as an interconnect line. Loss and phase delay are compared between gold and the superconductor line. Bit-error-rate and crosstalk will also be examined.

Human–Computer Interfaces

Adaptive/Reflective Middleware System
R. Campbell,* K. Nahrstedt,* R. Kravets,* L. Sha,* J. Tanner, P. DeRose
Defense Advanced Research Projects Agency Grant, INT NBCH 1030017

Lockheed-Martin; BBN Technologies; Johns Hopkins University; Scientific Research Corporation; Telecordia; Conducted in the Digital Computer Laboratory

The ARMS project investigates Multi-Layer Resource Management for next generation Navy battleships. This collaborative effort is developing a system that encompasses many major aspects of computing resource management. Our team’s focus is the management of the human element of mission tasks, identifying and tasking the best user for each task, and locating the best hardware to perform that task within a distributed system platform. Intelligent algorithms dynamically adjust to current conditions when selecting users and also learn from a user’s previous performance. We are integrating current research in pervasive computing, allowing users to perform their tasks more efficiently by allowing them mobility that existing systems lack.

* Denotes principal investigator.
Magnetic Resonance

Constrained Spectroscopic Imaging
Z. P. Liang,* P. C. Lauterbur*
National Institutes of Health, 1R01CA51430-01A4
Conducted in the Beckman Institute for Advanced Science and Technology

Magnetic resonance spectroscopic imaging promises to provide an entirely new way to examine the dynamics of human biochemical processes in vivo noninvasively. However, its practical applications have been limited because of low sensitivity and long imaging time. The primary objective of this research is to develop mathematical methods to effectively utilize the readily available anatomical information to constrain the spectral distribution to reduce imaging time without compromising spatial resolution.

Functional Brain Imaging
Z. P. Liang,* J. Ji
National Science Foundation, BES 95-02121; Beckman Institute for Advanced Science and Technology
Conducted in the Beckman Institute for Advanced Science and Technology

The primary objective of this project is to develop new signal-processing algorithms for detecting brain activities from functional MRI data. Researchers are investigating a wavelet-transform-based filtering and t-test method for signal detection and a multiscale method for image registration and motion correction.

MR Imaging of Time-Varying Objects
Z. P. Liang,* Y. Bresler,* J. Ji, A. Sen Gupta, A. Guo
National Science Foundation, BES 95-02121; National Institutes of Health, NIH-R21-HL062336

Conventional MR imaging techniques have been widely used to obtain high-resolution images from stationary objects. For time-varying objects such as the beating heart, however, significant image artifacts often arise that render the image useless. This project aims to develop a new class of data acquisition and image reconstruction methods for real-time imaging of cardiac structures and functions.

Materials Chemistry

Metal Boride Thin Films: Synthesis of New Molecular Precursors and Growth by Remote-Plasma CVD
J. R. Abelson,* Y. Yang, N. Kumar, S. T. Lazarz, G. S. Girolami* (Chem.), D. Kim, W. Noh, C. Spicer
National Science Foundation 0420768; Intel

We synthesize new single-source precursors and deposit thin films of the "metallic ceramic" compounds ZrB2, HfB2, and CrB2 that are technologically attractive as hard, wear-resistant coatings and as diffusion barriers in ULSI microelectronics. We also deposit films of the 39K superconductor MgB2. Our approach, remote-H2 plasma chemical vapor deposition, combines the best features of the chemical and physical deposition routes: the high rate and conformal coverage characteristic of CVD, and the low substrate temperature characteristic of PVD. The research includes analysis of the growth chemistry using real-time spectroscopies and evaluation of the resulting film properties and performance.

Synthesis and Characterization of Nanostructured Alloys with Enhanced Mechanical Properties
J. R. Abelson,* N. Kumar, P. Bellon,* A. Chaterjee
National Science Foundation, NSF-DMR 03-54060

Metal diboride thin films are developed into a novel hard coating technology. We have demonstrated superhard films of HfB2: with a grain size of only 5 nm, the films have a nanoindentation hardness of 40 GPa, exceeding the bulk value of 29 GPa. The Young's modulus of the films is adjusted by alloying with nitrogen during growth. Recent work explores the wear properties using pin-on-disc tests, including the formation of chemically mixed layers at the wear interface, as well as nanoscratch methods.

Nano-, Micro-, and Meso-Technology

Tooling and Instrumentation for High-Resolution Electrohydrodynamic Printing
P. M. Ferreira,* A. G. Alleyne,* D. Mukhopadhyay, J. Luebbering, K. Barton
National Science Foundation, DMI-0328162 (through Nano-CEMMS); Ford Motor Company

This project is part of a multi-investigator effort (J. Rogers, materials and inks; P. Kenis, microfluidics; Georgiadis, computational modeling) that attempts to build a high-resolution electrohydrodynamic jet (e-jet) printer for manufacturing microstructures for bio and organic electronics applications with functional features in the

* Denotes principal investigator.
range of 100 to 500 nm. This work address the issues for creating MEMS-scale multinozzle print heads and instrumentation and sensors for detecting e-jet emission and regulating process parameters such as stand-off height and the electrical potential gradient between the print head and the substrate.

**Nanoscience and Technology**

**Thermodynamics of Nanostructures and Buried Interfaces Using Scanning Nanocalorimetry**

L. H. Allen*

*Nationa l Science Foundation, DMR 0108694*

This project aims to investigate a variety of basic materials issues in thin films and at interfaces, such as coalescence during initial stages of film growth and silicide formation with restricted dimensions. The research also seeks to reveal new thermodynamic information about behavior of materials at nanometer length scales. The research will contribute basic materials science knowledge at a fundamental level to important aspects of electronic/photonic materials.

**Networking**

**Ad hoc Wireless Communication Between Vehicles**

R. H. Campbell,* S. Myagmar

*Motorola, Inc.*

*Conducted in the Digital Computer Laboratory*

We propose an ad hoc routing protocol with location service for vehicle-to-vehicle communication. As an example of feasibility, we developed and tested application prototypes of voice chat, location filtering, and roadside information service for moving vehicles. Our protocol takes into account the motion of vehicles on a highway. It broadcasts location updates only when the velocity or direction of a vehicle "space reservation" to avoid transmission collisions.

**Efficient Resource Management for Controlled-Mobility Wireless Networks**

E. Frazzoli,* L. Sha, P. R. Kumar, M. Caccamo, N. A. Neogi

*National Science Foundation, CCF-0325716*

A controlled-mobility wireless network (CMWN) is defined as a network of embedded devices endowed with computation, communication, and motion capabilities. The purpose of this project is the development of a new conceptual framework for the design, development, and operation of efficient and reliable networks with such characteristics.

**Data-Centric Sensor Networks**

J. C. Hou,* L. Sha, P. R. Kumar, N. Li, H. Zhang

*National Science Foundation, Special Projects in Networking, ANI-0221357*

*Conducted in the Digital Computer Laboratory*

In this research project, we first lay an integrated framework in which a comprehensive solution can be designed that comprises a set of component solutions at each layer to achieve the targeted goals of data-centric sensor networks. Then, we consider under this unified framework, research issues along the following thrusts of research: hierarchical cluster formation and routing; topology control and power management; Quality-of-Service provisioning within/between clusters; MAC design for timely dissemination of delay-sensitive data; and empirical study with the use of Motes.

**A Component-Based Software Environment for Simulating and Synthesizing Network Protocols inLarge-Scale Networks**

J. C. Hou,* R. Campbell, L. Kung, H. Kim

*University of Illinois*

*Conducted in the Digital Computer Laboratory*

In this project, we propose to design, implement, and evaluate a component-based software environment for a wide variety of emerging network architectures and applications. The environment expedites execution and evaluates network protocols and services in a systematic manner. We follow three research thrusts: We extend JavaSim to include base classes and packages for grid networking technologies. We investigate issues of parallelizing real-time process driven simulation engines and explore the use of fluid models, network calculus models, and rescaling techniques to expedite simulation. In a related project, we build a software-programmable router platform, called CROSS, that is dynamically extensible, configurable, and able to predictably process network flows that require QoS-aware access to multiple resources. We will leverage JavaSim components as building blocks for CROSS/Linux router services, and realize differentiated multicast and secure video proxy systems as CROSS services.

* Denotes principal investigator.

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**Application/System Quality-of-Service (QoS) Interface Capabilities**
K. Nahrstedt,* W. J. Jeon, B. Kalter, J. H. Seo
*National Aeronautics and Space Administration, NAG 2-1250*
*Conducted in the Digital Computer Laboratory*

Researchers are investigating application-system Quality-of-Service (QoS) interface capabilities for visual tracking distributed applications. The interface between the application and the underlying QoS-aware resource management system must provide several important functionalities: application QoS application programming interface, translation between the application QoS into the system QoS parameters, integrated reservation coordination policies and protocols to avoid and prevent deadlock situations, adaptation policies and their application enforcement, and others. These functions will reside in the end-system management entity called the QoS Broker, which represents the application/system interface for provision of end-to-end QoS guarantees.

**Hybrid Adaptive Algorithms for End System Middleware**
K. Nahrstedt,* B. Kalter, B. Li
*Defense Advanced Research Projects Agency, F30602-97-2-0121*
*Conducted in the Digital Computer Laboratory*

Current distributed multimedia applications demand Quality-of-Service (QoS) from the supporting system. However, within the QoS demands, lower level transport facilities may not constantly provide guaranteed QoS without perturbation. In this scenario, researchers are investigating hybrid adaptive algorithms in the middleware level of end systems to perform QoS adaptation on a critical QoS metric. The research concentrates on analysis of QoS adaptation in dependence of system resource availability changes by applying theories from digital control systems.

**QoS Routing**
K. Nahrstedt,* J. Qian, L. K. Shan
*Defense Advanced Research Projects Agency, F30602-97-2-0121*
*Conducted in the Digital Computer Laboratory*

The task of Quality-of-Service (QoS) routing is to find a path in the network that satisfies constraints on such metrics as bandwidth, delay jitter, and cost. This study focuses on QoS routing algorithms and their design within routers. The problem of finding a path with constraints on two or more additive metrics (delay and delay jitter) is NP-complete. This research concentrates on heuristic algorithms and study of the family of distributed and hierarchical routing algorithms to solve the multiconstrained routing problem. The QoS routing solutions are applied to point-to-point as well as multicasting scenarios.

**QoS-Aware Resource Management**
K. Nahrstedt,* K. Kim, A. K. Viswanathan, J. Wang
*Partnerships for an Advanced Computational Infrastructure*
*Conducted in the Digital Computer Laboratory*

Operating systems and communication systems need new algorithms, services, and protocols to support processing of audio/visual streams according to Quality-of-Service (QoS) specification. This project concentrates on the CPU brokerage service with advanced reservation, admission, scheduler, and adaptation control for soft real-time and non-real-time tasks. At the communication level, researchers provide IntServ bandwidth brokers in the edge networks and DiffServ brokers within the backbone routers to provide end-to-end guarantees.

**Operating Systems and Security**

**Choices: A Reliable and Secure Operating System for Mobile Devices**
R. H. Campbell,* J. Hou,* Z. Anwar
*National Science Foundation, CNS 03-05537*

Distributed denial of service, man-in-the-middle attacks, message tampering, eavesdropping, and replaying threaten to cripple the Internet infrastructure. They are especially harmful to killer applications for the Internet such as voice over IP (VoIP) and voice over wireless. There is a need to develop innovative strategies to detect, mitigate, and counter these threats. Unfortunately various key components are required to realistically model a large VoIP infrastructure and study its vulnerable spots. J-Sim is a composable and extensible network simulation and emulation environment. We extend J-Sim to include representative security mechanisms/policies for VoIP such as IPsec, firewalls, Media Gateways, Soft Switches, key distribution and authentication mechanisms, and popular VoIP protocol stacks such as RTP, SIP, and H.248. We also provide various attacker models and IDS mechanisms to allow vendors to plug in their VoIP components and test them for vulnerabilities in a controlled and simulated environment before actual deployment. In addition we are exploring the use of virtualization techniques and reference

* Denotes principal investigator.
monitors to choose secure paths for VoIP information flows.

**Composing Security in Large-Scale Cyber-Infrastructures**

R. H. Campbell,* S. R. Katasani

*National Science Foundation*

Present day cyber infrastructures like the power grid are very complex assortments of various devices with different security requirements and differing ability to provide security. Not all the devices in the system can provide the necessary security according to the enterprise policies, but the presence of these devices is indispensable. In such a scenario, it is really difficult for the system managers or the system administrators to monitor and maintain these devices. We are developing a methodology that will allow a system administrator or a manager automatically to analyze the system and reason about the security and decide the necessary security measures to install. In order to achieve this goal, we developed a representation for modeling the cyber assets of an organization based on workflows and common information models. In our modeling formalism an organization can be defined as a combination of subjects, objects, services, tasks, and communication protocols.

**ITR: Active Information Spaces Based on Ubiquitous Computing**


*National Science Foundation, CCF-00-86094*

The project researches a new form of operating system to manage a model of computing called an Active Space. This model integrates physical spaces that contain ubiquitous computers into a computational environment that supports human activity and applications. The physical space, augmented with communicating computer devices, becomes a distributed computing system. Gaia, an operating system for Active Spaces, will accommodate diversity by exploiting standards for interoperation and cooperation. System services track, authenticate, and support mobile users with reconfigurable graphics, multimedia, and Active Space applications. A unifying object bus, component model, and adaptive stream model extends plug and play to distributed mobile computers within physical spaces like cities, buildings, and rooms.

Active Spaces have the potential for creating multibillion dollar industries. Automated surgery, collaboration, and engaged learning are a few of the compelling examples.

**Mobile Sensor-Network Authentication**

R. Campbell,* V. Welch,* C. Andrews, P. Naldurg, H. Khurana

*Office of Navy Research*

Authentication is a critical security requirement for sensor network nodes and provides a high quality of assurance in a hostile deployment scenario, when it is important for a data-gathering source to confidently verify the origin of sensor data. We focus on higher-end sensors that have significantly more processing power and memory than first-generation sensors. We question some of the existing weak cryptograhic protocols and investigate the feasibility of using limited public-key encryption to address the sensor origin authentication problem. The challenge of key distribution is addressed by imprinting sensors with public key certificates, as well as the corresponding private keys, before being deployed. A line-of-sight transmission may be used to update the key.

**Security and Configuration of Software Defined Radios**

R. H. Campbell,* S. Myagmar

*Various Donors*

Reconfigurability of software defined radios (SDR) supports integration and co-existence of multiple radio access technologies on a general-purpose radio equipment. An SDR terminal is able to switch its operating mode by configuring its radio parameters and component composition to suit the appropriate radio access technology, user preferences, and local conditions. The main challenges are how to provide a methodology to dynamically and securely configure software components originating from several, different vendors, and how to remotely attest the validity of the radio configuration to external parties such as a network operator or service provider.

**Optical and Discharge Physics**

**Startup Processes in Metal Halide Lamps**

J. G. Eden,* M. J. Kushner, R. Moss, A. Bhoj, T. Sommerer (GE)

*General Electric R&D Center*

*Conducted in the Everitt Laboratory*

High pressure, metal halide lamps are typically the lighting sources used for street lamps, stadiums, warehouses, and other large indoor arenas. Metal halide lamps start as room
temperature, glow discharges. Upon heating, metal-halide compounds in the lamps vaporize to generate multiatmosphere pressure plasmas, which then produce nearly continuum radiation. The starting process usually involves applying high-voltage pulses to tens to one hundred Torr of Ar gas with a small admixture of mercury or another low ionization potential rare gas. Optimizing this process will ultimately produce longer lived, more reliable lamps. In this research project, advanced computer modeling and laser diagnostics are being used to investigate the fundamental plasma processes that occur during startup of metal-halide lamps. Of particular interest are the plasma-surface interactions on the cathode that result in sputtering of cathode materials. Methods to minimize sputtering without using costly exotic materials are being formulated.

Optical Imaging

Targeted Contrast and Therapeutic Agents for Molecular Biomedical Imaging
boppart@uiuc.edu
Beckman Institute for Advanced Science and Technology
Conducted across the University of Illinois campus

Recent advances in biomedical imaging have drawn from diverse fields to develop multifunctional targeted agents that serve not only to generate contrast for detection and imaging, but also provide a targeted therapeutic approach. While many forms of contrast agents exist, and much effort has focused on optimizing contrast enhancement, less is known about the potential for delivering controlled local release of drugs or other local therapy, such as hyperthermia or mechanical disruption, from these agents. Additionally, our understanding of targeting strategies is limited, largely due to the complexity of the cellular biology under normal and disease states. This project assembles an interdisciplinary team of investigators across campus to focus on these problems, and to develop new targeted, multifunctional agents.

Near-Field Optical Power-Extinction Tomography
P. S. Carney,* V. Markel, J. C. Schotland, E. Wolf, G. S. Agarwal
carney@uiuc.edu
U.S. Air Force Multidisciplinary Research Program of the University Research Initiative Grant, F49620-03-1-0379; National Science Foundation Career Award, 0239265
Conducted in the Beckman Institute for Advanced Science and Technology
Near-field optical power-extinction tomography (NOPET) represents the intersection of total internal reflection tomography (TIRT) and optical power-extinction tomography (OPET) where the probe beams of OPET are replaced with evanescent waves as in TIRT for sample illumination. With this technique it is possible to produce sub-wavelength resolved tomographs of scattering objects from the power lost from the probe fields.

Near-Field Scanning Optical Tomography
P. S. Carney,* J. C. Schotland
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National Science Foundation Career Award, 0239265
Conducted in the Beckman Institute for Advanced Science and Technology
Near-field scanning optical tomography (NSOT) explores the extension of imaging modalities such as photon scanning tunneling microscopy (PSTM) and near-field scanning optical microscopy (NSOM) to samples that contain three-dimensional structure or when the probe tip is not scanned in grazing proximity to the sample. We solve the linearized inverse scattering problem to produce sub-wavelength resolved tomographs of the object under these conditions.

Optical Power-Extinction Tomography
P. S. Carney,* E. Wolf, G. S. Agarwal
carney@uiuc.edu
Beckman Research Award; U.S. Air Force Multidisciplinary Research Program of the University Research Initiative Grant, F49620-03-1-0379
Conducted in the Beckman Institute for Advanced Science and Technology
Optical power-extinction tomography (OPET) makes use of the power lost from two coherent beams, which simultaneously interrogate a scattering object, to generate a tomograph (three-dimensional image) of that object in a similar manner as computed axial tomography (CAT) makes use of the attenuation of individual beams of x-rays through an absorbing object to generate a tomograph. We

* Denotes principal investigator.
are currently developing a prototype instrument. Initial results are promising.

**Photon Scanning Tunneling Microscope**
P. S. Carney*
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*University of Illinois

Conducted in the Beckman Institute for Advanced Science and Technology

A photon scanning tunneling microscope (PSTM) is a device where the object is illuminated by an evanescent wave generated at the face of a prism or slide and the field is detected via a fiber probe in the near-zone of the sample (as in near-field scanning optical tomography). The data obtained with a PSTM are not amenable to direct interpretation, but we show sufficient information exists in the raw data to numerically compute the two-dimensional structure of a thin sample, thus achieving a computational lens for the near-field. Demonstration of this work has just been accepted for publication in Physical Review Letters.

**Total Internal Reflection Tomography**
P. S. Carney,* J. C. Schotland, R. A. Frazin;
D. G. Fischer (NASA)
carney@uiuc.edu
NASA, NAG3-2764

Conducted in the Beckman Institute for Advanced Science and Technology

Total internal reflection tomography (TIRT) is an imaging modality that makes use of the evanescent waves to illuminate and probe a sample. The probe depth is controlled through the exponential decay of the evanescent wave. In principle, this form of illumination can also enable super-resolved imaging where features smaller than a wavelength can be resolved. To take practical advantage of this capability, it is necessary to solve the inverse scattering problem that is the focus of this project. We are currently constructing an instrument to take the appropriate measurements.

**Optical Physics and Engineering**

**Investigation of Carbon Nanotube Nano-Optics**
P. S. Carney*
carney@uiuc.edu
National Science Foundation NER Grant, 0210495
Conducted in the Beckman Institute for Advanced Science and Technology

Carbon nanotubes and semiconductor nanowires are tiny objects (1000 times thinner than a human hair) that have recently drawn considerable attention in the scientific and engineering communities because of their novel structural and electrical properties. We will theoretically investigate the optical and optoelectronic properties of these structures.

**Arrays of Microdischarges: A New Generation of Lighting Sources**
Electric Power Research Institute, EP-P6654/C3385

Conducted in the Everitt Laboratory

This experimental and computational program is devoted to investigating diatomic molecules as efficient emitters for lamps. The microdischarge serves as the platform with which a wide variety of diatomics (excimers, metal-halides, etc.) will be studied. A close linkage between experimental results and theoretical predictions is a key element of this research effort.

**Equipment for Machining of Microdischarge Devices**
J. G. Eden,* C. Herring, J. Gao, A. Oldenburg

Conducted in the Everitt Laboratory

Under the DOD DURIP program, equipment is being purchased to facilitate the fabrication of microdischarge devices in silicon and other materials systems. A 1-kHz pulse repetition frequency Ti:sapphire regenerative amplifier will be used with an existing oscillator to ablatively machine microchannels in silicon for use in arrays of discharge devices. Also, vacuum ultraviolet optics enabling arrays of sub-50 μm diameter cylindrical channels to be machined in Si metals or SiO₂ at 193 nm have been obtained. The introduction of polymer films into these multilayer devices as dielectrics or emission down-converters is another thrust of this program.
Experimental Studies of Microdischarge Devices and Arrays
Conducted in the Everitt Laboratory

This research program is focused on fabricating and examining the properties of arrays of microdischarge devices. A variety of processes (wet and dry chemical processing, laser ablation, and ultrasonic milling) are employed to fabricate cylindrical and pyramidal cathodes in silicon as part of a multilayer structure suitable for large-scale production. The properties of arrays and single devices operating in the rare gases are of particular interest, and emphasis is being placed on the characteristics of devices smaller than 50 μm.

Fabrication of Large Area, High Density Microdischarge Arrays on Flexible Substrates
J. G. Eden*
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National Science Foundation; Anvik Corporation

In collaboration with the Anvik Corporation, the fabrication of large arrays of microcavity discharge devices on flexible substrates is being pursued. Excimer laser micromachining techniques, combined with roll-to-roll processing, are attractive for inexpensively manufacturing microdischarge devices in large area arrays.

Femtosecond Nonlinear Optical Phenomena
J. G. Eden*
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Northrop Grumman Corp.

Experiments are being conducted in which ultrafast laser pulses (~100-150 fs) produce ionized filaments in air or other gases. Peak optical field intensities exceeding 10^{13} W-cm^{-2} are sufficient to produce stable channels having extraordinary optical and electrical characteristics. In particular, emphasis is being placed on the coherent nonlinear optical processes occurring in these filaments.

Large Microdischarge Arrays: Diagnostic and Fabrication Equipment
U.S. Army Research Office, DAAD19-01-1-0417
Conducted in the Everitt Laboratory

Funds have been provided to purchase equipment for experiments exploring nonlinear optical processes in intense optical fields and the behavior and fabrication of microdischarge devices having dimensions below 100 μm. These equipment items have significantly improved the characterization and functionality of microdischarge devices and arrays fabricated in Si and glass. Improvements in the regenerative amplifier of a Ti:Al_{2}O_{3} femtosecond system, including its pulse energy and bandwidth, have also been made.

Microdischarge Arrays: Phase 2
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U.S. Air Force Office of Scientific Research, AF EWING TECHNOLOGY 03-1
Conducted in the Everitt Laboratory

The focus of this research program is scaling of microdischarge arrays to 10^{4}-10^{5} devices and emitted power densities of 0.1-1 W-cm^{-2} in the ultraviolet. Arrays are being fabricated in silicon with devices having inverted square pyramidal cathodes and polymer or multicomponent dielectrics. Large arrays have also been successfully constructed and operated in glass in which the pixels are excited with an interdigitated electrode configuration. Several diatomic molecular emitters and excitation processes are under investigation, with initial emphasis on mid- and near-UV emitters.

Microdischarge Devices and Arrays: Quantum and Coherence Effects
U.S. Air Force Office of Scientific Research, F49620-00-1-0372
Conducted in the Everitt Laboratory

A family of photonic devices, known as microdischarges, is being developed under this multiyear program. Based on microplasmas confined to volumes of nanoliters or less, these devices have remarkable properties, including the ability to operate as stable glows at atmospheric pressure and with specific power loadings of several tens of kW-cm^{-3}. Single devices and arrays as large as 30 x 30 pixels have been fabricated in silicon, ceramic, and metal/polymer structures. Many applications, including broad-area UV sources, pump sources for microchip lasers, arc lamp ignition, and gas chromatography, are being pursued. Other research thrusts in this program are femtosecond spectroscopy of small molecules by coherent nonlinear optical processes and the study of the optical properties of nanoparticles for lasers and biosensing applications.

* Denotes principal investigator.
Microdischarge Long Wave Infrared Source Technology Development
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Northrop Grumman Corp.
The characteristics of microcavity plasma devices as emitters in the infrared (5-12 μm) are being studied in experiments with a variety of device designs. Spectroscopic and power measurements of single devices and arrays are being carried out in conjunction with theoretical studies.

Microdischarge Micro-Thruster Technology Development
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Ewing Technology Associates
The potential of microcavity discharges as sources of thrust for small ("pico") satellites is under investigation. Experiments measuring the electrical characteristics of robust device structures, including Ni/BN/Ni designs, are being conducted to assess the magnitude of thrust attainable as well as the device lifetime.

Microdischarges and Rare Earth-Doped Waveguide Devices: Visible and Ultraviolet Sources for Lasers and Sensors
U.S. Air Force Office of Scientific Research,
F49620-98-1-0030
Conducted in the Everitt Laboratory
The demonstration of new sources of ultraviolet and visible radiation is the thrust of this research program. Current efforts are two-pronged. Microdischarge devices developed in this laboratory are under study as emission sources for displays or as chemical sensors. Cylindrical and typically 20 to 400 μm in diameter, these microdischarges have properties (VI characteristics, specific power loading) that are unique and quite attractive for a variety of applications. The second facet of this research effort is the study of nonlinear optical phenomena on the sub-100 fs time scale and at intensities exceeding 10^{19} W-cm^{-2}. Using colliding pulse mode-locked and Ti:Al_{2}O_{3} laser systems, wave packet formation, four-wave mixing, and high-order harmonic generation are being studied, both experimentally and theoretically.

Microdischarges for Phased Arrays of Low Coherence Emitters, and Microchip and Microsphere Lasers
J. G. Eden*
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U.S. Air Force Office of Scientific Research,
F49620-03-1-0391
A new family of photonic devices, known as microcavity discharges, is being developed under this multiyear program. Based on microplasmas confined to volumes of nanoliters (or less) and spatial dimensions of nominally 10-100 μm, these devices exhibit remarkable optical and electrical properties. The fabrication of single devices and arrays as visible or ultraviolet emitters for applications in biomedical diagnostics, displays, and environmental sensing is being pursued. Microcavity discharge devices with semiconductor cathodes have also been observed to be sensitive detectors of visible and near-infrared radiation, and the properties of these new photodetectors are under investigation. An emphasis of this program is the realization of two-dimensional arrays of microemitters in which adjacent pixels are optically coupled.

Novel Miniature Diagnostic Using Microdischarge Technology
J. G. Eden,* C. Wagner
National Science Foundation; SBIR; SBC ETA UI-99-09-P1
Conducted in the Everitt Laboratory
This SBIR program is developing chemical sensors based on microdischarges fabricated in a "flow through" geometry. Because of the high specific power loadings accessible with microdischarges (> 100 kW-cm^{-3}), arrays of these devices are well suited for the remediation of toxic gases. The emission spectra of gases flowing through a single 100–400 μm diameter microdischarge are presently being studied as a diagnostic of molecular fragmentation in the discharge and as a means of detecting impurities in the gas flow stream.

Spatially-Resolved Detection of Weak Magnetic Fields by Laser Magneto-Optical Techniques
J. G. Eden,* J. Gao,* J. M. Talmadge, R. Roth, A. Fai
U.S. Air Force Office of Scientific Research,
F49620-01-1-0546
Conducted in the Everitt Laboratory
Magneto-optical techniques are being developed under this program to detect weak (< 1 nT) magnetic fields for biomedical applications. By employing epitaxial films of novel garnet films in combination with nonlinear optical
processes and synchronous detection, magnetic fields as low as 10 nT have been detected reliably.

**Visible and Infrared Laser Spectroscopy**

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Northrop Grumman Corp.

*Conducted in the Everitt Laboratory*

Atomic and molecular laser spectroscopy in the visible, ultraviolet, and infrared is the focus of this research effort. Currently, emphasis is being placed on the spectroscopy of the Rydberg states of the neon dimer and rubidium dimers. Excitation spectroscopy of the neon dimer has yielded the first rotationally resolved bands as well as observation of triplet splitting. As a result, structural constants of the molecule have been determined. Femtosecond studies of the dissociation of diatomic molecules, observed in real time, are also being carried out.

**Metal Halide Lamp Plasma Model**

J. Gao,* J. G. Eden,* F. Shen

APL Engineered Materials

Calculations of ground and excited state potentials of excimer molecules of interest for lamp applications are being carried out. Comparison of experimental photoassociation spectra with quantum calculations has resulted in improved molecular spectroscopic constants for the xenon-monoiode excimer that emits in the deep ultraviolet at 254 nm. The optimization procedure also involves comparison with emission data, and subsequent studies will focus on the mercury dimer.

**Optoelectronics**

**Next-Generation Optical Materials and Devices**

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National Science Foundation

The goal of nanotechnology is to create materials and devices that exhibit novel and significantly improved properties due to their nanoscale size. We are developing nanophotonic light sources with enhanced characteristics for future photonic ultra-high-capacity communication systems. We seek to combine aggressive advances in 3-dimensional electronic confinement obtained from quantum dots with the unprecedented optical confinement achieved from photonic crystals to develop the next generation of highly efficient microcavity optical sources.

**Spatial, Temporal, and Spectral Localization for Advanced Photonic Applications**

K. D. Choquette,* J. J. Coleman
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Defense Advanced Research Project Agency

Future chip-based optoelectronic systems will require an unprecedented decrease of size and operating power, while simultaneously incorporating greater functionality and complexity. This research program builds on advanced materials and device concepts to create a multifunctional photonic crystal based photonic integrated circuit that incorporates quantum dot active regions. We will explore diode injection and extraction to and from engineered quantum dot structures, integrated with spatial selectivity within photonic crystal waveguides and optical nanocavities. This project will encompass three levels of technology research: system integration, novel device structures, and advanced epitaxial growth. In the Photonic Device Research Group, our objective is to demonstrate a photonic microsystem composed of an electrically injected optical source, compact waveguides, detectors, and optical memory elements.

**High-Speed Wavelength-Agile Optical Network**

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National Science Foundation

We propose to explore the architecture and device development issues necessary to develop optical local area networks (LANs) that are ready to interface with optical metropolitan area networks (MANs). Our goal is to develop a clear plan for integration of multiwavelength LANs and MANs in order to improve the degree to which the benefits of high bandwidth in the MANs are delivered to end users on the LANs. Our tasks include the following: quantitatively evaluate the impact of wavelength conversion on network reliability and study the design of all-optical access architectures that leverage high-speed wavelength conversion and add/drop channel capabilities; design and fabricate tunable laser sources and wavelength converters using composite resonator vertical cavity lasers; design and fabricate a novel semiconductor-based wavelength converter capable of format-transparent and ultrafast wavelength conversion; and design and fabricate add/drop filters and photodetectors.

* Denotes principal investigator.
Parallel Processing

Intelligent Information Spaces: A Testbed to Explore and Evaluate Intelligent Devices and Augmented Realities
D. A. Reed,* R. H. Campbell, R. Kravets, M. D. Mickunas, K. Nahrstedt, L. Sha
National Science Foundation, EIA 99-72884
Conducted in the Digital Computer Laboratory

To support information environments where ubiquitous, intelligent devices unobtrusively share data, preferences, and contexts about users and their movement among environments, this project is developing interoperable component architectures for device coordination, seamless object communication for user quality of service, and adaptive user context and modality management. The goal is to define a software architecture capable of enabling a mobile, responsive, and contextual information environment where a broad collection of high-end data display and visualization systems, low-power mobile devices, and "smart" devices with widely varying capabilities are seamlessly integrated using dynamically tailored software components.

Power and Energy Systems

Fully Integrated Switch-Mode Power Supplies
P. L. Chapman,* C. Liu
Grainger Center for Electric Machines and Electromechanics
Conducted in the Everitt Laboratory

A typical switch-mode dc power supply involves several integrated circuits and discrete passive components. By moving all the circuitry to a single integrated circuit, the circuit is reduced in size and potentially cost. Power management and distribution within a chip are better enabled. Several versions of a step-up dc-dc converter have been demonstrated. Newer versions will take advantage of MEMS technology to improve the quality of the passive components and reduce the space occupied by the chip.

Capabilities of Finite Element Analysis and Magnetic Equivalent Circuits for Electrical Machine Design
P. T. Krein,* M. Yilmaz
Grainger Center for Electric Machinery and Electromagnetics
Conducted in Everitt Laboratory

Capabilities and limitations of finite element analysis (FEA) and magnetic equivalent circuit (MEC) analysis are reviewed for electrical machine design. Conventional designs employ equivalent circuits, supplemented with FEA. MEC methods offer advantages of reduced model complexity compared to FEA, enhanced accuracy compared to circuit approaches, methods for extension to 3-D, and fast computation. Few past efforts report thorough comparisons between measurements and simulations. With limited exceptions, past comparisons report “good agreement,” but in fact show errors of 15% or more. When magnetic saturation, eddy currents, hysteresis losses, and similar effects are modeled in detail, simulations and experiments agree within 5%.

Clean Power Supply for Dynamic Loads in Low-Voltage Digital Systems
P. T. Krein,* G. Pitel
National Science Foundation, ECS 06-21643

Fast dc-dc dynamic performance is crucial for supplying clean power to dynamic loads, especially in low-voltage digital systems where fast, high-current load steps can lead to significant transients. Control and systems change are two approaches that allow converters to reject disturbances without sacrificing bandwidth. Sophisticated control methods that harness load information can increase rise time performance by nearly an order of magnitude. Modern digital systems have the necessary communication infrastructure to transmit this data to the supply so it can respond intelligently. Hitherto unexplored topologies can route current around system bottlenecks to achieve ultra-fast performance. Both approaches are being evaluated.

Comparison between Hard and Soft Turn-Off of IGBTs in PWM Inverters
P. T. Krein,* A. Banerjee
Delphi DEGS Scholarship

To ensure optimum benefit of insulated gate bipolar transistors (IGBT), their appropriate operation is crucial. Pulse-width modulation (PWM) exposes IGBTs to variable duty cycles and frequencies. Hence, IGBT robustness is necessary to ensure system reliability. Requirements such as low device stress versus low commutation losses demand conflicting gate-drive

* Denotes principal investigator.
designs. The potential gains of incorporating either hard turn-off (straight turn-off of the gate once over-current is detected) or soft turn-off (when over-current is detected, the gate voltage is brought down gradually to limit current, and then turn-off is initiated) techniques will be analyzed with respect to design conflicts.

**Design of Small Inverter-Fed Induction Motors**

P. T. Krein,* M. Amrhein  
Grainger Center for Electric Machinery and Electromechanics

*Conducted in the Everitt Laboratory*

Nearly all induction machines built today are based on previous designs, carrying on constraints imposed long ago. Although new materials are employed, the basic concepts have not changed in decades. However, with power electronic inverters, some constraints no longer apply. This project investigates fundamental design choices, such as number of phases, operating frequency, and number of poles, as well as geometric parameters. The goal is to derive design rules to yield machines with improved efficiencies and operating characteristics. Design tools and methods specialized for inverter-dedicated induction machines are being developed, and complete machines will be designed and tested.

**Development of an Automated First-Principles Design Tool for Electromechanical Devices**

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Grainger Center for Electric Machinery and Electromechanics

The objective is to use closed-form solutions of Maxwell’s equations as a tool for first-principles design of electromechanical devices. In this research, a Mathematica program has been developed that automates such a process. A generic layered is used to represent material in the rotor, stator, or air gap of an electric machine. Current work focuses on better understanding the nature of the fundamental fields and forces at work inside an electric machine. Conformal mapping based on the Schwarz-Christoffel mapping theorem is being explored to solve analytically for magnetic fields and forces in two-dimensional machine structures.

**Digital Control for Energy Optimization**

P. T. Krein,* J. Kimball  
National Science Foundation, ECS 06-21643

Discrete-time ripple-correlation control (DRCC), developed with SmartSpark Energy Systems, extends ripple correlation control (RCC) into the digital domain. Analog RCC is reduced to a sample timing problem: With correctly timed samples of variables, a microcontroller can determine the optimal operating point location. Convergence is fast and uniform. After the system is reset at open circuit, the solar panel is driven near maximum output power by choosing a voltage value relative to the open-circuit measurement, enabling the DRCC algorithm to quickly converge to global maximum output and avoid undesirable operating points. DRCC is demonstrated over a wide range of solar conditions.

**Flexible Digital PWM Control for Embedded Power Converters**

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University of Illinois, Motorola Center for Communications

*Conducted in the Everitt Laboratory*

Switching power conversion for portable communications, personal digital assistants and most other electronic products is controlled through pulse width modulation (PWM). Since PWM produces strong components at the switching frequency and its multiples, one objective of X. Geng and P. Krein is to study spectral characteristics of PWM for purposes of noise and switching loss management. Nonrandom switching schemes are being developed to reduce interference without extra losses. Applications include flexible digital implementations for the full range of dc-dc converters and small motor drive units for automotive loads.

**Input Power Minimization of an Induction Motor Operating from an Electronic Drive Under Ripple Correlation Control**

P. T. Krein,* A. Bazzi  
Smartspark Energy Systems SBC PK 2007-02694

*Conducted in Everitt Laboratory*

Ripple correlation control is applied to induction motor input power minimization. Simulations and experiments verify that the direct component of the rotor flux in the synchronous frame can minimize input power to the motor and maintain required output power. Motor characteristics are shown to give a convex input power function with respect to λedr. Results include the use of torque and flux estimators from stator-side voltage and current measurements. System analysis uses dynamic models of the induction motor, three-phase rectifier, three-phase inverter, estimators, and ripple correlation controller. Efficiency improvement is verified across the load torque.
range. A technique indicates if the motor is run at its optimal operating point.

Mitigation of Power System Collapse through Active Dynamic Buffers
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National Science Foundation Grant, NSF ECS-0224829

Power electronics continues to grow as an element of electrical loads. Loads such as motor drives, computer power supplies, and compact fluorescent lighting serve to "isolate" load dynamics from the utility grid and enforce constant power behavior. They tend to destabilize the grid. In this study, power buffering is examined as a way to mitigate effects of constant power loads by controlling the dynamic impedance of the converter during a disturbance. Experiments have shown the advantages of using power buffers. Further work involves studying the interaction of multiple power-buffer converters in a distributed system.

A Microgrid-Based Telecom Power System Using Modular Multiple-Input Dc-Dc Converters
P. T. Krein,* A. Kwasinski
Grainger Center for Electric Machinery and Electromechanics

A microgrid is an independently controlled portion of an electrical grid. It comprises its own power sources (such as fuel cells, solar cells, microturbines), energy storage devices (such as flywheels, batteries, ultracapacitors), and loads, usually interconnected with a larger grid. With independent control, a microgrid with a utility tie can deliver high reliability, high efficiency, and uninterruptible power functions, while reducing energy storage needs compared to traditional systems. This work explores a microgrid-based telecommunications power plant with a distributed architecture. Combinations of converters and controls create a flexible, reliable plant that meets performance needs of modern telecommunication systems.

A Stochastic Approach to Power Factor Correction
P. T. Krein,* J. Kimball
National Science Foundation, ECS 06-21643

Power factor correction (PFC) converters enable computers and other electronic devices to operate near unity power factor. Without PFC, they would inject harmonic currents into the power grid and disrupt other equipment. Kalman filters and related stochastic techniques are used to extract current information from voltages and eliminate current sensors. Kalman filter-based controllers can be modified to generate any current waveform, allowing both unity and non-unity PFC to be accomplished with a small software adjustment. This allows the power converter designed to exploit allowed harmonics and, depending on the application, to either reduce cost or improve reliability.

Critical Cutsets for Static Transfer Stability Limits
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National Science Foundation and Grainger Foundation Endowments

This project is investigating possible direct data indications (line flow measurements) of closeness to voltage collapse and methods to increase margins to voltage collapse. The goal is to evaluate this information using SCADA measurements rather than model-based computation.

Dynamic Behavior and Load Model Estimation from Measurements
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National Science Foundation and Grainger Foundation Endowments

This project is investigating the use of phasor measurement unit data to provide real-time estimates of system dynamic behavior and estimates of load model structures and their associated parameters. The dynamic behavior would be quantified by estimated levels of system damping for critical modes.

Trustworthy Communication and Computing Architectures for Power Systems
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National Science Foundation

This project is investigating the needs of power system communication and computing environments for future use in deregulated power systems. This includes the need to share information between regions and independent operators.

Value of Real and Reactive Power Reserves
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Roberto Rocca Fellowship and Grainger Foundation Endowments

This project is investigating the technical and economic issues associated with determining the value of real and reactive power reserves. These reserves can be broken down into various components that reflect their operational benefits to the system. The issues with each component are

* Denotes principal investigator.
being addressed from an economic and reliability point of view.

Voltage and Reactive Power Computation for Contingency Analysis using Sensitivities
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Roberto Rocca Fellowship and Grainger Foundation Endowments

This project is investigating alternatives to full AC power flow techniques in contingency analysis. While sensitivity analysis is normally limited to real power computation for estimating line flows, this work is considering piecewise linear methods that reflect the physical limits on reactive power sources and voltage control. This preserves the linear nature of the contingency analysis while recognizing an important nonlinearity.

Programming Languages, Formal Systems, and Software Engineering

Actor Coordination Abstractions, Semantics, and Implementation
G. Agha,* C. Varela
University of Illinois
Conducted in the Digital Computer Laboratory

This research focuses on the complexity of expressing interaction and coordination in Web-based computing. Researchers are working on providing high-level mechanisms to manage the complexity of scaling up computations over the Web, piggy-backing on the availability of Java byte-code for portability. The project defines several actor-based abstractions (casts, directors, messengers) to effectively harness the power of the World Wide Web as a global computing infrastructure. Groups of actors, or casts, represent an abstraction unit for naming, synchronization, migration, composition, and load balancing. Each cast contains a director, and intercast communication is performed via special actors named messengers.

Agent Generation and Control
G. Agha,* N. Jamali, P. Thati
U.S. Air Force Office of Scientific Research, F49620-97-1-0382
Conducted in the Digital Computer Laboratory

Agents provide a natural abstraction for using geographically distributed computational and memory resources. Agents are autonomous mobile actors that may be invoked to satisfy specific goals that may require traveling across physical and economic boundaries. Agents and agent ensembles can exhibit resource consumptive or otherwise unsafe behavior, raising security and resource management concerns. Agents must, therefore, be limited by the resources they consume in pursuing a goal. The project is developing concepts necessary to provide linguistic and system support for defining multiagent architectures. A related goal is to extend the mathematical theory of actors to allow reasoning about multiagent systems.

Customizable Coordination Services for Large-Scale Network Embedded Systems
G. Agha,* P. Chang, P. Thati, R. Ziaei
Defense Advanced Research Projects Agency, F49620-97-1-0382
Conducted in the Digital Computer Laboratory

The focus of this research is on developing application independent services to coordinate large scale network embedded systems. The coordination services will use customization and composition to enable dynamic adaptation in uncertain environments. The approach is to define algorithms that are based on stochastic models of system behavior, which enable the research team to represent the incompleteness in information about the current global system state as well as the unpredictability of the environment. The operational model uses probabilistic transitions rather than simple nondeterministic interlavings of actions, and it explicitly accounts for duration of transitions. The goal is to develop algorithms that provide for coordination in real-time and that guarantee the desired properties with sufficiently high probabilities. Examples include algorithms for approximate consensus (such as approximate synchrony), recovery, and hierarchical coordination. The algorithms will be implemented to provide a code basis for application independent coordination services. The implementation strategy is to build a repository of basic coordination services using reflective middleware. The goal will be to derive more complex algorithms based on simpler core resource management services.

Parametric Models for Large-Scale Agent Systems
G. Agha,* N. Jamali, P. Thati, R. Ziaei
Defense Advanced Research Projects Agency, F30602-00-2-0586
Conducted in the Digital Computer Laboratory

A goal of this research is to develop mathematical models to support the analysis and modeling of complex, large-
scale agent systems. Instead of simple nondeterminism, the new theory will represent behavior stochastically. Moreover, instead of the current approach of using input-output behavior of individual agents, it will allow the behavior to be parametric in terms of variables that represent aggregated behavior of large numbers of agents. The operational model uses probabilistic transitions over an abstract representation of the current state of the system. The use of statistical techniques on this model for aggregating behaviors opens up the possibility of studying conditions under which either a stable equilibrium or chaotic behavior may occur. Another goal is to develop a radically different logical framework for expressing properties of large-scale agent systems. The framework is inspired by Quantum Logics, which allow the expression of testable properties. This is in contrast to the usual algebraic approach that assumes every sentence (whether testable or not) can be assigned a truth value. Specifically, this research will enable macroscopic properties to be expressed without implying assertions about how they arise.

Software Architectures for Distributed Systems
G. Agha,* M. Astley
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Conducted in the Digital Computer Laboratory

The term middleware describes a set of services for integrating components of a distributed application, such as coordination and communication mechanisms. Recently, middleware services have been developed that support fault-tolerance, security, and other high-level policies. Such services have a fixed semantics, their implementation being influenced by the semantics of the application and the nature of the execution environment. The goal of this research is to provide a modular framework for developing middleware services. The project is formulating theoretical, linguistic, and run-time support for developing the needs of a particular application. Particular attention is paid to placement and mobility issues and vertical integration requirements.

Specifying and Deriving Mobile Systems
G. Agha,* P. Thati, R. Ziaei
U.S. Army, JHU 8812-48151
Conducted in the Digital Computer Laboratory

This research is focused on studying formal methods for specifying and verifying distributed software systems. The objective is to use automated deduction tools to reason about certain properties of mobile agents in open distributed systems. More specifically, security issues in authentication protocols and agent design are being studied. The project is formalizing an appropriate semantic framework that captures the fundamental properties of mobile computing and simplifies the task of reasoning. A specification language and logic will be developed based on the semantic framework. Finally, automated reasoning environments will be explored to find a suitable platform to implement the reasoning system.

Real-Time and Embedded Systems

SoD: A Feedback-Based Architecture for Highly Reliable Embedded Software
T. Abdelzaher,* L. Sha, M. Caccamo, D. Marinov
National Science Foundation, CNS-0613665

The focus of this project is on developing a theory and architectural framework for incorporating feedback control as a main principle of software engineering. This proposal develops scientific foundations, tools, and architectural design principles to improve the reliability and reduce the development cost of mission-critical software. Two common approaches to ensure reliable system behavior are: scientific foundations, tools, and architectural principles for ensuring elimination of errors; and foundations, tools, and architectural principles for ensuring tolerance to such errors. While the first solution is sufficient, building completely error-free large-scale systems has been an elusive exercise as evidenced by experiences with today’s engineering artifacts (e.g., recalls on vehicles, cascading power blackouts, and so forth). Consequently, a new approach to robust software design, development, and certification is needed that addresses the increasing cost and safety implications of the current practices. Feedback control has proven to be a very successful tool for ensuring correct behavior of complex, poorly modeled systems in the presence of uncertainty. This project applies principles of feedback control and stability envelopes to the engineering of software systems.

SoD-TEAM: A Feedback-Based Architecture for Highly Reliable Embedded Software
T. Abdelzaher,* L. Sha,* M. Caccamo,* D. Marinov*
National Science Foundation, CNS-0613665

The focus of this project is on developing a theory and architectural framework for incorporating feedback control as a main principle of software engineering. This proposal develops scientific foundations, tools, and architectural design principles to improve the reliability and reduce the development cost of mission-critical
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**ITR: Collaborative Research: Efficient Resource Management for Controlled-Mobility Wireless Networks**
E. Frazzoli, L. Sha, P. R. Kumar, M. Caccamo, N. A. Neogi  
*National Science Foundation, CCF-0325716*

A controlled-mobility wireless network (CMWN) is defined as a network of embedded devices endowed with computation, communication, and motion capabilities. The purpose of this project is the development of a new conceptual framework for the design, development, and operation of efficient and reliable networks with such characteristics. The overall objectives of the basic research proposed in this project are: the development of a conceptually sound, consistent, and complete framework for the analysis of the interactions between competing computation, communication, and motion control requirements, arising in the design of CMWNs; the design, analysis, and performance characterization of distributed algorithms and communication protocols for provably efficient and adaptive CMWNs; the specification, implementation, and verification of software, middleware, and networking services for the deployment of representative CMWNs.

**Defect-Tolerant System Integration and Evolution**
L. Sha*  
*U.S. Office of Naval Research, Sha 2063*

Conducted in the Digital Computer Laboratory

Large software systems are developed by integrating software components. Unfortunately, many complex software components often contain defects. On the other hand, the technology exists to develop modest-size software components with a high degree of confidence. Flight control software is an example. This research focuses on algorithms and architectures that can leverage simple high-assurance components to ensure the integrity of large distributed real-time systems in spite of faults in complex software components.

**Dependable and Secured Embedded Systems**
L. Sha,* V. Adve, M. Spong  
*National Science Foundation, CNS 0209202*

Conducted in the Digital Computer Laboratory

Faults and attacks during upgrades can be classified into three categories: application level control logic faults or attacks; code, data, thread, or process access faults or attacks; and resource depletion faults or attacks. To protect against them, our work will focus on integrated compiler static analysis and runtime checks to enforce the resource usage limits and to protect code, data, thread, and processes; and advanced safety controllers that can protect against coordinated control logic faults or attacks. Together with real-time scheduling technology, they form a foundation upon which applications can be upgraded without shutting down normal operation. Furthermore, the system stability can be maintained in spite of insider attacks masquerading as upgrades.

**Quality of Surveillance and Control in Network Centric Warfare**
L. Sha,* J. C. Hou,* M. Caccamo, W.-P. Chen, P. R. Kumar, R. Iyer, R. Zheng  
*Office of Naval Research, Multidisciplinary Research Program of University Research Initiative*

Conducted in the Digital Computer Laboratory

In this project, we aim to develop a sound scientific foundation and technologies to allocate computing, sensing, and communication resources in a way that will enhance the quality of surveillance and control for the Department of Defense's vision of network centric cooperative engagement. We are working with the DoD community to develop model problems that embody the fundamental scientific and engineering challenges faced by DoD systems, including network of multifunction radars, distributed sensor network, and advanced avionics systems. We are working to solve these model problems, demonstrate the solutions, and transition the technologies to major DoD programs through technology transition partners.

* Denotes principal investigator.
Reliable and High-Performance Computing

Detecting and Preventing Attacks with Vulnerability Signatures
N. Borisov,* D. Nicol, W. H. Sanders
National Science Foundation, #CNS 06-27671
Conducted in the Information Trust Institute
This research is working to develop a new network-filtering defense mechanism to detect and prevent intrusions using fast and precise vulnerability signatures. The work will provide a sound and fundamental approach for representing vulnerabilities, detecting attacks via exploits that make use of those vulnerabilities, and preventing (through filtering) the harmful effects of many network-based attacks. Though directed at network-based attacks, the approach should also be effective in protecting other communication channels inside a host.

Composable Processors
N. P. Carter,* R. Gupta, G. Rasche, J. Stine
Defense Advanced Research Projects Agency, MARCO Center
As silicon fabrication technology improves, processors and system-on-a-chip (SOC) designs are moving toward gridded layouts to minimize the impact of wire delays on performance. The composable processors project is studying techniques to reduce the design time and cost of grid-based custom processors through the use of a set of pre-designed "tiles" that can be composed together to form a variety of custom system architectures. In addition to the design of the tiles and systems that use them, we are developing software techniques to automatically generate high-performance, low-cost architectures for specific applications in this design methodology.

Magnetoelectronic Reconfigurable Logic
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U.S. Office of Naval Research, N00014-02-1-1038
We are developing reconfigurable logic systems based on a novel magnetoelectronic device: the Hybrid Hall Effect device. These circuits can be configured to compute a wide range of logic functions with nonvolatile storage of their outputs and can be easily integrated into CMOS designs. Current challenges include reducing the power consumption of our circuits and developing system architectures that best take advantage of their capabilities.

Self-Healing Reliable Reconfigurable Systems
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University of Illinois
Reconfigurable logic is an attractive fabric for reliable system design because faults in portions of the logic can be corrected by reconfiguring the system to avoid the faulty resources. We are developing design techniques for reliable systems implemented using reconfigurable logic. These techniques combine application-directed synthesis of redundant functionality to tolerate errors, run-time detection of faults, incremental synthesis for fast repair, and global resynthesis to avoid cumulative effects from multiple faults.

The Amalgam Programmable-Reconfigurable Processor
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Amalgam combines several conventional processors and blocks of reconfigurable architecture into a single microprocessor, using a clustered architecture to minimize the impact of wire delay on cycle time. Our results show that this architecture generates an average of greater than 12x speedup over a simple microprocessor on a range of benchmarks. We are currently developing compiler techniques for this architecture, as well as investigating architectural features to improve performance in far-future fabrication processes.

Architectural Models for Highly Concurrent Instruction Execution
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Superscalar processors can concurrently execute several instructions from a single thread, but are limited in the amount of concurrency they can find and exploit because they must fetch and rename instructions in program order. We build on compiler-assisted thread level parallelization mechanisms that concurrently fetch, rename, and execute multiple, widely separated, portions of the program. We are developing new dynamic techniques for using control-dependence information to find and exploit global instruction-level concurrency within a single thread of execution. Using these techniques, we can achieve execution rates four to ten times that achievable by superscalar processors.
Advanced Predicate-Domain Code Optimization
W.-M. Hwu,* J. W. Sias
Intel Corporation

The predicated representation, in which control is implemented via conditional execution of instructions rather than branches, presents two general categories of new optimization opportunities: the optimization of program decision logic and the optimization of computation code using predication. This project aims to reduce control overhead by extracting control expressions from predicated code, optimizing these expressions using Boolean minimization techniques, and re-expressing control using more efficient sequences of predicate defining instructions. In the second area, this project works toward a paradigm in which stores, branches, and loop boundaries can be reordered freely to achieve performance goals.

Architecture and Compiler Techniques for Optimizing Memory Accesses
W.-M. Hwu,* H.-S. Kim, E. M. Nystrom
National Science Foundation, CCR 96-29948/98-09478; Intel Corporation

The goal of this research is to develop an integrated compiler and architecture approach to drastically reduce the frequency and cost of memory accesses in future computer systems. In particular, a compiler strategy that is built upon interprocedural pointer analysis and new heuristics for estimating the probability of colliding pointer contents will be developed to take full advantage of the data speculation features in future microprocessors. The insights provided by fully disambiguated memory accesses may drastically change the future course of run-time data speculation supports.

Automatic Transformation of Traditional Software Components into a Data-Flow Execution Model
W.-M. Hwu,* C.-W. Li, H.-S. Kim
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Due to the cost of building ever-larger uniprocessors with standard, single global on-chip storage, future gigascale computing platforms will increasingly rely on special-purpose hardware accelerators that employ decentralized data-flow computation models. However, the traditional von Neumann programming model will continue to be strongly preferred due to the high cost of changing the fundamental software model. To improve design productivity in the presence of the widening gap between the programming model and the underlying hardware platform, we are developing deep program analysis and transformation techniques that will enable tools to automatically extract data flow computation components from a von Neumann program.

Compiler and Architecture Support for Program Tunneling
Hewlett-Packard

Modern programming paradigms often impose major performance penalties on application programs. Object oriented programming, structured exception handling, automatic memory management, middleware services, and operating system calls are all examples of such costly features. The goal of this research is to eliminate the cost of these features for the frequently traversed paths of executable programs. Architecture support, in the form of new protection schemes and no-overhead profiling mechanisms, will be developed to enable the run-time optimizer to safely perform aggressive optimizations.

Configurable On-Chip Memory Microarchitectures
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Simple technology scaling offers little hope for breaking the difficult scalability and power/performance barriers associated with traditional on-chip memories. This project seeks to design new configurable on-chip SRAM microarchitectures that will enable large SRAM structures to approach the power efficiency of small custom memories for memory-intensive applications such as media and signal processing. The proposed structures support configurability in access ports, access latencies, and sleep-drowsy states. Our deep analysis toolset, a carefully engineered symbiosis of whole-program data flow, control flow, and pointer/data structure analyses, will disaggregate the application's memory data flows and will allow transformation of existing programs to take full advantage of the configurability of the new SRAM structures.

* Denotes principal investigator.
CRI-A Configurable Application-Aware High-Performance Platform for Trustworthy Computing
National Science Foundation #CNS 05-51665
Conducted in the Information Trust Institute

This project is enabling groundbreaking experimental research by creating large-scale, demonstrably trustworthy, cluster computing platforms for on-demand/UTILITY computing and/or adaptive enterprise computing. Specifically, it is investigating new sets of application-aware methods to provide customized levels of trust (specified by the application) via an integrated approach involving reprogrammable hardware and novel compiler methods to extract security and reliability properties, all supported by a configurable OS and middleware.

Deep Program Analysis
Intel Corporation; National Science Foundation, 98-09478

Current code analysis techniques draw dependences based largely on program structure and on register and memory accesses, many of which are not inherent to algorithms but are merely side effects of implementation in a particular architecture or coding paradigm. The conservative nature of these analysis techniques limits the compiler's ability to perform broad, powerful code optimizations. Deep program analysis is intended to discern the fundamental algorithmic dependences of input programs from among those artificially imposed. The application of deep program analysis techniques could revolutionize program optimization, memory access microarchitecture, software development process, software verification, and software debugging.

IMPACT Post-Link Optimization Framework
W.-M. Hwu,* M. C. Merten, R. D. Barnes, E. M. Nystrom
Hewlett-Packard; Microsoft Corp.

Commercial software vendors distribute products in binary executable form, compiled for a specific processor. Very limited technology exists for optimizing binary executables, thus preventing end users from optimizing programs for their particular machines and usage patterns. To remedy this problem, this project is creating a binary optimization framework that will serve as a bridge between the binary executable and the IMPACT compiler. Using this framework, the team can experiment with optimizations targeted machine. Such optimization could be performed at the time of program installation or offline, while the user's machine is idle.

IMPACT Run-Time Optimization Framework
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Advanced Micro Devices; Microsoft Corp.

Aggressive code specialization at compile time can achieve significant performance gains, although it is typically limited by risks of profile-dependence and code-explosion. Therefore, we are developing a framework for adaptive, runtime optimization, allowing profiling and specialization of code regions based on the current workload profile. Rather than solely focusing on opportunities in relatively unoptimized applications, this framework focuses on providing an efficient architecture for targeting optimization of opportunities presented by even the most aggressively optimized code. Components of these frameworks include efficient runtime optimization algorithms, techniques for identifying optimization candidates using nonintrusive profiling, and seamless deployment of optimized code.

Java Run-Time Architecture
W.-M. Hwu,* M. T. Conte, H.-S. Kim
Hewlett-Packard

This project focuses on enhancements needed to create highly optimized native code for dynamic Java server applications. This includes the construction of a next-generation Java run-time prototype that offers a means of integration between dynamic code production and static code reuse. Also included are a streamlined object model, nonintrusive profiling, dynamic optimizations, reduced intermodule communication overhead, run-time deployment of optimized code, improved memory management subsystem, and hardware enhancements to support Java specific features.

Memory-Efficient EPIC Processors
W.-M. Hwu,* N. P. Carter, H. Hunter, C.-W. Li
Semiconductor Research Corporation

Researchers are developing an improved EPIC architecture that will provide the high performance required by upcoming embedded applications while significantly reducing power consumption and memory bandwidth requirements. This architecture divides the processing resources of the chip into four independent clusters, with each cluster having its own program-controllable data memory. A decoded instruction buffer in each cluster reduces instruction fetch bandwidth and power.

* Denotes principal investigator.
consumption in loops. Compiler techniques are being developed to coordinate intercluster data movement to eliminate many of the memory accesses required during the execution of media programs on conventional architectures.

**Multipass EPIC Microarchitecture**
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Intel Corporation; Hewlett-Packard

It is well established that the in-order microarchitecture used by EPIC processor such as Itanium can exploit the compiler's proficiency in planning parallelism. However, the inability of this substrate to accommodate unexpected latencies, such as data cache misses, is its most vexing weakness. To address this problem, we propose multipass pipelining, a new class of in-order microarchitectures in which the processor pipeline defers execution of instructions with unready operands for later processing, thereby avoiding stalls. A first-generation design of this technique delivers substantial performance improvements for applications with significant memory stalls. Future generations promise to further enhance the performance while reducing complexity, area, and power.

**Next-Generation EPIC Compiler Technology**
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Intel Corporation; Hewlett-Packard

We have demonstrated that IMPACT's aggressive use of predication, speculation, and code replication in its structural transformation approach can attain substantial integer code performance increases over contemporary compilers for Itanium2. Challenges and opportunities remain: sophisticated combinations of transformations required to expose desired levels of instruction-level parallelism pose profile-dependence and stability issues. Selective specialization, while not yet controlled with great precision, shows an ability to improve instruction caching as well as ILP. Control and data speculation interact nontrivially with optimizations and operating system models. Finally, more sophisticated region selection and optimization techniques promise increasingly efficient use of wide EPIC resources.

**OpenIMPACT Compiler Release**
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Gelato; Hewlett-Packard; National Science Foundation, CCR 98-09404

This project aims to release the IMPACT research compiler as a general-purpose, open-source compiler for the IA64 Linux platform. The research compiler's features, such as predicated compilation, instruction-level parallelism optimizations, compiler-engineered speculation, and profile-based optimizations, as well as its extensible research framework, will be retained. In addition, an easy-to-use interface will be provided that will allow OpenIMPACT to be used as a high-performance alternative to traditional compilers. This project will be released under the University of Illinois (UIUC/NCSA) Open Source License.

**Predicate Analysis and Predicate-Aware Dataflow Analysis**
W.-M. Hwu,* J. W. Sias
Intel Corporation

Efficient and accurate analysis of predicate relationships and predicate-aware dataflow analysis are essential to effective optimization and scheduling of predicated code. A predicate analysis engine must first quickly analyze the code at the function level to determine all relationships among predicates. Then, it must store its findings in a database that can accurately and efficiently answer queries about the relations among predicates. The first objective of this project is to create a function-level, accurate, and efficient predicate analysis engine. The second objective is to create a predicate-aware dataflow analysis engine that is both accurate and fast.

**Rapid Customization of Systems Software**
MARCO, Defense Advanced Research Projects Agency (part of MARCO Center Soft Systems Thrust)

The objective of the project is to develop compiler-based, deep program analysis that transcends the boundaries currently separating the application, the dynamically linked libraries, and the operating system. Code-specialization of library functions and operating system services is based on interprocedural analysis of applications, programmatic logic analysis, data value analysis, and interthread escape analysis. Unnecessary code and modules are eliminated. A new fundamental model of the operating system functions, based on microkernel concepts, is developed to systematically...
verify the correctness of each customized version. Customization technologies are developed at the source and then at the binary level, with the long-term goal of handling commercial software. Potential benefits include rapid generation of software, smaller software footprints, reduced energy consumption, and higher performance.

**Scalable Deep Program Analysis**

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DARPA/MARCO FCRP Gigascale Systems Research Center (GSRC); National Science Foundation, Information Technology Research

Future breakthroughs in computer architecture, software engineering, and trustworthy computing will rely on the compiler to perform program analyses that are considered infeasible today. Deep program analysis refers to compile-time techniques that can derive important properties of the program execution accurately. Examples of deep analysis include value ranges that can be assumed by variables, realizable data flow through memory objects, and memory locations that can be accessed by program components. New scalable approaches to deep program analysis are being developed to enable their application to large, complex software systems.

**Scalable, Accurate Interprocedural Pointer Analysis**

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DARPA/MARCO FCRP Gigascale Systems Research Center (GSRC); National Science Foundation, Information Technology Research, CCR 98-09478

Pointer analysis is a critical foundation for virtually all advanced program analysis techniques. In a programming language like C that supports an explicit address operator, indirect calls, structures, heap allocation, and pointer casting, memory activity can easily be obscured. We believe that highly accurate results and the ability to scale to large programs do not have to be mutually exclusive goals. To this end, a pointer analysis framework has been developed that provides an efficient representation for achieving accurate results through novel mechanisms to deal with procedural side effects, global variables, heap locations, and fields.

**Ubiquitous Instruction-Level Parallelism Architectures**


Intel; Motorola, Inc.; Microsoft Corp.; National Science Foundation, 98-09478

As instruction-level parallelism (ILP) architectures such as Intel IA-64 and TI C6x move into the mainstream of computing, it has become critical to solve the technical problems involved in making these architectures appropriate for future embedded applications. The goal of this research is to develop new compiler, architecture, and microarchitecture concepts to drastically reduce the code size, data transfers, energy consumption, and die size of future ILP processors. New techniques will also be developed to further enhance the performance of future ILP microprocessors.

**Ultra-efficient Giga-scale Computing Platform Architecture**

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This project seeks to achieve orders of magnitude of improvement in power efficiency in future computing platforms by systematically synthesizing and utilizing hardware accelerators in the forms of ASIP, ASIC, and FPGA. This approach is motivated by the availability of immense numbers of transistors in future chips and the limitation of activating only a tiny fraction of them at any given time. New system architectures allow seamless integration of accelerators with processors containing extremely high-bandwidth, short-latency communication. Advanced program analysis and transformation techniques convert traditional memory side-effect-based execution activities into explicit data flow, enabling extremely efficient direct hardware execution.

**Value Analysis Compilation Framework**

W.-M. Hwu,* J. W. Sias

Intel Corp.

Analyzing the flow of values through program computation provides many opportunities for improving the performance of computer systems. This project has two related objectives: the optimization of existing control flow through value analysis and value speculation. Value flow analysis facilitates dead code elimination and control.

* Denotes principal investigator.
optimization. Value speculation refers to the execution of instructions before all source operand values have been determined. This can be done when instructions generate the same value for each execution, the same value for a high percentage of executions, or predictable values. Compilers can exploit these regularities through code specializations, collectively referred to as value speculation.

**Verification of Run-time Optimized Code**
Hewlett-Packard

Executable programs are increasingly optimized and modified in the field. Just-in-time compilation of Java programs is a well-known example of such run-time code modification. The goal of this research is to overcome the technical challenges involved in automatic verification of run-time optimized code. An interdisciplinary approach that integrates program analysis algorithms and hardware test and verification techniques will be developed to cover a wide variety of software defects.

**An Engineering Prototyping Environment for Compiling C Program Components into Application-Specific Logic**
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DARPA/MARCO FCRP Gigascale Systems Research Center (GSRC); Xilinx; IBM; Mentor Graphics

This project seeks to establish an engineering prototyping environment to enable research in ultra-efficient gigascale computing platforms. In this environment, we are prototyping processor design, operating system support, compiler technology, synthesis paths, libraries, and device drivers needed in future heterogeneous software and logic systems. The first generation prototype is based on the Xilinx ML300 board, the Linux kernel, the Mentor Graphics ASAP tool chain, and the IMPACT compiler. The initial applications being prototyped are from the design driver applications of the MARCO Gigascale Systems Research Center with emphasis on future home entertainment applications.

**Application-Aware Trust: Providing Security and Reliability**
R. Iyer,* Z. Kalbarczyk
Sun Microsystems
Conducted in the Coordinated Science Lab

The objective of this project is to develop a compiler-based approach for automatic program transformation to generate runtime security checks for target software, including both applications and the operating system. Our goal will be to provide a methodology and a framework for automatic analysis of applications to extract their security and reliability properties, convert the identified properties into runtime checks and program the checks directly into the hardware. By leveraging application properties in hardware, the checks can, with low performance overheads, selectively detect errors and attacks pertaining to the application.

**Ensuring Safety and Security in Software Intensive Aerospace Systems**
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Boeing
Conducted in the Coordinated Science Lab

The goal of this research is to investigate and develop technologies that allow for the verification and validation of safety and security properties in aerospace systems throughout the requirements, modeling, design, implementation, and testing product lifecycle phases.

**Fault-Injection-Based Benchmarking**
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In this research, we propose to explore issues and techniques for intrusion detection and intrusion tolerance in networked environments. Specifically, we will focus on analyzing data on security attacks to determine vulnerabilities exploited by attackers and to classify the attacks according to their causes; generating measurement-based security attack models depicting the attack process; creating stochastic models that reflect behaviors of the system in the presence of variable workloads, errors, and security attacks; investigating measures and experimental procedures for benchmarking system reliability and security; understanding potential inconsistencies in application and system implementation; and proposing software and hardware intrusion detection and prevention techniques.

**Gigascale Systems Research Center (GSRC): Reliable Systems Thrust**
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DARPA/MARCO FCRP Gigascale Systems Research Center (GSRC)

Our focus is on designing hierarchical systems of hardware and software detection and recovery mechanisms to handle
multiple and/or near coincident errors and to limit (or prevent) error propagation. We will explore a four-tiered approach to develop and integrate detection and recovery support at different levels of the system hierarchy. These levels can be classified as embedded programmable hardware support; operating system support; compiler support; and application support. Additional work will include updates to the ARMOR (adaptive reconfigurable mobile objects of reliability) software, NFTAPE, and the Reliability and Security Engine (RSE) project.

**ITR: Methodologies and Tools for Designing and Implementing Large-Scale, Real-Time Systems**

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National Science Foundation, Information Technology Research Program, #0121658 (Subcontracted from Vanderbilt University)

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The research proposed is to develop methodologies and tools for designing and implementing very large-scale, real-time embedded computer systems that achieve ultrahigh computational performance through use of parallel hardware architectures; achieve and maintain functional integrity via distributed, hierarchical monitoring and control; are required to be highly available; and are dynamically reconfigurable, maintainable, and evolvable. The specific application that will drive this research and provide a test platform for it is the trigger and data acquisition system for BTeV, an accelerator-based high-energy physics experiment to study matter-antimatter asymmetries in the decays of particles containing the bottom quark.

**Processor Level Error Detection and Recovery Techniques**

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Intel Research Council

This research is aimed at providing hardware-level, low-latency error detection and recovery. To achieve this goal we will develop and demonstrate hardware-implemented error detection and security mechanisms embedded as modules in the hardware-level framework, which is implemented as in integral part of a superscalar microprocessor. While the framework closely interacts with the processor pipeline, we do not propose to redesign the pipeline. Rather, the intent is to understand the pipeline to the extent needed for defining a robust interface with which we can demonstrate the operation and efficacy (coverage) of the modules. The framework and its interface with the pipeline are implemented in a reconfigurable portion of the die along with the processor. Example hardware modules we will explore include preemptive control-flow checking, a process health monitor, hardware-based checkpointing, and pointer-taintedness tracking.

**Quality of Distributed Control and Surveillance**

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Defense Advanced Research Projects Agency; Multidisciplinary Research Program of the University Research Initiative, N000914-01-1-0576

Conducted at the Coordinated Science Laboratory

The objective of this proposal is to create a scientific foundation for the distributed optimization problem of control and surveillance. The goal of our research is to investigate fault-tolerant and secure communication in a wireless or wireline environment, (e.g. an ad-hoc sensor network). In our approach, we explore and prototype a transparent, high-availability framework for supporting client-server applications operating over wireline or wireless networks, investigate issues and solutions (e.g. protocols) in supporting reliable and secure communications in wireless (e.g. sensor networks), and develop a remote vehicle testbed to investigate and test real-time, secure, and fault-tolerant control.

**A Compiler-Enabled Model and Measurement-Driven Adaptation Environment for Dependability and Performance**

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National Science Foundation, CNS-0406351

Conducted in the Coordinated Science Laboratory

This proposal has the potential for innovation of new measurement-driven and compiler enabled early detection, making the task of detection and diagnosis of performance problems and operational faults more efficient. To build detectors that can predict the likelihood of failures, we will use experimental system analysis to identify correlations between system behaviors and subsequent failure occurrence. Our research will employ measurement data and their analysis, together with compiler analysis of program behavior, to devise a methodology for data-driven discovery of early symptoms of errors, characterization of system/application sensitivity to errors, and identification of locations to place new detectors and guide engineering of application-specific detectors.
Future Communication Technology for Public Safety
L. Liu,* J. P. Monks, W.-M. Hwu
Motorola, Inc.

In the next decade, the communications technology for public safety officials will be revamped to take advantage of the capability of modern digital communication systems. It is, however, unlikely that current commercial digital communication schemes will be able to satisfy the stringent requirement of constant connection, very low power, congestion control, and ease of use. The goal of this project is to define the architecture of the public safety digital communication systems via careful analysis of field requirements and creation of new communication protocols. An interdisciplinary approach is taken to integrate user behavior studies with core technology development.

Assessment of Student Teams in an Engineering Course for Freshmen
M. Loui,* B. Robbins
University of Illinois

Conducted in the Coordinated Science Laboratory
ECE 110 is a large, required course for freshmen in electrical and computer engineering and for students in general engineering. We assessed the ECE 110 optional supervised study sessions, which implemented peer-led team learning. Students were assigned randomly to learning teams, which were led by peer students who had previously taken ECE 110. In the sessions, the learning teams worked on difficult problems selected from examinations given in previous semesters. Students who regularly attended the sessions reported cognitive and social benefits. They earned significantly higher scores on the final examination, after controlling statistically for ACT-Math scores.

Role-Play Scenarios for Teaching Responsible Conduct of Research
M. Loui,* C. K. Gunsalus,* B. Brummel, K. Kristich
National Science Foundation, ERC-0628814

Conducted in the Coordinated Science Laboratory
We are developing and assessing role-play scenarios to teach central topics in the responsible conduct of research to graduate students in science and engineering. Because few previous studies have carefully assessed the effectiveness of role-play in teaching ethics, we are conducting a systematic assessment of role-play, using multiple methods, in multiple departments. We have conducted formative assessments of role-play scenarios in several departments, using survey and focus group methods.

Capacity Versus Robustness: A Tradeoff for Restoration in Mesh Networks
S. Lumetta,* S. Kim
Defense Advanced Research Projects Agency,
MDA972-99-1-0005

Researchers are investigating capacity-efficient recovery methods in high-speed networks. The team recently demonstrated an extension of generalized loopback that operates on a subgraph of the full backup graph in an existing network. The backup capacity on remaining links can then be used to carry unprotected traffic, while all primary fibers retain failure protection. The results demonstrate robustness comparable or superior to that available with covers of rings while providing an additional unprotected traffic capacity of roughly 20% of the network's primary capacity.

Reliable, Efficient Communication on a Fast Ethernet Cluster
S. Lumetta,* J. Joh
University of Illinois, Campus Research Board

Networks of workstations (NOWs) have proven to be an inexpensive yet effective alternative to vendor-packaged parallel architectures. The performance of NOW's running on Fast Ethernet is often limited by TCP/IP communication overhead between the nodes in NOWs. Researchers are developing a new, lightweight, reliable communication protocol incorporating ideas of user-level communication, lightweight flow control, and multiple network interfaces per connection. The protocol supports the large body of existing parallel applications written to the Message Passing Interface standard. Researchers will evaluate the effectiveness of their design in terms of the performance of these applications when using their protocol.

Survivability and Reliability in Direct Access Networks
S. Lumetta,* L. Li
Defense Advanced Research Projects Agency,
MDA972-99-1-0005

Researchers are developing routing and recovery protocols to provide reliable connectivity in direct access optical networks (DANs). DANs decouple access from routing, allowing new users to access the network without incurring the high cost of an optical switch. Through this decoupling, researchers enable more cost-effective and reliable network expansion. Direct access also simplifies the models of ownership by reducing the depth of the ownership hierarchy and the number of potential security

* Denotes principal investigator.
hazards and points of failure for a connection. Finally, DANs allow network providers to offer a wider variety of bandwidth and reliability options.

**An Adaptive, High-Performance Software Infrastructure for Hierarchical Systems**
S. Lumetta*

*National Science Foundation, CISE/ACIR Career Award*

Machines with deep memories now dominate supercomputing and provide most enterprise-level computing, making the successful development of a general-purpose approach to such platforms imperative. Researchers are developing a high-performance infrastructure for these systems through the construction of four key components: a virtual machine that abstracts resource allocation and management issues into a simple interface; a hierarchy-aware run-time system that offers the illusion of a nonhierarchical system by adapting to the current hierarchical virtual machine; language constructs and dynamic compiler support to tune application behavior; and applications that demonstrate the value of the framework.

**Assessable Identity and Privacy Protection: End-to-End Assessment of Identity and Privacy Protection**
D. Nicol,* C. Gunter, W. H. Sanders

*Department of Homeland Security through the Institute for Information Infrastructure Protection (I3P)*

#5-36428.5730

*Conducted in the Information Trust Institute*

This effort has three main objectives: to develop a methodology for end-to-end assessment of systems that provide identity management; to demonstrate adaptive credentialing, in the context of a secure medical messaging application; and to demonstrate the assessment methodology, on systems to include the medical messaging system and an emergency response credentialing system being built at the University of Illinois at Urbana-Champaign and deployed by the Illinois Counter-Terrorism Task Force. Providing a proof-of-concept in assessable credentialing systems will motivate the identity management interest community to work toward assessable designs. This will ultimately raise the level of confidence in systems as they are deployed.

**Immersive Network Simulation Testbed**
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*U.S. Department of Homeland Security*

We are developing a network simulator for use in exercises by organizations interested in practicing their response to attacks on their IT infrastructure. The simulator uses high performance modeling and execution techniques, runs in real-time, and supports user interaction with simulated devices using emulation to provide a transparent veneer. A key goal is to use the simulator to automatically produce exercise "injects" that prompt players to react to simulated events.

**MLS Computing Platform Based on COTS and Open Source Technology**
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*Rockwell Collins RPS #3 4502607308*

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This project is developing a multilevel security-computing platform based on COTS and open source technology. The work began with an investigation into the available and emerging technologies developed to support separation, security, and assured computing, and proceeded to identification of any gaps in the available technology components that would preclude the development of a high-assurance MLS computing platform including I/O capabilities. The project is also developing candidate architectures based on COTS and open source technology components. The project will conclude with an information flow demonstration that shows the feasibility of one of the most promising candidate architectures.

**Modeling and Analysis for Network Security Assessment**
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*Defense Advanced Research Projects Agency*

We are developing simulation-based tools and technology to help a network analyst assess the impact of hypothetical attacks in a network, the effectiveness of defenses and countermeasures, and the quantified ability to continue operations in the face of a network attack. The result of our work will better enable network administrators and designers to protect their systems, and to quantify the cost, risk, and functionality tradeoffs inherent in network defense.

* Denotes principal investigator.
Policy Assessment and Verification in Survivable Process Control Systems
D. Nicol,* W. H. Sanders
Department of Homeland Security through the Institute for Information Infrastructure Protection (I3P)
#5-36425.5780
Conducted in the Information Trust Institute

The security of process control systems is largely a function of the security policies that are implemented within them. However, there are different policies that apply to network access, to processes in computer hosts, and to users. The interaction of these policies is difficult to understand, and gaps in security coverage may occur as a result. The objective of this project is to provide methodologies and tools to aid PCS operators in the assessment and validation of the security policies used to protect their systems.

Survivable Trust for Critical Infrastructure
D. M. Nicol*
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National Science Foundation

We are exploring the design of a distributed trust backbone, based on computational nodes that provide hardened attestation for their hardware and software identities, organized as a peer-to-peer network. We are focusing on application of this technology to security applications in IT management of critical infrastructure systems, such as SCADA.

Measurement of Transient Errors in Microprocessors
J. Patel,* K. Wells, H. Kommaraju
Jet Propulsion Laboratory

This research addresses the measurement of error rates in commercial microprocessors. Microprocessors are core computing engines in the NASA Remote Exploration and Experimentation Project (REE). One serious problem is single-event upsets due to high intensity radiation in outer space. Knowledge of these error rates is essential in the design of the highly fault-tolerant REE computing systems. The measurement of these error rates is the focus of the proposed research. The research will generate software tools that are capable of measuring and characterizing any errors in microprocessors.

VLSI Test
J. Patel,* A. Pandey
Semiconductor Research Corp.

The cost of test application of a single chip grows as a function of the number of clock cycles and/or number of storage bits required to test a chip. As a result, test application time and test data volume have become serious problems in testing of system-on-chip designs. In this research, new scan and BIST organizations are being devised that reduce not just data volume but also test time and associated hardware. Hybrid DFT techniques that combine BIST with deterministic scan vectors are also being investigated.

Algorithms for Quantifying Security and Survivability
W. H. Sanders,* D. M. Nicol
Boeing

Conducted in the Information Trust Institute

This project is developing a method to probabilistically quantify the security and survivability of practical systems. The method must guide the design process by quantifying the differences between design alternatives, and by quantifying the quality of a particular design or implementation. The work will result in a comprehensive methodology for quantifying the security and survivability of networked information systems that integrate modeling, measurement, and attack injection.

CT-CS: Trustworthy Cyber Infrastructure for the Power Grid
National Science Foundation, #CNS-0524695
Conducted in the Information Trust Institute

The Trustworthy Cyber Infrastructure for the Power Grid (TCIP) NSF Cyber Trust Center was created to address the challenge of how to protect the nation’s power grid. It will significantly improve the way the power grid cyber infrastructure is built, making it more secure, reliable, and safe. TCIP is working to provide the fundamental science and technology needed to create an intelligent, adaptive power grid that can survive malicious adversaries, provide continuous delivery of power, and support dynamically varying trust requirements. The project will achieve this by creating the necessary cyber building blocks and architecture, and by creating validation technology to quantify the amount of trust provided by the proposed approach.

* Denotes principal investigator.
NGS: A Compiler-Enabled Model- and Measurement-Driven Adaptation Environment for Dependability and Performance
National Science Foundation, CNS-0406351

Next-generation parallel and distributed computing must be dependable and have predictable performance in order to meet the requirements of increasingly complex scientific and commercial applications. This research will result in the production and distribution of a practical, integrated compiler and middleware system that uses online models and measurement techniques to achieve performance and dependability in a scalable manner under a wide variety of changing conditions. The techniques we develop could ultimately impact many diverse and critical applications, including those in the electric power distribution, aerospace, healthcare, and financial services sectors.

Efficient Algorithms for Temporal Planning under Nonlinear Constraints
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National Science Foundation, NSF 03-12084

This research involves the development of formal mathematical conditions for reducing the search space of planning problems and the demonstration of performance improvements in search engines of planner and other discrete searches. By formulating temporal planning problems as dynamic optimization problems with dynamic variables that evolve over time, this research finds new node-dominance conditions by developing the necessary and sufficient conditions for local optimality. By partitioning the search into stages and by finding only dominating states in each stage using the conditions developed, the search for feasible or optimal plans can be restricted to a much smaller subspace in each stage.

Loss Concealment for Real-Time Multimedia over IP Networks
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Motorola Communication Center

This research entails the design of effective multiple-description coding (MDC) algorithms at senders of IP networks, like the Internet, that take into account the reconstruction method used at receivers for concealing lost packets, in order to deliver audio and video data packets over these networks in real time with high quality (both subjectively as well as objectively). Loss concealment of compressed multimedia data is essential because many coding algorithms remove temporal differences in order to achieve high coding efficiency, thereby introducing a pervasive dependency structure into the bit stream. As a result, losses due to dropped packets or late arrivals will result in the loss of subsequent dependent frames, leading to audio or visual artifacts that can be long lasting and annoying. We have chosen MDC because it is effective for concealing losses in transmissions without explicit redundancy control and for networks without priority transmissions. Empirical tests on the Internet show that packet losses are bursty with small burst lengths. Statistics also shows that two descriptions in MDC are adequate in most situations, whereas four descriptions will allow us to control unrecoverable losses under 8% in the worst site measured. Our research results in efficient MDC algorithms that are input independent, without requiring run-time adaptation of the algorithms to new inputs.

Stochastic Anytime Search with Applications in Autonomous Planning and Scheduling
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National Aeronautics and Space Administration, NASA NCC2-1230

Conducted in the Coordinated Science Laboratory

This research entails the development of a theory and its associated derivative-free search algorithms in order to solve constrained nonlinear programming problems (NSPs) with discrete, continuous, or mixed-integer variables. Our secondary goal is to apply the algorithms developed in autonomous control and planning in NASA applications. The research characterizes constrained local minima in NLPs by necessary and sufficient conditions on points in the unconstrained penalty function, develops stochastic anytime search algorithms that generate solutions of improved quality when given more time and computational resources, and applies the search algorithms to solve problems in autonomous control and planning.

Streaming Audio and Video Data with Transformation-Based Error Concealment
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Motorola Center for Communications, University of Illinois

Conducted in the Coordinated Science Laboratory

This research is on the design of protocols and coding methods for the concealment of errors that occur during real-time transmissions of audio and video data over unreliable IP networks, such as the Internet and wireless...
networks. Since video and audio transmissions may tolerate some degree of loss, this research analyzes schemes that involve trade-offs in their real-time requirements and tolerance to loss. By studying proper coding of transmitted data, protocols to schedule transmissions and feedbacks, and reconstruction schemes to recover lost data, the results developed can be applied to emerging multimedia-ready 3G and 4G cellular networks.

**Helmet Integrated Nanosensors, Signal processing and Wireless Real Time Data Communication for Monitoring Blast Exposure to Battlefield Personnel**

Department of Defense

*Conducted in the Coordinated Science Laboratory*

In this project we will develop and test a modified battlefield helmet integrated with smart nanotechnology sensors to record and analyze in real time the oxygen saturation, cortical EEG, pressure, acceleration, and vital signs, using a small footprint, low power consumption, ARM-based system embedded within the helmet straps and head band. Levels of blast injury algorithms (LBIs) will be developed based upon physiological data on pre- and post-blast exposure to the brain. Using wireless communication, the data recorded before and after blast exposure will be uploadable using small, cell-phone-like devices by first responders for an injury status and ported to remote locations prior to injured personnel movement to medical team facilities. Our novel approach focuses directly on helmet-based recording and on real time, transparent, highly reliable algorithms that predict the LBI and simultaneously provide vital information profiles. Integrating magnitude of blast with predictive algorithms regarding the level of blast injury would provide early predictors of soldier status.

**CSR-PDOS: Improving System Reliability via Delta Execution**

Y. Y. Zhou,* D. Marinov, W. H. Sanders, C. Zilles
National Science Foundation #CNS 06-15372

*Conducted in the Information Trust Institute*

Various reliability assurance tasks perform MARE (multiple almost-redundant executions). This project is pursuing an innovative route via delta execution to making MARE more efficient without requiring extra resources. The work will dramatically increase software reliability because it enables efficient online validation of software patches against realistic live workloads before deployment in production systems; it will reduce the number of administrative configuration errors by providing an efficient way to validate reconfiguration online; it will improve software robustness by improving testing; and it will increase software dependability by enabling efficient partial replication-based fault detection and recovery.

**Development of Concept Inventories for Computer Science**

National Science Foundation, DUE-0618589

*Conducted in the Department of Computer Science and in the Coordinated Science Laboratory*

We are developing concept inventories for three introductory computer science subjects: discrete mathematics, digital logic, and programming fundamentals. Modeled after the successful Force Concept Inventory that was developed to assess student learning of Newtonian physics, our concept inventories will test understanding of key computer science concepts in a manner that enables reliable comparisons between courses at different universities. We conducted a Delphi process to determine the topics in each of the three subjects that experts rated as most important and most difficult for students.

**Remote Sensing**

**CAREER: Multi-Technique Study of Ionospheric Irregularities at Mid-Latitudes**

J. J. Makela*
National Science Foundation

*Conducted in the Coordinated Science Laboratory*

Two clusters of instrumentation consisting of a wide-field ionospheric imaging system, a dual-frequency GPS receiver, and a single-frequency GPS scintillation monitor will be deployed to the Caribbean as part of the proposed research. The deployed instruments, in conjunction with other instruments in the region (especially those at the Arecibo Observatory), will allow us to address questions as to the evolution and effects of ionospheric irregularities at mid-latitudes.

* Denotes principal investigator.
Coordinate Imaging and Scintillation Study of the Conjugate Nature of Equatorial Plasma Irregularities
J. J. Makela,* B. M. Ledvina
National Science Foundation
Conducted in the Coordinated Science Laboratory
A suite of instruments will be fielded at two astronomical sites in South America: Neiva, Colombia and Cerro Tololo, Chile. The instruments, including an ionospheric imaging system and GPS L1 scintillation monitors, will operate autonomously over the duration of the proposal. The data collected will be analyzed with other datasets in the region when available to gain a broader understanding of how the local data fit into the physics of the entire magnetic flux tube. The data are to be analyzed jointly both between the different types of instruments and at the different locations.

Studies of Ionospheric Plasma Structuring at Low Latitudes from Space and Ground, their Modeling and Relationship to Scintillations
J. J. Makela*
Naval Research Laboratory
Conducted in the Coordinated Science Laboratory
This project combines observations and modeling of the low-latitude nighttime ionosphere to come to a better physical understanding of the factors that contribute to the day-to-day variability of the development of equatorial irregularities. The observations to be used come from the global ultraviolet imager (GUVI) on NASA’s thermosphere, ionosphere, mesosphere, electrodynamics (TIMED) satellite and the portable ionospheric camera and small-scale observatory (PICASSO) imager, to be deployed in Colombia. The data collected by GUVI will be compared to the SAMI3 model to determine the conditions that favor irregularity development.

African Studies of the Equatorial Thermosphere-Ionosphere System with a Remote Equatorial Nighttime Observatory for Ionospheric Regions (RENOIR)
J. W. Meriwether,* J. J. Makela
NASA and Clemson University
Conducted in the Coordinated Science Laboratory
In conjunction with the International Heliospherical Year (IHY), we will deploy a suite of instrumentation comprising a remote equatorial nighttime observatory for ionospheric regions (RENOIR). The station consists of a single wide-field imaging system, two Fabry-Perot interferometers, a dual-frequency GPS receiver, and an array of single-frequency GPS scintillation monitors.

When installed in Cape Verde, the RENOIR station will provide an unprecedented view of the nighttime ionosphere/thermosphere system. We hope to come to a better understanding of the variability in the nighttime ionosphere and the effects this variability has on critical satellite navigation and communication systems.

Consortium Resonance Lidar for Mesospheric Studies
G. Swenson,* A. Liu
National Science Foundation ATM 05-45704
Conducted in the Coordinated Sciences Laboratory
A University of Illinois Sodium wind/temperature lidar has been developed and modified to make improved measurements of Doppler winds and temperature in the 80-100km mesospheric region of the atmosphere. The system is planned for integration into a new facility at Cerro Pachon, Chile, for summer 2008 for long-term studies of the upper atmosphere with lidar and airglow imagers. The focus of the studies is the investigation of atmospheric gravity waves (AGWs) and tidal effects in the upper atmosphere.

Imaging Studies of Mesospheric Gravity Waves
G. R. Swenson,* A. Liu
National Science Foundation, ATM 00-03180
Small-scale waves propagate from the lower atmospheric convection and mountain driven sources to the upper atmosphere. Existing chemiluminescence produces airglows, which are perturbed by the waves. Airglow imagers observe the perturbations and the horizontal wavelength, and amplitude of the waves is measured. The waves carry momentum and energy, which can interact with the large-scale dynamics to cause major dynamic effects. Observations are being made at Socorro, New Mexico, and have been at Maui, Hawaii, where the University of Illinois lidar has made complementary measurements. Signal processing is accomplished to extract the intrinsic wave parameters and power and spectral characteristics of the horizontal wave structure.
systems and eigenvalue problems, nonlinear problems, multigrid methods, and fast multipole methods for summer school (summer 2001 and summer 2004) and general curriculum in the College of Engineering.

Multidimensional Computation of Electronic Properties of Semiconductor Microstructures of High-Performance Heterojunction Devices
National Science Foundation, EET-87-19100

The goal of this research is to design numerical programs for the simulation of multidimensional quantum wells. The numerical model consists of Poisson's equation coupled with Schrodinger's equation. Poisson's equation is solved as an elliptic boundary value problem, while Schrodinger's equation defines an eigenvalue problem. The model is nonlinear and requires repeated solution of such eigenvalue problems. Researchers compare the performance of Lanczos procedures with subspace iteration and examine the use of inverse iteration. Consistency of the two problems is obtained in an outer iteration that will be accelerated with a conjugate gradient procedure.

Semiconductor Lasers

1065 and 1040 nm DBR Laser Diodes
J. J. Coleman*
HRL Laboratories

Conducted in the Micro and Nanotechnology Laboratory

Narrow linewidth, tunable semiconductor lasers are of interest to a variety of applications, including fiber optic communication systems, optical generation of microwave radiation, remote optical sensing, and molecular spectroscopy. Various configurations of tunable lasers have been analyzed, and a two- or three-section distributed feedback (DFB) or distributed Bragg reflector (DBR) laser is often the choice. The goal of these programs is to develop narrow linewidth, single longitudinal mode, strained layer InGaAs DBR laser diodes operating near 1065 and 1040 nm for remote sensing applications.

Development of Advanced Laser Diode Sources for Remote-Sensing Applications
J. J. Coleman,* G. C. Papen*
National Aeronautics and Space Administration, NAG 1-1861

Conducted in the Micro and Nanotechnology Laboratory

Several outstanding technical issues for narrowband systems, such as water vapor DIAL lidars, must be resolved before solid-state, laser-based remote-sensing systems have widespread use. One issue is the development of cw local oscillators (LOs) based on semiconductor laser diode technology for use as injection seeders, which has not been fully realized because of the severe linewidth, tunability, and stability requirements of narrowband systems. This project will develop novel semiconductor devices specifically for use as tunable LO sources for narrowband water vapor DIAL systems operating in the 940 nm region. Researchers will focus on a novel ridge-waveguide, distributed-Bragg-reflector laser, which has significant performance improvements for optical remote-sensing applications relative to conventional Fabry-Perot or distributed-feedback lasers.

EOSS+ Laser Diode Substrate
J. J. Coleman*
Northrop Grumman Corp.

Conducted in the Micro and Nanotechnology Laboratory

The electro-optic test station known as the EOSS+ is designed to support the testing of laser platforms at 1.064 μm through the use of a laser diode source. The characteristics of this diode, such as center wavelength and peak power, are determined by the capabilities of the test receiver and the design of the EOSS+ unit itself. The purpose of this program is to provide for the fabrication of a custom-built diode grown from a novel substrate designed to meet specification.

High Brightness Laser Diodes
J. J. Coleman*
Nuvonyx, Inc.

Conducted in the Micro and Nanotechnology Laboratory

The objective of this program is to address several issues related to the MOCVD growth and characterization of InGaAs-GaAs strained layer lasers in the range of 920 nm to 1080 nm for high brightness applications. This approach will be to develop a real index guided laser with integrated beam expanders and other active and passive optics formed by selective area epitaxy. Present narrow stripe semiconductor lasers are generally limited to less than 200
mW of fundamental mode output power, because of the narrow aperture. If the beam can be expanded while retaining fundamental mode operation, then the operating power can be correspondingly increased.

**Narrow Linewidth, Multiple Wavelength, Simultaneous-Emission Laser Diodes for Remote Optical Sensing and Other Applications**

J. J. Coleman*

*National Science Foundation, ECS 9900258

Conducted in the Micro and Nanotechnology Laboratory

The proposal describes a program to develop multiwavelength, simultaneous-emission lasers based on a ridge-waveguide distributed Bragg reflector semiconductor laser. The specific example of an application that defines the need of such lasers is the differential absorption, remote optical sensing of water vapor. A multiwavelength source with closely spaced narrow laser lines would be useful to obtain the detailed absorption profile without having to turn the laser on and off the absorption peak as is practiced currently. This program is designed to study and develop a simple multiple wavelength source suitable for these kinds of applications.

**Semiconductor Physics**

**Concurrent Electro-Thermal Modeling of Ultra-Scaled MOS Technologies**

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*National Science Foundation, SBC PU 501-1045-01

This is an interdisciplinary collaborative project with Mechanical Engineering at Purdue University. The goals are to couple Monte Carlo device simulation of nanoscale devices with detailed phonon transport simulation, to understand thermal effects in ultrascaled integrated devices, and to formulate device design strategies to minimize heat generation.

**3-D Self-Consistent Simulation of Quantum Dot Spin Transistors of Quantum Information Processing**

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Semiconductor Research Corporation, 2003-NJ-1045

Conducted in the Beckman Institute for Advanced Science and Technology

This research concentrates on developing 3-D self-consistent computer tools for realistic simulation of spin operation in silicon quantum dot spin effects transistors in order to assess their feasibility and viability for applications in quantum information processing. We consider Si FET-device configurations similar to Kane's proposal to achieve a C-NOT gate. Our purpose is to obtain a coherent 3-D picture of the interdependence among physical parameters and device considerations for spin-qubit operations, and to provide design rules for optimizing the device.
Scalable Spin-Qubit Circuits with Quantum Dots
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Defense Advanced Research Projects Agency, QuIST program, DAAD19-01-1-0659
Conducted in the Beckman Institute for Advanced Science and Technology

This research is aimed at achieving a scalable elementary spin-qubit circuit for quantum computing that is based on the manipulation of electron spins in coupled III-V semiconductor quantum dots (QDs). We take advantage of the advanced technology for planar and lateral QDs AlGAs/GaAs heterostructures and the fact that the electron effective mass is small, which eases the conditions for quantum confinement. Moreover, III-V materials enjoy long spin coherence times, which is of utmost importance for preserving quantum information over many qubit operations. For this purpose, we have assembled an international research team involving the University of Basel, the University of Delft, Harvard University, Princeton University, and Tokyo University. Team members have complementary expertise in the physics of quantum computation and spintronics in nanostructures. These areas of expertise are fully integrated into a coherent and interactive effort, leading to the realization of an elementary qubit circuit.

Interactive Tools for Nanotechnology Education
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This project involves a multidisciplinary, multi-university team involving Northwestern University (lead institution), University of Illinois at Chicago, University of Illinois at Urbana-Champaign, Purdue University, and University of Michigan. One of the goals is to pursue research in education addressing the introduction of nanotechnology concepts at various school levels, from middle school to undergraduate programs. Our group is developing interactive simulation and visualization tools to explore new ways to introduce advanced concepts in the curricula.

Simulation of Charge Transport in Ionic Channels
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The well developed tools of computational electronics have been adapted to simulate ion transport in biological channels, treated as nanoscale natural devices. Continuum (drift-diffusion) and particle (Transport Monte Carlo) simulation approaches have been developed where interaction with the aqueous environment is resolved in terms of mobility or scattering rate. The goal of this work is to provide a scalable input-output description of natural nanopores for uses in bioelectronic sensor design. Artificial or biomimetic nanopores are also investigated with similar simulation tools, for the design of artificial membranes incorporating features of biological ones.

Simulation of Electro-Thermal Processes in MEMS and NEMS Structures
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Micro- and Nano-Electro-Mechanical Systems have reliability problems that are not easily addressed by trial-and-error experimental procedures. An attractive alternative is to develop multiscale multiphysics models to simulate and optimize structures but this is a very challenging multidisciplinary effort. In this project, we study the coupling between thermal and electrical processes to capture some of the essential failure mechanisms in MEMS/NEMS and consider the heterogeneous system, including metals, oxide, and semiconductor materials.

Simulation of Nanoscale Biological and Biomimetic Systems
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Simulation of ion charge transport in membranes is studied using various engineering simulation approaches, including continuum and particle models, to develop design methodologies for nanoscale systems. Physical approaches like classical and quantum molecular dynamics are relied on to provide first-principle calibration of
transport parameter for the engineering reduced order models. The goal of this multidisciplinary project is to create a software infrastructure to support the future design of biomimetic components for a variety of applications in nanomedicine, including implantable self-sustaining power sources and artificial organs.

**The Science and Technology of Nano/Molecular Electronics: Theory, Simulation, and Experimental Characterization**

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*Defense University Research Initiative on Nanotechnology, U.S. Army Research Office, SIT 527826-08*

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This project is part of a DURINT multi-university effort, with Stevens Institute of Technology as lead institution. The specific goals of this subcontract are to develop nanoelectronics simulation tools to understand the ultimate limits of silicon technology and explore new device concepts based on quantum effects. The emphasis of the work is on 3-D simulation and high performance parallel computing, using nonequilibrium Green’s function and Monte Carlo simulation approaches.

**Semiconductors**

**Ge-Sb-Te Phase Change Materials: Optical and Electronic Properties, Structural Transformations, and Fabrication of Nanostructures**

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*National Science Foundation, DMR-0412939*

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The properties of Ge-Sb-Te alloys and the rapid amorphous-crystalline phase change that they exhibit are being investigated using ellipsometry, optical absorption and reflection spectroscopy, photoconductivity, photoluminescence, electrical conductivity, Hall effect, high resolution TEM, and fluctuation electron microscopy. Specific problems include: optical, electronic, and structural characterization of sputtered thin films of the materials; the effects of composition, conditions of synthesis, thermal annealing, and optical or e-beam irradiation on their properties; detection and characterization of nano-crystallites in the amorphous phase and their role in the phase change mechanism; and the spatial limits/resolution of the phase change, aimed at fabricating quantum structures.

**Photoluminescence Studies of Semiconductor Nanostructures and Rare Earth-Doped Semiconductor Materials**

S. G. Bishop,* I. Adesida, J. J. Coleman
University of Illinois

Conducted in the Micro and Nanotechnology Laboratory

This research program applies photoluminescence (PL), photoluminescence excitation spectroscopy, time resolved PL, and PL imaging to the characterization of defects and impurities in bulk and epitaxial semiconductor materials, and the composition, doping, thickness, interfaces, uniformity, and quantum confinement effects in semiconductor nanostructures. Rare earth-doped semiconducting glasses and rare earth implanted GaN are being developed as sources of near- and mid-IR radiation. Excitation of the intra-4f shell emission from rare earth dopants (e.g. Er$^{3+}$, Pr$^{3+}$, Dy$^{3+}$) in chalcogenide glasses by broad band optical absorption in the Urbach edge of the host glass is under investigation as a novel optical pumping mechanism.

**High Quantum Efficiency Infrared Photodetector Arrays Based on Nanowire Heterostructures**

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Conducted in the Micro and Nanotechnology Laboratory

The goal of this project is to developed high quantum-efficiency, high color-contrast multi-wavelength quantum wire infrared photodetector (QWRIP) arrays. The QWRIP uses a self-assembly approach to create high-density nanoscale quantum wire structures that provide the basis for high quantum efficiency infrared detection. The QWRIP combines the best features of the quantum well infrared photodetector (QWIP) and quantum dot infrared photodetector (QDIP) to offer normal incidence absorption, high quantum efficiency, and adjustable infrared absorption from 8 to 40 μm. Unique polarization sensitive absorption properties of quantum wires enable two distinct quantum wire infrared detection layers (or a quantum wire layer and a quantum well layer) with different spectral responses to be monolithically integrated without interference, yielding excellent color contrast.

* Denotes principal investigator.
Center of Hyper-Uniform Nanophotonic Technologies for Ultra-Fast Optoelectronic Systems (HUNT Center)
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Defense Advanced Research Projects Agency, University Photonics Research Centers Program,  
HR0011-04-1-0034  
Conducted in the Micro and Nanotechnology Laboratory

The mission of the HUNT Center (Center of Hyper-Uniform Nanophotonic Technologies for Ultra-Fast Optoelectronic Systems) is the development of critical technologies, including hyper-uniform nano-photonic fabrication, high performance quantum dot vertical-cavity surface-emitting lasers, and ultra-fast light-emitting transistor-based lasers for the realization of ultra-fast (≥100Gb/s) optoelectronic interconnect systems. Center programs encompass semiconductor nanoscale materials growth, nano-patterning, nanoscale material analysis, nanostructure laser device design and fabrication, optical receiver design and fabrication, as well as high-speed optoelectronics integrated heterogeneously on a common semiconductor platform to perform ultra-fast optical interface functions.

GaAs-Based Metal-Oxide-Semiconductor Structures
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Conducted in the Micro and Nanotechnology Laboratory

The goal of this research program is to develop oxide deposition techniques for the fabrication of GaAs-based metal-oxide-semiconductor field effect transistors (MOSFETs). Various oxides, including SiO2, Al2O3, Ga2O3, and Ga2O3 are deposited on GaAs in an ultrahigh vacuum system at Bell Laboratories to form MOS structures. Researchers will characterize their structural, optical, and chemical properties through transmission electron microscopy, photoluminescence spectroscopy, and Auger electron spectroscopy, respectively, to improve the oxide deposition process.

Ultra-High-Speed Heterojunction Bipolar Transistors
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Semiconductor Research Corporation, SRC-2001-NJ-946  
Conducted in the Micro and Nanotechnology Laboratory

The goal of this research is to develop viable techniques that allow demonstration of Inp-based HBTs with fT>400GHz for insertion into the ultra-high-speed (>100 GHz) circuits.

VCSEL and Smart Pixel Research for VLSI Photonic Systems
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Defense Advanced Research Projects Agency,  
DAAG55-98-1-0303  
Conducted in the Micro and Nanotechnology Laboratory

The purpose of this research is to develop technology related to VLSI photonic systems. The scope of the program ranges from basic materials research, to the fabrication of large-scale integrated circuits, to advanced technologies for the integration of systems in heterogeneous materials. Goals of the project include the design, growth, fabrication, and testing of III-V semiconductor vertical cavity surface-emitting lasers; the development of smart pixels, circuits for the detection of optical signals, intelligent routing of the information, and re-emission of optical signals; and the development of techniques for the integration of heterogeneous materials.

Surface Engineering for Compliant Epitaxy
K. C. Hsieh,*  K.-Y. Cheng,*  I. Adesida  
Defense Advanced Research Projects Agency,  
F49620-98-1-0496  
Conducted in the Micro and Nanotechnology Laboratory

The goal of this research is to realize dislocation-free and stress-relaxed lattice mismatched epitaxy growth of different compound semiconductors on various substrates across the whole wafer or on selected areas for device integration applications. Our immediate goals include fundamental understanding of the growth conditions related to the formation of strained-modulated and defect-absorbing templates and the development of techniques to fully control the formation of strain-absorbing and deformable growth templates with an emphasis on processing simplicity and system integrability. InP-based optoelectronic and microwave devices will be integrated selectively on surface-engineered GaAs substrates.

* Denotes principal investigator.
Wafer Bonding for Advanced Optoelectronic Devices
K. C. Hsieh,* K.-Y. Cheng
Defense Advanced Research Projects Agency, MDA
972-00-1-0020

Conducted in the Micro and Nanotechnology Laboratory

The goal of this research is to develop wafer-bonding technologies for hybrid integrating mismatched device structures for advanced optoelectronic integrated circuits. The potential applications include fabricating high-performance visible LEDs, vertical-cavity-surface-emitting lasers, resonant-cavity photodetectors, 2-D and 3-D photonic crystals, and high-performance semi-insulating wafer substrates. Our current efforts are focused on developing high-efficient wafer-bonding strategy and fundamental understanding of the hybrid interface properties, including interface microstructures, electrical and optical characteristics, interface strain/stress and adhesion properties, and so forth. The long-term goals will include developing chip-scale photonic/electronic integration methodologies for high-density 3-D architectures.

ITR/SY: Foundations of Solid-State Quantum Information Processing
National Science Foundation, EIA-01-21568

The core of this program is an exploration of three distinct but related solid state technologies as candidates for quantum information processing: single spins on individual P-donors in silicon, ferromagnetic particles in close proximity to a superconductor, and superconductor phase electronics based on Josephson tunneling and SQUIDs. Supporting this effort will be a theory component that addresses key issues concerning the evolution and monitoring of quantum-entangled states and an experimental study of qubit dynamics using the highly developed techniques of modern quantum optics.

Biologically Inspired Artificial Haircell Sensors
C. Liu,* D. L. Jones, F. Delcomyn
U.S. Air Force Office of Scientific Research,
F49620-01-1-0496

Conducted in the Micro and Nanotechnology Laboratory

This work is aimed at developing artificial haircell sensors that are inspired by biological haircell sensors. This work is focused on studying the fundamental principles of neurological responses of haircells to develop micromachined devices that mimic the performance of biological entities.

CAD Design Tools for Millimeter-Wave Wireless Communication Microsystems
C. Liu,* M. Feng, S. M. Kang, E. Michielssen, J. Schutt-Ainé
Defense Advanced Research Projects Agency, Composite-CAD Program, F30602-97-0328

Conducted in the Micro and Nanotechnology Laboratory

A mixed technology computer-aided design system is being developed for the cost effective design of wireless communication modules that will ultimately enable networked distributed MEMS. The module, operating at millimeter-wave frequencies, will allow direct interface between MEMS transducers and the free-space electromagnetic radiation. MEMS components offer unique advantages for RF circuits. As an example, micromechanical switches exhibit lower insertion loss and higher isolation compared with conventional electronics switching components. MEMS fabrication technology for silicon and composed semiconductor materials is being studied in order to realize mechanical RF switches as well as high-gain antennas to validate results of the E-M simulation.

Integrated Sensitive Skin with Advanced Data Architecture
C. Liu,* N. Shanbhag, D. L. Jones
National Science Foundation, IIS 00-80639

Conducted in the Micro and Nanotechnology Laboratory

An interdisciplinary team of researchers will develop microfabricated, multiple modality sensor skin with advanced data structure and signal processing algorithms. A flexible sensor skin that imitates biological tactile sensors faces important challenges in terms of microfabrication, materials, density of sensors, and accompanying circuits. Prof. Liu and students will develop advanced multimodal sensors with self-configuration capabilities. Prof. Shanbhag is developing energy efficient signal processors, while Prof. Jones is interested in developing signal processing algorithms that are biologically inspired.

Controlled Coupling of Donor Atom Wavefunctions in Silicon
J. Tucker,* J. Kline, S. Robinson, T. C. Shen (Utah State Univ.)
U.S. Army Research Office, DAAD 19-00-1-0407

The goal of this project is to selectively place PH³ molecules onto the hydrogen-terminated silicon surface via STM lithography and overgrow them into the crystal

* Denotes principal investigator.
as phosphorous donors. If successful, this work could provide a means for constructing quantum computers based on control of ground-state wavefunctions on individual P-atom donors. Other potential applications include single-charge electronics, cellular automata, and nanometer-scale field-effect transistors. Reproducible characteristics are made possible by the large ~5nm Bohr diameter for individual donor bound states, so that coupling between nearest neighbors will be defined accurately if redistribution is limited to ~1nm or less during ultra-low-temperature overgrowth.

**Wavefunction Engineering of Individual Donors for Si-Based Quantum Computers**
J. Tucker,* M. Feng, Y. C. Chang, T. C. Shen (Utah State Univ.), R. R. Du (Univ. of Utah)
U.S. Army Research Office, 42257-PH-QC

The goal of this multi-investigator program is to develop the basic fabrication and measurement technologies needed to implement a silicon-based quantum computer. To do this, researchers must place individual phosphorous donors into the silicon lattice with atomic precision, establish electrical control over wavefunction overlap between donor-pairs, and successfully detect spin states of the resulting two-electron system by measuring the presence or absence of electronically-induced polarization. The research team does not propose working quantum logic gates within this three-year project. If successful, however, that goal will be undertaken in a follow-up program that incorporates SiGe overgrowth and patterning of individual top-gates for each P-atom donor.

**Signal and Image Processing**

**Directional Multiresolution Image Processing: Theory, Algorithms, and Applications**
M. N. Do,* Y. Lu, J. Zhou, A. Cunha
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National Science Foundation (CAREER Award)

This project seeks to develop new "true" two-dimensional representations that can deal more effectively with typical images having smooth contours. The focus is on the development of directional and multiresolution image expansions using nonseparable filter banks, in much the same way that wavelets were constructed from filter banks. In essence, the proposed research pursues nonseparable extensions of wavelets and multiresolution techniques so that they can capture the directional information—an important and unique feature of multidimensional signals. In parallel, newly developed image representations will be explored in a variety of applications, where substantial improvements over current methods are expected.

**Practical Compressed Sensing**
M. N. Do,* Y. Bresler
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National Science Foundation

Conducted in the Coordinated Science Laboratory

A recent breakthrough in mathematics under the name compressed sensing shows that sparse or compressible finite length discrete signals can be recovered from small number of linear, nonadaptive (i.e., universal), and random measurements. This project aims to extend the current methods in compressed sensing to other setups that have overwhelming practical significance. These extensions include constrained acquisition, additional statistical prior on sparse signals, and infinite dimensional cases. The specific goals of this project are to: improve signal reconstruction quality; reduce number of measurements required to achieve a specified reconstruction quality; speed up the reconstruction time; and demonstrate these gains on real applications, and in particular in challenging magnetic resonance imaging applications, including functional imaging of the human brain.

**Audiovisual Speech Recognition in Automotive Environment**
M. Hasegawa-Johnson,* T. S. Huang, S. Levinson
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Motorola, Inc.

Conducted in the Beckman Institute for Advanced Science and Technology

Speech recognition in an automobile is typically performed using a single microphone, often mounted in the sun-visor in front of the driver. With typical road noise, most recognizers generate too many errors for practical use. This research project experiments with speech recognition using multimodal recordings acquired by a visor-mounted array including eight microphones and four cameras. We focus on accurate visual face tracking lip feature extraction and robust audio noise cancellation. Our goal is to demonstrate that error rate of a multichannel audiovisual recognizer is much lower than error rate of a standard recognizer under automotive test conditions.

* Denotes principal investigator.
Landmark-Based Speech Recognition in Music and Speech Backgrounds
M. Hasegawa-Johnson*
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National Science Foundation, CISE 0132900
Conducted in the Beckman Institute for Advanced Science and Technology
Human listeners are able to recognize speech based on dynamic portions of the signal, even if all static portions are masked by noise or by background music. This research seeks to develop mathematical models capable of abstracting the perceptual response patterns of human listeners. Probabilistic auditory scene analysis uses cognitive stochastic automaton models, combined with use of dynamic Bayesian network methods, in order to imitate the ability of listeners to understand speech mixed with loud background music. Landmark-based speech recognition imitates the extra sensitivity of humans to dynamic as opposed to static signals.

Prosodic, Intonational, and Voice Quality Correlates of Disfluency
M. Hasegawa-Johnson,* J. Cole, C. Shih
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National Science Foundation
Conducted in the Beckman Institute for Advanced Science and Technology
Prosody is the stress and rhythm pattern of naturally spoken language. Linguists agree that the sound of a phoneme depends on its prosodic context, but experimental data describing the prosodic-phonemic interaction are only now becoming precise enough to support efforts in automatic speech recognition. Our research seeks to precisely describe the prosodic-phonemic interaction using both detailed phonetic analysis and probabilistic speech recognition models. This research has already succeeded in demonstrating, for the first time in the literature, that the use of prosody can lead to improved word recognition accuracy in a large-vocabulary speech recognition experiment.

Face Processing
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Yamaha Motor Corporation
Research Conducted at the Beckman Institute for Advanced Science and Technology
Researchers are developing methodologies and algorithms for 2-D and 3-D face analysis with applications in face detection, recognition, tracking, and animation. For analysis, we are particularly interested in outdoor scenarios where the illumination and head pose are highly varying. For animation, a major project is text- and speech-driven realistic synthetic talking faces.

Image and Video Databases
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Conducted in the Coordinated Science Laboratory and the Beckman Institute for Advanced Science and Technology
A number of challenging issues in image and video indexing and retrieval are being studied. Of particular interest are the following: similarity- and example-based retrieval, the use of relevance feedback from users to improve retrieval performance, and the recognition of semantic concepts in video based on multimodal cues.

Multimodal Human–Computer Interaction
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National Science Foundation, CCF 04-26627
Conducted in the Coordinated Science Laboratory and the Beckman Institute for Advanced Science and Technology
The term "human-computer interaction" is used in a broad sense to include communication between persons and computers as well as communication between persons mediated by computers. Researchers are investigating a variety of issues related to the use of computer vision and image processing in HCI, as well as the integration of vision, audio, and speech. Examples include visual human (body, face, hand) tracking and analysis, combining speech and visual hand tracking in manipulating virtual objects, audio-visual speech recognition in noisy environments, and audio-visual human emotion recognition.

Video Analysis
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Research conducted at the Coordinated Science Laboratory and Beckman Institute for Advanced Science and Technology
Researchers are using generative probabilistic models (GPM) to do video analysis. Tasks include stabilization, denoising, superresolution, segmenting video into layers, and video event retrieval based on examples. Applications

* Denotes principal investigator.
include online surveillance and monitoring, and offline
analysis using video archives.

Remote Reality: 4-D Audio-Visual Reconstruction and
Compression from Multiple Sensors
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National Science Foundation (ITR Grant)
This project develops new signal processing techniques for
reconstruction of the audio and visual recording at an
arbitrary location in space and time from multiple acoustic
and video sensors, but extending recent research in
adaptive beamforming, multisensor signal processing of
nonstationary signals, and fundamental new advances in
multidimensional signal representation. Practical four-
dimensional audiovisual recording, transmission,
playback, and remote reality will be demonstrated with
low-cost, conventional sensors attached to networked
computers, thus confirming the practicality of the proposed
methods and applications.

Soft Materials

Polymer Studies in Thin-Film Microelectronics
L. H. Allen,* M. Y. Efremov, E. A. Olsen, M. Zhang,
S. Zhang
ACS-PRF, 37027-AC7
Polymer material is used extensively in microelectronics
including nm thick resists (photoresist) for image
patterning and self-assembled monolayers (SAMs) thin
coating for microelectronics. It can also be used as an
active component in terabit/in² storage devices such as the
millipede where the thermal (at ultrafast heating rates)
properties of nanometer thick polymers (e.g., polystyrene
and PMMA) are of critical importance. We use a recently
developed MEMS device, the nanocalorimeter, to study
the thickness dependence of glass transition temperature in
ultrathin polymer films. This new technique is 1000 times
more sensitive than conventional DSC systems. Our
preliminary results show that it has the capability to
measure polymer films with thickness of only 1.5 nm.

Supercomputing Research and
Development

An Integrated Framework for Performance
Engineering and Resource-Aware Compilation
C. Polychronopoulos,* F. Breg, J. Brokshi, S. Carroll,
Y. Chen, A. Christensen, S. M. Chu, G. Clark, I. Cohen,
T. Courtney, D. Craig, D. Daly, D. D. Deavours,
S. Derisavi, J. Doyle, M. Drzal, X. Han, P. Hong,
T. S. Huang, Y. Huang, P. Kalogiannis, W. Ko,
C. Koopmans, F. Koopmans, A. Kulothungun,
V. V. Lam, D. J. Lin, J. Lin, K. Marukawa,
D. S. Nikolopoulos, N. Petrovic, H. Saito,
W. H. Sanders, N. Stavrakos, Q. Tian, J. Tu, P. Webster,
Y. Wu, M. Yankelevsky, H. Zhou, X. Zhou
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National Science Foundation, EIA 99-75019
This project developed a comprehensive and integrated
approach to application composition and development,
system and application modeling and evaluation,
performance characterization, compiler optimization, and
low-overhead runtime support. Achieving these
capabilities required fundamental advances in methods for
hierarchical, multilanguage modeling, simulation, and
evaluation, and techniques for adaptive, resource-aware
compilation and runtime support. We took a systematic and
synergetic approach to making these advances and
incorporated them into an integrated performance
engineering framework and resource-aware compilation
and runtime system. In addition, we demonstrated the use
of the integrated framework/system via application to
several important parallel and distributed multimedia,
video database, and computer vision applications.

Surfaces and Interfaces

Synthesis and Characterization of Nanostructured
Alloys with Enhanced Mechanical Properties
P. Bellon,* J. R. Abelson,* S. Jayaraman, A. Chaterjee
National Science Foundation, DMR 0354060; CECM-
Vitry (CNRS France)
This collaboration is to carry out synthesis and
characterization of nanostructured diborides of zirconium,
titanium, and chromium for super-hard coatings with low
friction coefficients and low wear rates. The following
areas are investigated: novel synthesis techniques, in
particular by CVD of mixed phase materials;
characterization of structure and defects in amorphous and

* Denotes principal investigator.
nanocrystalline films through advanced TEM techniques; and analysis of the friction and wear behavior using the driven systems approach as a theoretical framework. Our goal is to produce an improved understanding of how microstructure varies with stoichiometry, with transition metals, CVD conditions, and wear parameters.

**Systems and Control**

**Efficient Resource Management for Controlled-Mobility Wireless Networks**
frazzoli@uiuc.edu, neogi@uiuc.edu  
National Science Foundation, Information Technology Research Program, CCR-0325716

Today's embedded computers are increasingly mobile and ubiquitous, are capable of interacting with the environment, and can communicate with one another over possibly vast and pervasive networks. Mobile wireless networks are envisaged to revolutionize the way people and organizations will interact and communicate. While most of the wireless networks are not expected to be capable of controlling their own motion, new technological possibilities are emerging to provide small embedded devices with the means to propel themselves, with an energy expenditure that is comparable to the energy budget of communication and computation. Since the power required for propulsion typically decreases with the mass of the device, cheap mobility has the potential to dramatically impact the way networks of small, “smart” devices are designed and operated. We will call a network of embedded devices endowed with computation, communication, and motion capabilities a controlled-mobility wireless network. The purpose of this project, and its intellectual merit, are to be found in the development of a new conceptual framework for the design, development, and operation of efficient and reliable networks with such characteristics.

**Creating An Integrated Modular Environment for the Modeling, Analysis and Verification of Embedded Hybrid Systems**
N. Neogi,* B. Sanders  
neogi@uiuc.edu  
National Science Foundation, CCR-0311616

This project involves the development of an integrated modeling environment for the fast simulation and verification of systems that have both continuous and discrete components, such as air traffic control systems and biological systems. The modeling environment uses an abstract functional interface to allow a wide variety of modeling formalisms and solvers to be incorporated and leveraged throughout the simulation and verification process.

**Ensuring Safety and Security in Software Intensive Aerospace Systems**
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Boeing

Successfully building software for complex aerospace systems demands that qualities such as reliability, safety, security, and timing be rigorously addressed and systematically built into the software from the beginning. In addition, simply concentrating on initial development is not enough: These qualities must be preserved as the software evolves during its lifetime. Independent efforts to ensure individual qualities in narrow domains, i.e. safety, security, and reliability, have made significant progress. We are creating an approach that combines diverse techniques into an integrated methodology for developing and maintaining software for critical systems. Furthermore, the methodologies that are developed are designed to be readable, reviewable, and usable by parties other than the developers and can be incorporated into traditional techniques for increasing the quality of the software.

**Fast Scanning and Fast Image Reconstruction in Atomic Force Microscopy**
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Air Force Office of Scientific Research, FA9950-06-1-0252

This work addresses the challenges of high precision, high throughput and high bandwidth imaging. The approach is in two steps. The first step is to substantially increase the imaging throughput by closely packing an array of microcantilevers for sensing, which will image a large area of the sample in a parallel operation. This is in contrast to most current AFMs that use a single microcantilever to image the entire sample. In this context, the PIs propose a framework to model and analyze the dynamics of the closely packed microcantilever arrays, and develop new results in structures and distributed control for a control design that will conform to structural constraints, compensate electronically for the dynamic coupling between the components, and account for communication links between the subcontrollers in the design. The second

* Denotes principal investigator.
step is to develop numerical algorithms to construct high resolution images from the scan data (typically corrupted with noise and blurring effects) that are time and storage memory efficient. The aim of this step is to make real-time image construction from high throughput scan data possible. Toward this effort, we propose to develop fast algorithms that solve integral equations defined on irregularly (as opposed to rectangular) shaped domains, which model the scan data from most AFM applications. The accomplishment of the project goals will be mainly pursued from analytical and computational perspectives, but an experiment component will also be incorporated by using existing facilities to motivate and test theory.

Fast Simulation of Hybrid Biological Systems
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Pioneer Corporation

This project investigates techniques for the fast simulation of large discrete event systems that are prevalent in biological models. The research leverages hybrid modeling techniques that allow for the approximation of discrete interactions by continuous differential equations. Examples of current relevance, such as the biological toggle switch, are currently being studied.

Control of Spatio-Temporal Systems
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National Science Foundation

Many modern applications of controlling distributed systems pose spatial invariance. A typical example is a symmetric array of micromechanical systems, where many such devices are located according to some usually symmetric pattern. Using suitable extensions of the one-dimensional results, one can design optimal and robust controllers. However, the resulting control algorithms are, in general, centralized and impractical to implement. To alleviate this difficulty, a degree of decentralization is imposed on the controller, and algorithms are developed to optimize performance under such information-limiting constraints. The approach resorts to convex formulations of the underlying optimization.

Distributed Control for Large Telescopic Systems
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University of Illinois

In this project we study and develop distributed control methods for the primary mirror of large segmented telescopes. The aim is to determine the limits of imaging accuracy that can be achieved by the use of closed loop control of the individual mirror segments. Wind disturbances and structural couplings play a major role in limiting the position accuracy of such large structures. The main tools that we use in this study are recently developed robust control techniques for spatio-temporal systems.

Remote and Distributed Control over Networks
P. G. Voulgaris*
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National Science Foundation

Remote and distributed control over networks is a powerful concept that exploits the capabilities of the Internet (or any network) in order to remotely control critical tasks and complex dynamical interactions over long distances. The strategy of remote and distributed control also carries the great potential to lead to the development and deployment of new applications and technologies that can be very significant for the scientific and commercial worlds. Driven by the need for a systematic study of this concept, the research here aims at designing and developing novel algorithms, software, middleware, and prototypes for remote, real-time control of interacting complex systems over heterogeneous hierarchical networks built around the Internet backbone. A particular problem that is studied is the effect of decentralization and delayed information sharing in a networked system to the overall system performance.

Robust Communication
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National Science Foundation

The problem of reconstructing discrete valued signals is traditionally dealt with from a probabilistic point of view. In this project we develop a complementary, worst-case approach to this problem. The motivation comes from applications where security to malicious attacks is of paramount importance, and hence, hard performance guarantees are essential. The theoretical tools of optimal and robust control and filtering play a key role in this development. Connections to probabilistic approaches are also developed, and several trade-offs are analyzed in this new framework.

* Denotes principal investigator.
Structured Control and Application to Atomic Force Microscopy
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National Science Foundation

In this project the theory of optimal and robust design is developed when structural constraints are imposed on the controller architecture. Such constraints can be generated, for example, due to limited information exchanges among different local subcontrollers in a large and complex system. Although the general problem of optimal design with decentralized control is very hard to solve, there are certain specific classes of such problems that admit a convex formulation. Included are platoons of vehicles, MEMS, networked systems, congestion control, and integrated-based imaging where an array of microcantilevers is used to scan the sample. The speed and the accuracy of the scan depend crucially on the coordination of the microcantilevers, which in turn requires effective structured and distributed control algorithms.

Thermal Behavior of Materials

Development of MEMS Based Nanocalorimeter
L. H. Allen*
National Science Foundation, DMR-0108694 (Research);
NSF DMR-9803019 (Equipment); ACS-PRF #37027-AC7

Researchers are developing a new materials characterization technique that is potentially a very powerful method for directly obtaining quantitative values for small enthalpy of reactions at interfaces, surfaces, and near surface regions. This device operates at ultrafast heating ($10^5$ K/s) and scanning (1-scan/s) rates and is sensitive to nanometer thick films of material. This is a collaborative effort with the NNF facility at Cornell University (Ithaca, New York). To date we have achieved monolayer sensitivity, real-time in-situ characterization technique. Progress has been made not only in the fabrication of the device but also in quantitative techniques in analysis of heat capacity, or thermoelectrical characterization of the device.

Thin Films and Charged Particles

Epitaxial Growth and Characterization of GaN-Based Nitride Semiconductors Using Plasma-Assisted Molecular Beam Epitaxy for Development of High-Speed, High-Power Heterostructure Electronic Devices
K. Kim,* I. Adesida,* S. J. Hong, T. Day, C. W. Park
ETRI Electronics, Inc.

The dual objectives of this work are to grow and characterize device-quality heterostructure GaN-based films and use them to develop high-speed, high-power electronic devices. The materials growth is achieved using a plasma-assisted molecular beam epitaxy system designed and fabricated at the University of Illinois. The plasma source is capable of producing contamination-free nitrogen plasmas. The films are characterized using a variety of microanalysis techniques including RHEED, XRD, SEM, TEM, AFM, PL, CL, SIMS, and Hall measurement.

Nanowire and Nanotube Interconnect Technology for 3-D ICs
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Synchrotron Radiation Center

To improve on-chip interconnect performance beyond the 65 nm node, 3-D interconnects and nanotubes are investigated, with the focus placed on better understanding of their material properties, their compatibility with semiconductor processing techniques, and the development of macroscopic models to facilitate quantification of their impact on performance enhancement. The proposed research will be founded on novel processes for the growth of both vertical nanowires and carbon nanotubes along with a cross-disciplinary expertise in the areas of nanotechnology, novel materials synthesis, nanoscale chemical processing, and signal integrity-driven electromagnetic interconnect modeling and simulation.
Thin-Film Electronics

Ge-Sb-Te Phase Change Materials: Optical and Electronic Properties, Structural Transformations, and Nanostructures
National Science Foundation, NSF-DMR 04-12939

We synthesize and analyze the phase-change chalcogenide Ge$_2$Sb$_2$Te$_5$ and related alloys that are used as nonvolatile data storage media: they can be reversibly transformed from an amorphous semiconducting state to a crystalline semimetallic state, which dramatically changes the optical reflectivity (as employed in RW-CVDs) and electrical conductivity (as proposed for flash memory devices). The goals are to understand the relationship between nanostructure, transformation kinetics, and the resulting electronic properties.

Nanoscale Order in Amorphous Solids: Structure, Transformations, and Electronic Properties
J. R. Abelson,* S. N. Bogle, T. Li
National Science Foundation, DMR-06-05890

Conducted in the Frederick Seitz Materials Research Laboratory

This focused research group is a broad-ranging effort to understand nanometer-scale medium range order (MRO) in amorphous semiconductors and glassy materials, including its origins, structure, and electronic effects. We employ the fluctuation electron microscopy technique to evaluate whether solids that appear to be amorphous in diffraction in fact contain MRO. We have demonstrated that amorphous silicon cannot be described by the continuous random network model, but is paracrystalline, defined as the small grain size limit of nanocrystallinity. We are currently investigating the MRO in compounds, including chalcogenide glasses and transition metal diborides.

Investigation of Kinetics and Thermodynamics Properties During Reactions/Growth in Metal Systems in Devices: Silicides and W Deposition
L. H. Allen,* Z. Ma (Intel), D. Allman (LSI Logic Corp.)
Intel Corporation; LSI Logic Corporation
Conducted in the Frederick Seitz Materials Research Laboratory

Metallization plays an important role in state-of-the-art ULSI metallization process technology not only for S/D/gate contacts but also for interlayer interconnects. As device size decreases material challenges abound, including size-dependent silicide reaction and nanopipe diffusion paths for CVD W deposition. Using a new materials characterization tool, a nanocalorimetry, we are currently probing a model/metastable silicide system (Au/Si).

Cu(In,Ga)Se$_2$ Heterojunction Solar Cells for Extreme High-Efficiency Photovoltaic Concentrators
A. Rockett,* D. X. Liao, C. M. Mueller
National Renewable Energy Laboratory, U.S. Department of Energy, NREL AAT-1-30620-05

Conducted in the Frederick Seitz Materials Research Laboratory

The objective of this project is to demonstrate the potential for use of CuInSe$_2$ and related materials as the 1.00 eV energy-gap material in multijunction extremely high efficiency solar cells. Intermediate objectives include demonstration of solar cells based on p-CIS/n$^+$/GaAs and p-CIS/n-Ge heterojunctions as components of multijunction high-efficiency solar cell devices.

Next-Generation Processing Methods for Cu(In,Ga) Se$_2$ Heterojunction Solar Cells
A. Rockett,* A. Hall, D. Hebert

Conducted in the Frederick Seitz Materials Research Laboratory

A key goal of this research is to develop a low-temperature deposition process capable of producing device-quality chalcopyrite semiconductors for solar cell applications. This is an enabling technology for multijunction solar cells. To accomplish this, a unique next-generation method for low-temperature deposition of CIGS based on the ionized physical vapor deposition (IPVD) technique will be developed. IPVD has been shown to dramatically reduce required temperatures in other thin-film coatings. IPVD is a modified sputtering approach. It supplies energy to the growing film surface though the working gas rather than by heating the substrate.

Atomic-Scale Mechanisms of Crystal Growth
A. Rockett*
U.S. Department of Energy, DE-FG02-91ER45439
Conducted in the Frederick Seitz Materials Research Laboratory

This program seeks to improve understanding of the atomic-scale structure in thin films. The current focus is on point defects and their consequences for electronic

* Denotes principal investigator.
properties of semiconductors. The program includes both theoretical and experimental approaches based on density functional theory and physical vapor deposition, respectively.

**Tunneling Microscopy**

**Nanoelectronics: Low-Power, High-Performance Components and Circuits**


*U.S. Navy, ASUSG 98-152SG*

Conducted in the Beckman Institute for Advanced Science and Technology

This is a Multidisciplinary Research Program of the University Research Initiative (MURI) at the Beckman Institute with the goal of combining STM nanofabrication with atomistic simulations to develop novel nanoelectronic device structures on the atomic and molecular size scale. Techniques are being developed to fabricate and test these structures *in situ* in the UHV STM. This program also involves collaborations with Arizona State University, University of Notre Dame, and University of California at Berkeley, to explore new interconnect schemes for nanoelectronics and to interface nanoelectronic devices with conventional microelectronic circuits.

**Nanoscale Interface Characterization by UHV STM Spectroscopy**

J. W. Lyding,* L. Liu, J. Yu, J. Tolomei

*U.S. Office of Naval Research, N00014-00-1-0234*

Conducted in the Beckman Institute for Advanced Science and Technology

This research is focused on atomic scale dopant mapping and the determination of the rms roughness and correlation lengths associated with oxide-silicon interfaces. The substitution of deuterium for hydrogen at oxide-silicon interfaces is also being studied. It has been determined with modern scaling trends that deuterium becomes increasingly effective at reducing hot carrier degradation in CMOS technology.

**Protein Logic**


National Science Foundation, Nanoscale Interdisciplinary Research Teams

Conducted in the Beckman Institute for Advanced Science and Technology

This program seeks to integrate functional protein arrays with nanoscale CMOS on silicon. Natural and artificial ion channels are being utilized to interface between biology and silicon. Selective chemistry utilizing STM patterning is being used to fabricate the protein templates.

**Journal Articles**

**Advanced Automation**


* Denotes principal investigator.
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**Aeronomy**


**Artificial Intelligence: Machine Learning, Vision, and Robotics**


**Automotive Systems**


**Bioacoustics**


Circuits


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Yuksel, S. and Basar, T.  

**Digital Signal and Imaging Processing**

George, A. and Bresler, Y.  

George, A. K. and Bresler, Y.  

Xu, D., King, K. F., and Liang, Z. P.  


Dynamical Systems


Electromagnetic Communication and Electronics Packaging


Electromagnetics


Energy Systems and Thermodynamics

Genetic and Evolutionary Computation


High Frequency Devices


Materials Chemistry


Kumar, N., Yang, Y., Noh, W., Girolami, G. S., and Abelson, J. R. Titanium diboride thin films by low-temperature chemical vapor deposition from the single source precursor Ti(BH$_4$)$_3$(1,2- dimethoxyethane). *Chemistry of Materials, 19:*15, 3802-3807 (Jul. 2007) (http://dx.doi.org/10.1021/cm070277z).

Materials For Energy Systems


Nanoscience and Technology


Networking


Optical Imaging


Optical Physics and Engineering

Hafez, J. M., Gao, J., and Eden, J. G. Detection of weak (similar to 0.5-300 nT), low frequency (5-100 Hz) magnetic fields at room temperature by kilohertz modulation of the magneto-optical hysteresis in rare earth–iron garnet films [art. no. 132502]. *Applied Physics Letters, 90*:13, 32502 (Mar. 2007).


Zhu, C. J., Xiao, Y., Senin, A. A., Gao, J., and Eden, J. G. *Quantum beating in Rb at 18.3 THz (608 cm\(^{-1}\)) detected by parametric six-wave mixing and sum-frequency generation in LiIO\(_3\) [art. no. 053405]*. *Physical Review A*, 75:5, 3405 (May 2007).

**Power and Energy Systems**


**Product Development**


**Programming Languages, Formal Systems, and Software Engineering**


**Real-Time and Embedded Systems**


**Reliable and High-Performance Computing**


**Remote Sensing**


**Semiconductor Lasers**


**Semiconductors**


**Signal and Image Processing**


Surfaces and Interfaces


Systems and Control


Thin Films and Charged Particles


Thin-Film Electronics


Tunneling Microscopy


Albrecht, P. M. and Lyding, J. W. Local stabilization of single-walled carbon nanotubes on Si(100)-2 \times 1:H via nanoscale hydrogen desorption with an ultrahigh vacuum scanning tunnelling microscope [art. no. 125302]. *Nanotechnology*, 18:12, 25302 (Mar. 2007).


Book Chapters

Artificial Intelligence: Machine Learning, Vision, and Robotics


Control Systems

Networking


Operating Systems and Security


Programming Languages, Formal Systems, and Software Engineering


Papers Presented at Conferences and Symposia

Advanced Automation


Kumar, A., Ahuja, N., Hart, J. M., Vishes, U. K., Narayanan, P. J., and Jawahar, C. V. A vision system for monitoring intermodal freight trains. 7th Institute of Electrical and Electronics Engineers Workshop on Applications of Computer Vision (Austin, TX, Feb. 2007). Proceedings of the 7th Institute of Electrical and Electronics Engineers Workshop on Applications of Computer Vision 4118753 (2007) (http://dx.doi.org/10.1109/WACV.2007.9).

Algorithms and Theory

Artificial Intelligence: Machine Learning, Vision, and Robotics


Lim, S. H., Wang, L. L., and DeJong, G. Explanation-based feature construction. 20th International Joint Conference on Artificial Intelligence (Hyderabad, India, Jan. 2007).


Circuits


Communications


Lin, C., Raghavan, V., and Veeravalli, V. V. Optimal power allocation for linear dispersion codes over correlated MIMO channels with channel state feedback. 2007 Institute of Electrical and Electronics Engineers Global Communications Conference (Washington, DC, Nov. 2007).


Computer Architecture and Compilers


Computer Engineering


Construction Management


Control Systems


Decision and Control


Databases and Information Systems


Sharif, B. and Bresler, Y. **Adaptive real-time cardiac MRI using PARADISE: Validation by the physiologically improved NCAT phantom.** 4th Institute of Electrical and Electronics Engineers International Symposium on Biomedical Imaging: Macro to Nano (Arlington, VA, Apr. 2007). Proceedings of the 4th Institute of Electrical and Electronics Engineers International Symposium on Biomedical Imaging: Macro to Nano 1020-1023 (2007).


**Electromagnetics**


High Frequency Devices


Networking


Nahrstedt, K. **CA-AQM: Channel-aware active queue management for wireless networks.** IEEE International Conference on Communications (Glasgow, UK, Jul. 2007).

Nguyen, J. and Nahrstedt, K. **Attack containment framework for large-scale critical infrastructures.** International Conference on Computer Communication and Networking (Honolulu, HI, Aug. 2007).


**Nondestructive Evaluation and Testing**


**Operating Systems and Security**


David, F. M., Carlyle, J. C., and Campbell, R. H. *Context switch overheads for Linux on ARM platforms.* Workshop on Experimental Computer Science (San Diego, CA, Jun. 2007).


Singh, N. and Sreenivas, R. S. *On distributed algorithms that enforce proportional fairness in ad-hoc wireless networks.* 5th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (Limassol, Cyprus, Apr. 2007).

Optical Imaging


Optical Physics and Engineering


Power and Energy Systems


Programming Languages, Formal Systems, and Software Engineering

Chang, P. and Agha, G. Supporting reconfigurable object distribution for customized web applications. Association for Computing Machinery SIGAPP Symposium on Applied Computing (Seoul, South Korea, Mar. 2007).

Chang, P. and Agha, G. Towards context-aware Web applications. 7th International Federation for Information Processing International Conference on Distributed Applications and Interoperable Systems (Paphos, Cyprus, Jun. 2007).


### Real-Time and Embedded Systems


David, F. M., Carlyle, J. C., and Campbell, R. H. **Exploring recovery from operating system lockups.** USENIX Annual Technical Conference (Santa Clara, CA, Jun. 2007).

Kazman, R. and Agha, G. **Software technology track introduction.** 40th Hawaii International Conference on System Sciences (Waikoloa, Big Island, HI, Jan. 2007).


### Reliable and High-Performance Computing


Remote Sensing


Semiconductors


Signal and Image Processing


Fu, Y. and Huang, T. S. hMouse: Head tracking driven virtual computer mouse.  7th Institute of Electrical and Electronics Engineers Workshop on Applications of Computer Vision (Austin, TX, Feb. 2007). Proceedings of the 7th Institute of Electrical and Electronics Engineers Workshop on Applications of Computer Vision 4118759 (2007) (http://dx.doi.org/10.1109/WACV.2007.29).


Han, T. X., Liu, M., and Huang, T. S. A drifting-proof framework for tracking and online appearance learning.  7th Institute of Electrical and Electronics Engineers Workshop on Applications of Computer Vision (Austin, TX, Feb. 2007). Proceedings of the 7th Institute of Electrical and Electronics Engineers Workshop on Applications of Computer Vision 4118739 (2007) (http://dx.doi.org/10.1109/WACV.2007.4).


**Theses**

**Advanced Automation**


Aeronomy


Artificial Intelligence: Machine Learning, Vision, and Robotics


Astrodynamics


Bioacoustics


Circuits


Communications


Computer Architecture and Compilers

Computer Engineering


Control Systems


Databases and Information Systems


Decision and Control


Digital Signal and Imaging Processing


Electromagnetic Communication and Electronics Packaging


Electromagnetics


**High Frequency Devices**


**Human–Computer Interfaces**


**Materials Chemistry**


**Networking**


**Operating Systems and Security**


**Optical Physics and Engineering**


**Polymers**

Power and Energy Systems


Programming Languages, Formal Systems, and Software Engineering


Real-Time and Embedded Systems

Sun, M.  **Improving system design robustness by analyzing assumptions and dependencies.** M.S. thesis, L. R. Sha, advisor (2007).

Reliable and High-Performance Computing


Remote Sensing


Semiconductor Lasers


Semiconductors


Signal and Image Processing


Systems and Control


Tunneling Microscopy


Patents

Bioacoustics


High Frequency Devices


Optical Physics and Engineering


Power and Energy Systems


Awards and Honors

John R. Abelson
IBM University Partnership Award, 1995-1997
Fakultetsopponent (External Examiner), University of Linkoping, Sweden, 1995
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1996
Engineering Council Award for Excellence in Advising, University of Illinois, 1997
Incomplete List of Teachers Ranked as Excellent, University of Illinois, 2000, 2002
Fellow, American Vacuum Society, 2004

Ilesanmi Adesida
Scientific Member, Bohmische Physical Society
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Engineering Council Advisors List for Outstanding Advising, University of Illinois, 1993, 1999
Distinguished Lecturer, IEEE Electronic Device Society, 1977-1999
University Scholar, University of Illinois, 1997, 1999
Associate Member, Center for Advanced Study, 2000-2001

Vikram Adve
Best Paper Award, 15th Workshop on Parallel and Distributed Simulation, May 2001
C. W. Gear Outstanding Junior Faculty Award, University of Illinois Department of Computer Science, 2002
Associate Editor, ACM Transactions on Programming Languages and Systems, 2003-
Best Paper Award, Programming Language Design and Implementation, 2005

Gul A. Agha
Young Investigator Award, U.S. Office of Naval Research, 1989
Narendra Ahuja
Fellow, American Association for the Advancement of Science
Fellow, American Association for Artificial Intelligence
Fellow, Association for Computing Machinery
Fellow, Institute of Electrical and Electronics Engineers
Fellow, International Association for Pattern Recognition
Fellow, International Society for Optical Engineering
University Scholar, University of Illinois
Beckman Associate, University of Illinois Center for Advanced Study, 1990-1991
Associate, University of Illinois Center for Advanced Study, 1998
Donald Biggar Willet Professorship, University of Illinois College of Engineering, 1999
Incomplete List of Teachers Ranked as Excellent by Their Students, 2002

Leslie H. Allen
Racheff Professor of Materials Science, University of Illinois College of Engineering, 1991-1993

Andrew G. Alleyne
Outstanding Graduate Student Instructor Award, 1990-1991
Listed in Daily Illini "Incomplete List of Teachers Ranked as Excellent by Their Students," University of Illinois, Spring 1995; Fall 2004, 2006
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 1996
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 1998, 1999
Honorable Mention for paper (one of five finalist papers) at the Fourteenth International Federation of Automatic Control Congress, Beijing, Peoples' Republic of China, 1999
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2000
Best Paper Award, American Society of Mechanical Engineers International Mechanical Engineering Congress and Exposition, Fluid Power Systems and Technology Division, 2000
Who’s Who Among America’s Teachers, 2000
Accenture Award for Excellence in Advising, University of Illinois College of Engineering, 2001, 2003
Fulbright Fellowship, 2002-2003
College of Engineering Ralph M. and Catherine V. Fisher Professor, University of Illinois College of Engineering, 2002-2005
Student Best Paper Award, American Society of Mechanical Engineering International Mechanical Engineers Congress and Exposition, Dynamic Systems and Control Division, 2002
Best Paper Finalist (top 12 out of 150), 6th International Symposium on Advanced Vehicle Control, 2002
Ralph R. Teetor Educational Award, Society of Automotive Engineers, 2003
Distinguished Lecturer, Institute of Electrical and Electronics Engineers Control Systems Society, 2004-2007
Outstanding Young Investigator Award, American Society of Mechanical Engineers Dynamic Systems and Control Division, 2003
Invited Participant, National Academy of Engineering 19th Annual Symposium on Frontiers of Engineering, 2004
Fellow, American Society of Mechanical Engineers, 2005

Jont Allen
IBM Faculty Award, 2004
Honorable Mention, Campus Award for Innovation in Undergraduate Instruction, University of Illinois, 2005
Honorable Mention, Campus Award for Excellence in Graduate and Professional Teaching, University of Illinois, 2006
Teaching Excellence Award, University of Illinois College of Engineering, 2008
Defense Science Study Group, 2008-2010

Tamer Basar
Member, National Academy of Engineering
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, International Federation of Automatic Control (IFAC)
Member, European Academy of Sciences
Editor, JEEE Transactions on Automatic Control, 1992-1994
Nearing Distinguished Professor of Electrical and Computer Engineering, University of Illinois, 1998-
Zaborszky Lecturer, Washington University, St. Louis, 1999
IEEE Millennium Medal, 2000
President, IEEE Control Systems Society, 2000
Honorary Editor, J. Applied and Computational Mathematics, 2002-
Penner Distinguished Lecturer, University of California, San Diego, 2003
Editor-in-Chief, Automatica, 2004-
Tau Beta Pi Daniel C. Drucker Eminent Faculty Award, University of Illinois College of Engineering, 2004
Hendrik W. Bode Lecture Prize, IEEE Control Systems Society, 2004
Giorgio Quazza Medal, IFAC, 2005
Outstanding Service Award, IFAC, 2005
Professor, Center for Advanced Study, University of Illinois, 2005-
Richard E. Bellman Control Heritage Award, American Automatic Control Council (AACC), 2006
Editor-in-Chief, IEEE Expert Now, 2007
Swanlund Endowed Chair, University of Illinois, 2007
Honorary Doctorate (Doctor Honoris Causa), Dogus University, Istanbul, Turkey, 2007

Carolyn L. Beck
Alcoa Foundation Award, 1997
Junior Faculty Award, Oak Ridge Associated Universities, 1997
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 1998-2002

Young Investigator Award, Office of Naval Research, 2001-2004
Accenture Outstanding Advisor Award, 2004, 2005

Jennifer Bernhard
New Faculty Fellow, Sloan, 1997
Faculty Fellow, NASA-ASEE, 1999, 2000
Collins Scholar, University of Illinois College of Engineering, 2000
Senior Member, Institute of Electrical and Electronics Engineers (IEEE), 2001
Willett Faculty Scholar Award, University of Illinois College of Engineering, 2002-2005
Accenture Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 2004
H. A. Wheeler Applications Prize Paper Award, IEEE Antennas and Propagation Society, 2004

Stephen G. Bishop
Fellow, American Association for the Advancement of Science
Fellow, American Physical Society
Fellow, Optical Society of America
Board of Trustees, Gettysburg College, 1992-2006

Richard Blahut
Member, National Academy of Engineering, 1990
Fellow, IBM, 1980
Fellow, Institute of Electrical and Electronics Engineers (IEEE), 1981
Fellowship, Japan Society for the Promotion of Science, 1982
Henry Magnuski Professor, University of Illinois Department of Electrical and Computer Engineering, 2000
Alexander Graham Bell Medal, IEEE, 1998
Claude E. Shannon Award, IEEE, 2005

Yoram Bresler
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Technion Fellowship, 1995-1996
University Scholar, University of Illinois, 1999
Associate, University of Illinois Center for Advanced Study, 2001-2002

Donna J. Brown
Outstanding Young Woman of America, 1984

David Cahill
Fellow, American Vacuum Society
Peter Mark Memorial Award, American Vacuum Society, 1998
University Scholar, University of Illinois, 2000-2003
Willett Faculty Scholar Award, University of Illinois, 2002-2004
Fellow, American Physical Society, 2005
Donald B. Willett Professor of Engineering, University of Illinois, 2005-2010

Roy H. Campbell
Senior Visiting Research Fellowship at University of Newcastle upon Tyne, Science and Engineering Research Council of Great Britain, 1981-1983
Information Technology Committee, Illinois Terrorism Task Force, 2002-2003
Sohaib and Sara Abbasi Professor in Computer Science, University of Illinois, 2004-
Fellow, Institute of Electrical and Electronics Engineers (IEEE), 2005

Andreas Cangellaris
Fellow, Institute of Electrical and Electronics Engineers (IEEE)

Deming Chen
Most downloaded article from *IEEE Transactions on CAD, “Power Modeling and Characteristics of Field Programmable Gate Arrays,”*, 2006
Strathmore’s *Who’s Who*, 2007
Arnold O. Beckman Research Award, University of Illinois at Urbana-Champaign, 2007

Keh-Yung Cheng
Fellow, Institute of Electrical and Electronics Engineers (IEEE), 2001
Fellow, American Association for the Advancement of Science (AAAS), 2004
Ministry of Education Distinguished Visiting Chair Professor, National Tsing-Hua University, Hsinchu, Taiwan, 2003-2004

Yun Chiu
CalView Teaching Fellow Award, University of California College of Engineering, 2003
Jack Kilby Outstanding Student Paper Award, International Solid-State Circuits Conference, 2005
Chunhui Award for Foreign Visiting Scholars, China's Ministry of Education, 2006

James J. Coleman
Fellow, American Association for the Advancement of Science
Fellow, American Physical Society
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, Optical Society of America
IEEE LEOS William Streifer Scientific Achievement Award
Franklin Woeltge Professorship, University of Illinois Electrical and Computer Engineering Department, 2002

Gerald DeJong
Faculty Assistant Grant, Exxon Mobil Corporation, 1982
Arnold O. Beckman Research Award, University of Illinois Research Board, 1984
Faculty Recognition Grant, Alcoa Foundation, 1989
Fellow, American Association for Artificial Intelligence, 1992
International Scientist of the Year, International Biographical Centre, 2001
Accenture Award for Excellence in Advising, University of Illinois College of Engineering, 2007

Minh Do
Fellow, Center for Advanced Study, University of Illinois, 2006
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2003
Best Paper Award at the Institute of Electrical and Electronics Engineers (IEEE) International Conference on Acoustics, Speech, and Signal Processing, 2005
Most Innovative Paper Award, IEEE International Conference on Image Processing, 2006
Incomplete List of Teachers Ranked as Excellent, 2006
IBM Paper Award, IEEE International Conference on Image Processing, 2007

Geir E. Dullerud
National Sciences and Engineering Research Council of Canada Initiation Grant, 1996
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 1999
Willett Faculty Scholar Award, University of Illinois College of Engineering, 2002-2008
Listed in *Daily Illini* “Incomplete List of Teachers Ranked as Excellent by their Students,” University of Illinois, Fall 2004

Xerox Award for Faculty Research, University of Illinois College of Engineering, 2005

Fellow, Institute of Electrical and Electronics Engineers, 2007

**J. Gary Eden**
Fellow, American Physical Society
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, Optical Society of America
Associate, University of Illinois Center for Advanced Study, 1987-1988
Board of Governors, IEEE Lasers and Electro-Optics Society, 1990-1993
Associate Editor, *Photonics Technology Letters*, 1990-1994
Vice President (Technical Affairs), IEEE Lasers and Electro-Optics Society, (LEOS), 1993-1995
Editor, *IEEE Journal of Selected Topics in Quantum Electronics*, 1996
James F. Towey University Scholar, University of Illinois, 1996-1999
President, IEEE Lasers and Electro-Optics Society (LEOS), 1998
IEEE Third Millennium Medal, 2000
Faculty Advisors List, University of Illinois College of Engineering, 2001, 2004
Awards Chair, IEEE LEOS, 2003, 2004
Distinguished Lecturer, IEEE LEOS, 2003-2005
Aron Kressel Award, Institute of Electrical and Electronics Engineers Lasers and Electro-Optics Society, 2005

**Milton Feng**
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, Optical Society of America
Associate Member, University of Illinois Center for Advanced Study, 1998
Nick Holonyak, Jr. Professorship, University of Illinois, 2000-2005
Best Student Paper Award, International GaAs Manufacturing Conference, 2003

**Steven J. Franke**
Senior Member, Institute of Electrical and Electronics Engineers

**Chester S. Gardner**
Fellow, American Association for the Advancement of Science
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, Optical Society of America
CEDAR Prize Lecture, National Science Foundation, 1996

**Carl A. Gunter**
Best Paper Award, Fourth International Conference on Requirements Engineering, 2000
Editor, *Journal of Computer Security*, November 2004

**Christoforos Hadjicostis**
Fellow, Josephine de Karman
Fellow, National Semiconductor Corporation
Fellow, Grass Instrument Company
Recognized Reviewer of Institute of Electrical and Electronics Engineers (IEEE) *IEEE Transaction on Automatic Control*, 2001
Faculty Outstanding Teaching Award, University of Illinois Electrical and Computer Engineering Department, 2003
Engineering Council Award for Excellence in Advising, University of Illinois College of Engineering, 2004
Willett Faculty Scholar, University of Illinois College of Engineering, 2005
Senior Member, IEEE, 2005

**Bruce Hajek**
Member, National Academy of Engineering
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Beckman Associate, University of Illinois Center for Advanced Study, 1984
University Scholar, University of Illinois, 1986
Fellow, J. S. Guggenheim Foundation, 1992
President, IEEE Information Theory Society, 1995
Koji Kobayashi Computers and Communications Award, IEEE, 2003

**Mark Hasegawa-Johnson**
Senior Member, Institute of Electrical and Electronics Engineers (IEEE)
Thomas S. Huang
Member, National Academy of Engineering
Foreign Member, Chinese Academy of Engineering
Foreign Member, Chinese Academy of Sciences
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, International Association of Pattern Recognition
Fellow, Japan Society for the Promotion of Science
Fellow, Optical Society of America (SPIE)
Fellow, The International Optical Society
Fellow, J. S. Guggenheim Foundation, 1971
Associate, University of Illinois Center for Advanced Study, 1990
University Scholar, University of Illinois, 1990
Fujitsu Endowed Chair Visiting Professor, University of Tokyo, 1993
William L. Everitt Distinguished Professor, University of Illinois, 1996-
Peter H. Bartels Visiting Professor, University of Washington, 1997
Center for Advanced Study Professor, University of Illinois at Urbana-Champaign, 2003-
IEEE Third Millennium Medal, 2000
IEEE Jack Kilby Medal, 2001
King-Sun Fu Prize, International Association Pattern Recognition, 2002
IBM Faculty Award, 2003, 2007
Tau Beta Pi Daniel Drucker Eminent Engineering Faculty Award, University of Illinois College of Engineering, 2005
Okawa Award for Information and Telecommunication Technology, 2005
Scientist of the Year Award, Society for Imaging Science and Technology and SPIE Electronic Imaging, 2006
Honorary Chair, IEEE Conference on Multimedia and Exhibition, 2006

Wen-Mei Hwu
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Certificate of Appreciation, for Service as Both General and Program Chair for the Silver Anniversary MICRO Conference, IEEE Computer Society
Fellow, Association of Computing Machinery
Intel Associate Professor, University of Illinois Electrical and Computer Engineering Department, 1992-1993
University Scholar, University of Illinois, 1994

Franklin W. Woeltge Professorship, University of Illinois Electrical and Computer Engineering Department, 2000
Computerworld Medal Honors, 2002
Sanders III Advanced Micro Devices, Inc. Endowed Chair, University of Illinois Electrical and Computer Engineering Department, 2003
IEEE Micro's Top Picks, Microarchitecture Conference, 2005

Ravishankar K. Iyer
Fellow, Association for Computing Machinery
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, American Association for the Advancement of Science
Associate Fellow, American Institute of Aeronautics and Astronautics
Distinguished Visitor, IEEE, 1989-
Distinguished Service Certificate, American Institute of Aeronautics and Astronautics, 1997
George and Ann Fisher Distinguished Professor, University of Illinois College of Engineering, 1998-

Douglas L. Jones
Fulbright Fellowship, 1987
Fellow, Institute of Electrical and Electronics Engineers

Ralf Koetter
Co-Editor-in-Chief, Special Issue of the IEEE Transactions on Information Theory
Associate Editor, IEEE Transactions on Communications, 1999-2000
Associate Editor, IEEE Transactions on Information Theory, 2000-
Incomplete List of Teachers Rated Excellent, University of Illinois, 2000
Collins Scholar, University of Illinois, 2000
Willet Faculty Scholar, University of Illinois, 2002

Philip T. Krein
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
William E. Newell Power Electronics Award, IEEE
Grainger Endowed Director's Chair in Electric Machinery and Electromechanics
Grainger Associate, University of Illinois Department of Electrical and Computer Engineering, 1995-2002
Past President, IEEE Power Electronics Society
University Scholar, University of Illinois, 1999-2002
Division II Director, IEEE
Distinguished Lecturer, IEEE Power Electronics Society, 2005-2007

P. R. Kumar
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Member, National Academy of Engineering
Franklin W. Woeltge Professor of Electrical and Computer Engineering, University of Illinois, 2000-
IEEE Field Award, Control Systems
Fred W. Ellersick Prize, IEEE Communications Society
Donald P. Eckman Award, American Automatic Control Council

Jean-Pierre Leburton
Member, New York Academy of Science
Fellow, American Association for Advancement of Science
Fellow, American Physical Society
Fellow, Electro Chemical Society
Fellow, Institute of Electrical and Electronics Engineers
Fellow, Optical Society of America
Associate, University of Illinois Center for Advanced Study
Hitachi Ltd. Quantum Materials Chair, Research Center for Advanced Sciences and Technology, University of Tokyo, 1992
Chevalier Dans L’Ordre Des Palmes Academiques, 1994
King Albert II of Belgium, Round Table on the “Mobility of European Research Scientist” European Science and Technology Commission, 2001
Inaugural Montefiore Distinguished Lecture, Penn State University, 2002
Gregory Stillman Professor in Electrical and Computer Engineering, University of Illinois College of Engineering, 2004
Gold Medal for Scientific Achievement, 75th Anniversary of the Alumnus Association of the University of Liege, Belgium, 2004
Quantum Devices Award, Outstanding Achievement in the Area of Compound Semiconductor Research, 2004

Stephen Levinson
Fellow, Acoustical Society of America
Fellow, Institute of Electrical and Electronics Engineers

Zhi-Pei Liang
University Scholar Award

Beckman Fellow, University of Illinois Center for Advanced Study, 1997
Henry Magnuski Scholar, University of Illinois College of Engineering, 1999

Daniel Liberzon
Young Author Prize, International Federation of Automatic Control, 2002

Liang Y. Liu
Scholar, W. E. O'Neil Faculty, University of Illinois College of Engineering, 2002-2006
Teaching Award, University of Illinois College of Engineering, 2003

Michael C. Loui
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
University Distinguished Teacher/Scholar
Carnegie Scholar, Carnegie Foundation for the Advancement of Teaching
Executive Editor, College Teaching, 2006

Joseph W. Lyding
IBM Postdoctoral Fellow, 1983
Beckman Fellow, University of Illinois Center for Advanced Study, 1987-1988
Associate, University of Illinois Center for Advanced Study, 1996-1997
Fellow, American Physical Society, 1997
University Scholar, University of Illinois, 1997
Fellow, American Vacuum Society, 2000

Jonathan Makela
Editors' Citation for Excellence in Refereeing for Geophysical Research Letters, 2005
Associate Editor, American Geophysical Union, Geophysical Research Letters, 2007-
National Research Council Post-Doctoral Research Fellowship, 2002-2004
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2007
Incomplete List of Teachers Ranked as Excellent by Their Students, 2006

Sean Meyn
Fulbright Research Scholar for Research on Optimization and Network Scheduling, 1997
Pierre Moulin
Associate Editor, Institute of Electrical and Electronics Engineers (IEEE) *IEEE Transactions on Information Theory*, 1996-1998
Incomplete List of Teachers Ranked as Excellent by Their Students, 1996, 1999, 2000, 2005
Associate Editor, *IEEE Transactions on Image Processing*, 1999-
Area Editor, *IEEE Transactions on Image Processing*, 2002-
University of Illinois Center for Advanced Study, 2003
IEEE Fellow, 2003
Founding Editor-in-Chief, *IEEE Transactions on Information Forensics and Security*, 2005-
Board of Governors, IEEE Signal Processing Society, 2005-
Sony Faculty Award, 2005

Klara Nahrstedt
Weierstrass Prize, Weierstrass Institute of Mathematics, Berlin, 1985
Faculty Early Career Development Program (CAREER) Award, National Science Foundation (NSF), 1996
NASA Space Act Award, NSF, 1996
Xerox Award for Junior Faculty Research, University of Illinois College of Engineering, 1998
C. W. Gear Faculty Award, University of Illinois Department of Computer Science, 1999
Best Tutorial Paper Award, Institute of Electrical and Electronics Engineers (IEEE), for "A Control-based Middleware Framework for Quality-of-Service Adaptation," 2000
Campus Award for Innovation in Undergraduate Instruction Using Educational Technologies, University of Illinois, 2000
Editorial Board, *Journal on Multimedia Applications and Tools*, 2000-
Associate Editor, *ACM Computer Communications Reviews*, 2000-
Editor-in-Chief, *ACM Multimedia Systems Journal*, 2001-
Ralph M. and Catherine V. Fisher Professorship, University of Illinois College of Engineering, 2002-
Service Award, Association for Computing Machinery (ACM), 2006, 2007
Chair, ACM SIG Multimedia, 2007

David Nicol
Marion and Jason Whiting Fellowship, Oxford University, 2000
Fellow, Institute of Electrical and Electronics Engineers
Fellow, Association for Computing Machinery (ACM), 2006
Best Paper Award, IPSI Studenica Conference, 2004
Distinguished Contributions Award, ACM SIGSIM, 2007

Michael L. Oelze
Fellow, National Institute of Health Post-Doctoral Research, 2002-2004

Janak H. Patel
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, Association of Computing Machinery
Donald Biggar Willet Professor, University of Illinois College of Engineering, 1999

Constantine D. Polychronopoulos
Board of Directors, Association for Computing Machinery SIGARCH
Editor, *International Journal of High-Speed Computing*, 1989-
Mitsubishi Endowed Professorship, University of Tokyo, 1993

Umberto Ravaioli
Fellow, Institute of Physics, 1999
Fellow, Institute of Electrical and Electronics Engineers, 2003

Angus A. Rockett
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1992
Everett Teaching Award, University of Illinois College of Engineering, 1993
Fellow, American Vacuum Society, 1998
Donald Burnett Teacher of the Year Award, University of Illinois Materials Science and Engineering Department, 1998
Stanley H. Pierce Award, University of Illinois College of Engineering, 2002
Knight of St. Patrick, University of Illinois College of Engineering, 2007
Elyse Rosenbaum
Best Student Paper Award (co-author, faculty advisor), Electrical Overstress/Electrostatic Discharge Symposium, 2003
Bliss Faculty Scholar Award, University of Illinois, 2005
IBM Faculty Award, 2006

William Sanders
Fellow, Institute of Electrical and Electronics Engineers
Fellow, Association for Computing Machinery (ACM)
Elected Member, IFIP Working Group 10.4 on Dependable Computing
Member, Sigma Xi
Member, Eta Kappa Nu
Member, Motorola Research Visionary Board (RVB), 2005
Member, Advisory Board for the Computational Sciences and Engineering Division (CSED) for Oak Ridge National Laboratory, 2005
Elected Member, Board of Directors, ACM Sigmetrics, 2001-2003, 2005-2007
Incomplete List of Teachers Ranked as Excellent by Their Students, University of Illinois, 2002, 2003
Donald Biggar Willett Professor of Engineering, University of Illinois College of Engineering, 2005

Dilip V. Sarwate
Fellow, Institute of Electrical and Electronics Engineers (IEEE)

Peter W. Sauer
Member, National Academy of Engineering
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
U.S. Air Force Meritorious Service Medal, 1993
Honorary Professional Degree in Electrical Engineering, University of Missouri-Rolla, 1995
Academy of Electrical Engineering, University of Missouri-Rolla, 1996
Outstanding Electrical Engineer Award, Purdue University, 2004
Grainger Chair Professor of Electrical Engineering, University of Illinois, 1998-2006
IEEE Third Millennium Medal, 2000

Lui Sha
Fellow, Institute of Electrical and Electronics Engineers
Associate Editor, International Journal of Real-Time Systems, 1992-

Mark W. Spong
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Phi Beta Kappa
Visiting Professor, Catholic University, Leuven, Belgium, 1997
Editor, IEEE Transactions on Control Systems Technology, 1997-2000
Visiting Professor, National University of Singapore, 1999
Engineering Council Advisors List for Outstanding Advising, University of Illinois, 1999, 2005
Senior U.S. Scientist Research Prize, Alexander von Humboldt Foundation, Germany, 1999
Visiting Professor, Technical University of Munich, 2000
Vice President for Publications, IEEE Control Systems Society, 2000-2002
IEEE Third Millennium Medal, 2000
Southwest Mechanics Lecture Series Distinguished Speaker, 2001
Donald Biggar Willett Professor of Engineering, University of Illinois, 2003
John R. Ragazzini Control Education Award, American Automatic Control Council, 2004
President, IEEE Control Systems Society, 2005

R. S. Sreenivas
Research Initiation Award, National Science Foundation, 1994

John Tucker
Senior Member, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, American Physical Society
Nitin Vaidya
Distinguished Visitor Program Speaker, Institute of Electrical and Electronics Engineers (IEEE) Computer Society, 1998-2001
Best Paper Award, The Eighth International Conference on Personal Wireless Communications (PWC), Venice, 2003
Editor-in-Chief, ACM SIGMOBILE Mobile Computing and Communications Review (MC2R), 2003-2004
Editor-in-Chief, IEEE Transactions on Mobile Computing, 2005-

Venu Veeravalli
Beckman Associate, University of Illinois Center for Advanced Study, 2002-2003
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2003
Fellow, Institute of Electrical and Electronics Engineers (IEEE), 2006
Keynote Speaker at the International Workshop on Wireless Ad Hoc and Sensor Networks, 2006
IEEE Signal Processing Society Young Author Best Paper Award, 2006
Plenary Speaker at the IEEE Communication Theory Workshop, 2007
List of Teachers Ranked as Excellent by their Students, 2007

Pramod Viswanath
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2003

Petros G. Voulgaris
Research Initiation Award, National Science Foundation, 1993
Young Investigator Award, U.S. Office of Naval Research, 1995
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1996

Benjamin W. Wah
Fellow, American Association for the Advancement of Science (AAAS)
Fellow, Association for Computing Machinery
Fellow, Institute of Electrical and Electronics Engineers (IEEE)
Fellow, Society for Design and Process Science
University Scholar, University of Illinois, 1989
IEEE Distinguished Visitor, 1989-1992
Fujitsu Visiting Chair Professor on Intelligence Engineering, University of Tokyo, 1992

Editor in Chief, IEEE Transactions on Knowledge and Data Engineering, 1993-1996
Associate Editor-in-Chief, Information Sciences, 1993-
McKay Visiting Professorship, University of California, Berkeley, 1994
Second Vice President, IEEE Computer Society, 1998
First Vice President Elect, IEEE Computer Society, 1998
Robert T. Chien Professor of Electrical and Computer Engineering, University of Illinois, 1999-2003
IEEE Third Millennium Medal, 2000
President, IEEE Computer Society, 2001
Sun Yun-suan Honorary Chair Professor, National Tsinghua University, 2002
Raymond T. Yeh Life Time Achievement Award, Society for Design and Process Science, 2003
Franklin Woeltge Professor of Electrical and Computer Engineering, University of Illinois, 2004-
First Prize, Suboptimal Temporal Metric Track, Fourth Intel Planning Competition, 2004
Best Paper Award, IEEE International Conference on Tools for Artificial Intelligence, 2005

Martin Wong
IBM Faculty Award, 2000, 2004
David Bruton Centennial Professor in Computer Sciences, University of Texas at Austin, 2001
Best-of-20-Years ICCAD Paper, 2002
IEEE Distinguished Lecturer, Institute of Electrical and Electronics Engineers, 2005-