## The Institute for Systems Research

# 1996 Annual Report




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and Industry

## From the ISR Director

I am very proud of the success and distinction of the ISR over the past five years; these have been the result of vision, creativity, and hard work by the faculty, staff, students, and industrial partners. The ISR and its faculty and students have continued to receive recognition for their outstanding research program. Our successful recent research programs include the NASA-funded Center for Satellite and Hybrid Communication Networks, the new Advanced Telecommunications and Information Distribution Research Program funded by the Army Research Laboratory, and the program in semiconductor manufacturing funded by a supplemental grant from NSF. After a major strategic planning effort and success in an open competition, the ISR was re-established as an NSF Engineering Research Center, and we are in the process of transitioning to "self-sustaining ERC" status within the NSF ERC program.

I feel great pride in the quality of our education programs and the recognition they have received. Our comprehensive education program was highlighted both in the NSF publication "Highlights of Engineering Research Centers Education Programs" and in the 1994-1995 Annual Report of NSF to the President of the United States. Our Master of Science in Systems Engineering has increased in size and quality and has become a strong and vibrant academic program. The Master of Engineering in Systems Engineering, designed for the practicing engineer, began in 1995. This year, the ISR offered a series of short courses, developed from critical elements of the MSSE courses, for engineers at NASA/Goddard. At the undergraduate level, we are launching the ambitious and pioneering Gemstone program. I am delighted that we have continued to receive NSF funding for our summer Young Scholars Program for high school students.

Our Industrial Partnerships program has grown significantly, and has recently included the addition of such companies as Advanced Micro Devices, Silvaco, TD Technologies, and Bentley Systems. We have continued to work closely with our Sustaining Partners, Northrop Grumman and Lockheed Martin, and I am grateful for their support. ISR research is increasingly having a significant impact in industry, and our students are highly sought after by companies. For example, projects with industry involving ISR faculty have won a number of "best project" awards from the Maryland Industrial Partnerships Program.

I feel privileged to have been able to work with the ISR community to continue to make the ISR the dynamic and exciting organization that it has become. I look forward to working with the new Director to meet the challenges and opportunities facing the ISR and to maintain its excellence and leadership in research, in education, and in industrial collaboration.

**—Steven I. Marcus, Director 1991–1996**

*Dr. Gary W. Rubloff was appointed the Institute's Director in August 1996. Dr. Rubloff also holds a joint appointment with ISR and the Department of Materials and Nuclear Engineering.*

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# Vision

The mission of the Institute of Systems Research is to develop the fundamental knowledge and tools necessary for the integration of heterogeneous systems. The fulfillment of this mission is of critical importance to the global competitiveness of U.S. industry and during the past year, the ISR has made significant strides in advancing those objectives.

ISR research is driven by the present and future needs of U.S. industry. The ISR works with a wide range of industrial partners, to jointly identify future critical systems level research issues. A clear need has emerged for methodologies and tools that facilitate the integration of diverse technologies into better products and processes, as well as for cross-disciplinary education programs to fulfill the need for engineers who can understand and apply these advances in industry.

Systems challenges for industry over the next decade will arise in domains that include consumer products, manufacturing processes ranging from electronic materials processing to machining and very large scale systems such as flexible factories and communication networks. These systems will share a number of significant characteristics. They will be systems that change over time and for which there are critical time constraints. They will be modular and spatially distributed; increasingly complex functionality will be expected from them. They will incorporate many different technologies.

In short, engineers will be designing and controlling heterogeneous systems—systems that consist of diverse components and involve diverse technologies, but that must be made to work together in an efficient and cost-effective manner. For example, communication networks are composed of satellites, mobile users, fiber networks, receivers, transmitters, computers and databases—all of which must be managed or controlled to insure seamless operation. Systems for microelectronics manufacturing will include chemical and physical processes, temperature sensors, gas analyzers, wafer state sensors, electromechanical mass flow controllers, computers, software and databases, all of which will be connected into a network. In order to meet future requirements, such systems must be integrated—that is, their components must be combined into a coherently functioning and unified whole.

The key technical issues in the integration and management of complexity in heterogeneous systems are best framed in terms of **control, communication and computing**. These fields have traditionally provided the appropriate language for studying systems, through concepts such as representations of signals, systems, information and related data structures—and now we believe these fields will provide similar tools for heterogeneous systems. Real time constraints and requirements for high performance over time point to the need for control. Signal processing and communication methodologies underlie the processing and understanding of sensed signals; however, sensing and signal processing must be integrated with control for use in feedback control systems. For these reasons, we believe that a common set of underlying methodologies and tools, built on the foundation of control, communication and computing, can be developed and will provide the key to progress in the integration of heterogeneous systems.

The ISR's ability to synthesize and combine existing and new technologies into better systems fills a critical need in this time of economic restructuring. Such integration is not feasible in a traditional research structure featuring individual researchers. As the most difficult problems appear at the boundaries between disciplines, any serious advance toward the vision stated above requires the established cross-disciplinary structure and strategic research program of the ISR. ⌘

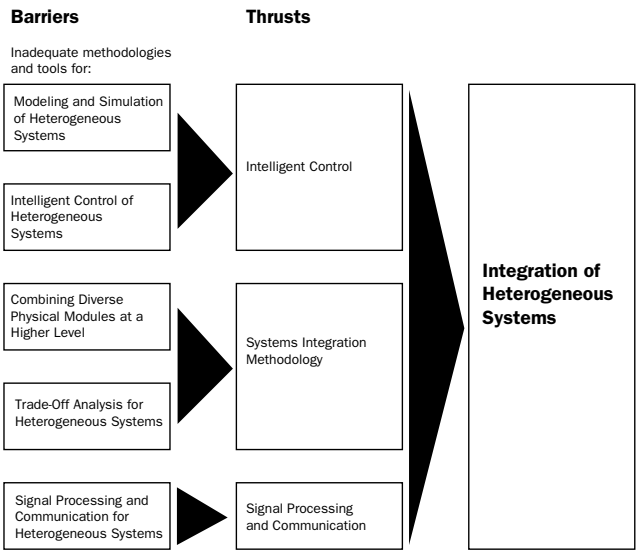
## Strategic Plan

ISR research focuses on the development of fundamental knowledge and tools for the integration of heterogeneous systems. New types of models and new methodologies are needed before engineers can perform integrated design and control of complex heterogeneous systems. These models must be hybrid models, in the sense that they include both continuous waveforms and logical variables, with dynamics modeled by both differential equations and automata and they may involve formal languages as well.

Industry can gain great advantage from a methodology that enables engineers to perform trade-offs and to better understand the systems they design. A model-based systems approach is the key. It is essential for performing tradeoffs—e.g., whether to route data through satellite or terrestrial links, or tradeoffs involving cost, quality and manufacturability in manufacturing systems. Taking a systems view can lead to the implementation of additional functionality with little added cost. For example, sensors for anti-lock brakes have been combined with the engine control system in automobiles to generate the additional functionality of anti-spin traction control. Similar possibilities exist, for example, in microelectronics manufacturing where sensors designed for diagnostics can be integrated with control systems for the purpose of feedback control.

However, there are serious barriers impeding the integration of heterogeneous systems and the ISR is focusing its research efforts to develop appropriate methodologies and tools (see *Figure 1* below).

**Figure 1 The ISR Research Plan**




The ISR is focusing its research efforts to develop methodologies and tools for:

- **Modeling and Simulation of Heterogeneous Systems.** Generic models that can be applied across a wide range of industrial applications do not exist. For example, what class of hybrid models will play the role that differential equations have in circuits and more classical control systems? How will we model succinctly systems with diverse components involving both waveforms and logic? We believe that answers to these questions can be built on the foundation of the models we have devised for hybrid analog / digital systems and for integrated planning and motion control.
- **Intelligent Control of Heterogeneous Systems.** New model-based intelligent control methodologies are needed, based upon these models. There must be rational design procedures, as well as hierarchical and feedback control structures to manage complexity. Such methodologies are emerging; they will build on work in motion control, nonlinear control and discrete event control.
- **Combining Diverse Physical Modules at a Higher Level**. The combining of diverse physical modules should be done at the information layer as opposed to the physical layer. Models must be linked across disciplines and levels of detail. One promising approach is to develop a new methodology for object based system representation. This methodology must enable integration of new systems with legacy systems in which companies have invested heavily.
- **Trade-Off Analysis for Heterogeneous Systems**. The design and operation of heterogeneous systems will require methods for optimization and trade-off analysis that go far beyond traditional methods and will involve research in planning and trade-off analysis in heterogeneous domains. These methods will build on the success of such trade-off analysis tools as the ISR's CONSOL.
- **Signal Processing and Communication for Heterogeneous Systems**. The design and control of heterogeneous systems involving multiple sensors, actuators and other subsystems also require advanced signal processing and communication algorithms. These involve, for example, *communication for control* in which there are constraints placed on the signal processing and communication functions when feedback control is the final goal.

## Strategic Plan

The implementation of our vision, which by its very nature is cross-disciplinary, requires the development of synergistic research teams and an environment that breaks down disciplinary boundaries. We have found the structure established at the ISR to be an effective and unique forum for carrying such an ambitious program to fruition. We have organized our research effort into three thrust areas that address the critical barriers identified above:

- **Intelligent Control.** This thrust focuses on modeling, simulation and intelligent control of heterogeneous systems and model-based sensing and control.
- **Signal Processing and Communication.** Major objectives are the hierarchical representation of signals and the integration of signal processing, networking and control in the design and control of heterogeneous systems, including communication and control networks.
- **Systems Integration Methodology.** The focus is on models, modules and object-based system representations; trade-off analysis for heterogeneous systems; and system architecture.

To ensure that the systems methodologies developed at the ISR will truly address the needs of a wide variety of industries, the ISR organizes cross-disciplinary major projects, each of which provides an application in an industrial domain. These projects will help to integrate the research of the thrusts and will test our fundamental advances and generate questions that will drive future research. They build on the strength of our research and existing industrial relationships.

Significant strides have been made in the Signal Processing and Communication thrust (and, in part, in the Systems Integration thrust) through the funding of the Center for Satellite and Hybrid Communication Networks and the Advanced Telecommunications and Information Distribution Research Program.

In the Systems Integration thrust, plans are in place for the formation of a Network Management club and a consortium centered around the theme "EMSYS: Design and Planning for Complex Electro-Mechanical Systems."

In the Intelligent Control thrust, we have already received supplemental ERC funding with the North Carolina State ERC in Sensor-Integrated Control for Semiconductor Manufacturing and the ISR is becoming a strong presence in this area through its research, its holding of the May 1996 workshop in "Model-Based Sensing and Control in Semiconductor Manufacturing," and with the addition of Prof. Gary Rubloff to the ISR faculty and as ISR Director.

Key issues in this transition are: (i) how to maintain a core of basic research and continue to work closely with industry; (ii) how to maintain coherence and not become fragmented; and (iii) how to develop additional funding to seed research and fund post-docs and fellowships. ⌘

# Intelligent Control Systems

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Intelligent control of products, equipment and processes is key to structuring, building and operating heterogeneous systems that function effectively in complex uncertain environments. The resulting complex systems function smoothly with appropriate levels of autonomy, primarily because of intelligent control capabilities. Intelligent control exploits information at multiple time scales, over distributed and multimodal sensors. The hierarchical structuring of intelligent control systems, meshing well with fine-to-coarse grain (or signal-to-symbolic) structuring of information flow is a key to managing complexity.

The growing awareness of the promise of intelligent control in key sectors of the economy such as semiconductor manufacturing, automotive assembly and process equipment is in part stimulated by the search for solutions to problems of equipment / line down-time, product quality / uniformity concerns and environmental safety. The market for user-adaptive, reliable consumer products demands that intelligent control be packaged into products. Real-time reconfigurability of product / equipment function is then achievable through intelligent control.

The ISR program is one of fundamental research in the methodologies of intelligent control, supported by experimental projects, in collaboration with industry.

The technical approach emphasizes breadth of applicability of the methodologies—i.e., we seek generic solutions to a wide variety of problems.

## ISR's unique contributions

The ISR program is based on group efforts within ISR and dynamic collaborative efforts with industry. Ties with SEMATECH initiated in January 1995 have grown stronger, leading to more direct collaborations with SEMATECH member companies such as Advanced Micro Devices and Texas Instruments. Specific ties of this nature have been based on unique ISR capabilities in modeling, analysis and control. ISR faculty have been at the forefront of bringing recent advances in signal processing methods such as wavelet analysis to bear on a broad range of technical problems such as thin film approaches to gas sensing and inversion of spectrally based temperature sensors. As a result, new ways of using sensor data in closed loop control have emerged.

ISR faculty have been at the forefront of nonlinear modeling and analysis in a wide variety of physical domains, including continuum mechanics, discrete electro-mechanical systems and more complex hybrid systems that include physical and information-based couplings. Certain process modeling problems such as chemical-mechanical polishing used in semiconductor planarization are extremely challenging, requiring the integration of thermal, flow and abrasive regimes and prior ISR expertise and accomplishments are strongly needed in such problems.

Major accomplishments in optimization algorithms and software continue to emerge drawing on earlier successes in FSQP and CONSOL. The use of geometric control theory to advance the state-of-the-art in motion control is a key ISR strength. The introduction of new motion control architectures based on combined continuous and discrete elements realized via motion description languages is another key ISR strength. These advances go together with a solid experimental program that has led to prototype hybrid motors and a parallel manipulator.

## Technical approach

A guiding principle governing the architecture for control of complex heterogeneous systems is the organization of sensor information flow and actuation in accordance with natural time scale decompositions in the dynamics (processes). Thus learning from repeated trials (or run-to-run control) coexists with model-based feedforward control and real-time feedback control, as well as supervisory control loops sensitive to alarm states and process / equipment failure. Effective use of physical models in the

forward path should take into account trade-offs between model complexity and computational burden.

To this end, novel model reduction approaches are being developed. The use of the modern theory of distributed parameter control systems based on evolution equations reveals close ties between certain rational decomposition approaches based on controllability (and observability) grammians and certain widely used computational reduction methods based on empirical orthogonal functions. These insights will serve as a useful theoretical guide in the systematic exploitation of reduced models in our research.

Extracting (or "mining") information (or patterns) from data is a key challenge in dealing with sensors that generate an abundance of data, e.g. spectral reflectance sensors in semiconductor processing, spectral pyrometers and surface mapping sensors. New techniques based on a combination of deterministic, statistical and neural signal processing will be heavily exploited in this arena.

Optimization-based design methods will be further advanced to carry out combined optimization of sensing, control and equipment configuration together with parameter tuning in each case. Issues of process visibility and learnability will be investigated. Sensor / actuator networking presents an attractive approach to modularity and reconfigurability needs in industry. Hybrid models are needed to develop a better understanding of the behavior of networked systems. Such hybrid models along with dynamic simulators and verification software will provide the basis for performance evaluation and design of networked systems.

A variety of motion control problems appear to be amenable to solutions based on sensor / actuator networking.

## Key advances within the past year

**Hybrid Models.** Significant progress has been made in a new class of formal languages, called lattice languages, invented for motion description with quantization conditions. Applications of this idea are being made in examples of motor networks. Analysis of hybrid models with synchronization conditions has been shown to be useful in the stabilization of networked systems.

Extensions of Brockett's motion description language (MDL) to support hierarchies of interrupts have been shown to be useful in attacking problems of motion control of nonholonomic robots.

**Neural Network Models.** Earlier (pioneering) work in ISR on a wavelet approach to neural networks has been extended to be applicable to recurrent networks and multi-dimensional state spaces. Stability analysis of adaptive controllers based on this approach has been carried out. Networks for recognition of patterns (as in visual processing) require internal degrees of freedom in the "neurons."

One approach based on oscillator neurons has been rigorously shown to be useful for a class of communication problems. Implementation of this class of networks in analog VLSI has also been studied. A nonlinear principal component analysis network is being tested on chemical process data. Oscillator networks inspired by neurophysiological investigations of the auditory cortex are suggesting new spatio-temporal representations for eventual applications in sensor signal processing and pattern extraction.

**Semiconductor Process Modeling, Sensing and Control.** Further progress in detailed understanding of a model of the three-zone RTP system at North Carolina State University has been made in collaboration with NCSU researchers. Issues of sensitivity of reconstruction accuracy from reduced order models have been investigated and quantified. Modern geometric control theoretic techniques have been applied to such reduced order models. Run-to-run process control algorithms have been developed and tested (including on-site at Advanced Micro Devices on an etch process).

Data obtained from a spectral wafer reflectance sensor was supplied by a group at the University of British Columbia. This data was analyzed by a combination of wavelet decomposition and principal components analysis to reveal useful patterns. It was shown that it is possible to extrapolate wafer temperature from such patterns. A key step in this approach is a reduction step of the same type used in dynamic model reduction. The technique appears to be promising for a variety of other sensory modalities as well.

**Motion Control.** A new type of parallel manipulator was designed and prototyped. This manipulator has been subject to a detailed stiffness analysis and dynamic models have been developed. The basic structure has been shown to be sound for possible large force applications as in machine tools.

Fundamental ideas in motion control of nonholonomic robots based on modern nonlinear dynamics, geometric mechanics, symmetry principles and reduction have been advanced. These ideas have been tested in simulation and further shown to be correct using a prototype nonholonomic mobile robot built in the Intelligent Servosystems Laboratory of ISR. This robot and the graphic

simulation also have served as a useful vehicle for the investigation of hybrid control strategies combining MDL style behavior programming/composition with oscillatory motion control primitives. This work continues in collaboration with researchers at INRIA.

Motion control techniques based on Lie group theory have been advanced to include models for autonomous underwater vehicles. General principles for strong accessibility properties have been worked out. These techniques are expected to be of wider applicability to problems such as those arising in air traffic control.

A new hybrid motor was designed, fabricated and tested. This motor combines piezo-electric and magneto-strictive materials as primitive actuators in a resonant circuit to produce rectified motion with a large "gear reduction." The concept is being submitted for patent consideration.

**Control Networks.** Two experimental efforts in control networks involving undergraduate and graduate researchers have been carried out. Using networkable motors from Animatics, hybrid control software has been written including low bandwidth updates of gains and set points over RS-232 and fast within-motor PID loops. In one effort it was shown that it is possible to synchronize the motors using RS-232 coupling alone, when properly designed. In another effort, CAN chips have been integrated into a network for ultimate use in actuator/sensor networking.

Modeling of motor networks is in progress. ⌘

## Intelligent Signal Processing and Communication Systems

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Signal processing and communication methodologies continue to play a central role in the activities of ISR. They provide the means to reliably and efficiently process and transfer information in and to control the operation of, a variety of complex heterogeneous systems. An example is a large communication network with varied components including terrestrial high-speed and wireless as well as satellite subsystems, which provides bandwidth-on-demand for services involving voice, data, video and imagery with different performance requirements. Another example is a network for control. The communication infrastructure in the first example involves diverse components that must interoperate to provide a transparent medium of connectivity between heterogeneous users; owing to the size and complexity of the combined network, network control is critical to its overall success, thereby creating a need to "control to communicate." In the second example, as in other applications ranging from smart appliances to HVAC systems, we must "communicate to control" a complex system on the basis of inferences from digital (e.g., rule-based) as well as analog (e.g., servo) signals; this involves communication among sensors, decision-making devices and actuators.

The design and control of such heterogeneous systems involves a coupling of signal processing and network control functionalities. For example, the hybrid nature of sensor signals and hard real-time constraints imposed by servomechanisms, will affect protocols for information transfer between sensors and actuators. Our objective is thus to develop an integrated approach involving signal processing and networking methodologies for heterogeneous systems, such as communication and control networks, which will result in superior design and performance.

### ISR's unique contributions

Over the years ISR has made significant contributions to basic issues in communication, control and signal processing that provide a firm basis for the proposed research and we continue to offer a unique combination of complementary expertise in this cross-disciplinary thrust area.

Our major accomplishments in networking include: key issues in radio networks such as access-scheduling and spread-spectrum techniques; performance evaluation methodologies and a simulation infrastructure for management, resource allocation and switching in heterogeneous networks; new object-oriented data models for hybrid network management; development of industrial collaboration projects leading to products; and design of experiments for the NASA ACTS satellite.

## Research Plan

In signal processing, our major accomplishments include: models for sound processing with applications to speech analysis and recognition, as well as perceptual models for real-world imagery with applications to compression; low-complexity signal compression schemes as well as error-control coding and combined source-channel coding methodologies with applications to speech transmission over digital cellular mobile links; VLSI algorithms and architectures for fundamental signal processing operations, e.g., discrete orthogonal transforms and vector quantization; and adaptive spatial-time domain signal processing algorithms and low-power architectures for enhancing antenna spatial diversity with applications to wireless environments.

### Technical approach

Methodologies for hierarchical representations of signals (in time, frequency and spatial domains) play a key role in our approach to unified signal processing and networking for communication and control networks. Such representations have applications including hierarchical compression for multiresolution multicasts, ATM cell prioritization to combat cell losses and dynamic bandwidth allocation at the interfaces of heterogeneous subsystems.

System constraints will have a major impact on the choice of signal representation and resulting system performance. For instance, network congestion levels and corresponding buffer occupancies can dictate the choice of quantization in a video codec. Another example is that the choice of compression algorithms for real-time video transmission affect the bandwidth of a servo loop. Recent advances in time- and spatial-domain adaptive array signal processing at the receivers have yielded significant gains in signal-to-noise ratios at the receiver outputs; these techniques are well-suited to rapidly changing channel conditions. These advances, in conjunction with appropriate multiple-access control schemes such as TDMA or CDMA, offer the potential of considerable improvements in spectral efficiency through spatial diversity, thereby allowing, for example, more users for a given set of frequencies in a wireless subsystem.

Modeling and performance evaluation methodologies play a pivotal role in design comparisons and network control; this effort is being carried in close collaboration with research in the Systems Integration thrust. Heterogeneous entities, e.g., analog and digital signals, will be modeled in a common mathematical framework. For instance, analog signals in communication and control networks, e.g., fluid-flow representations for ATM traffic and continuous servo dynamics, respectively, can then be modeled at the same level of abstraction as digital signals in these networks, e.g., network control commands and sensor measurements, respectively.

### Key advances within the past year

**Unified signal processing and networking.** A key to progress in this area is the development of hierarchical signal representations so as to support the multicasting of information through a network to multiple users with different QoS requirements.

Along these lines, by mean of information-theoretic methods we have obtained the fundamental performance limits of quantization schemes for hierarchical compression.

We also have provided a graph-theoretic formulation and solution to the problem of identifying optimal compression levels as well as determining optimal routes for conveying this information to multiple users with different QoS requirements over a network with link capacity constraints.

A complete video compression system based on the discrete wavelet transform was given a real-time implementation on a Texas Instruments Parallel Processing Development System; the underlying algorithm is fully scalable—both spatially and temporally.

We have developed a method for fast reconstruction of wavelet-based image coders which is suitable for telebrowsing applications.

Efficient systolic architectures have been developed for image compression using wavelet transform and spectral classification and for spectral classification using an auto-regressive (AR) model. A new scheme for bit variable encoding associated with the Ziv-Lempel encoding scheme was shown to yield significant improvements over previous known implementations. We introduced a novel "localized" wavelet-based approach to tomography which provides significant reduction in radiation exposure—e.g., for a 256 x 256 image, only 29 percent of radiation exposure is needed for a local region with a diameter of 16 pixels. We demonstrated that fractal image modeling can be used to effectively extract various mammographic features (e.g., microcalcifications), thereby facilitating the radiologists' diagnosis.

**Wireless channels and networks.** An algorithm for adaptive rate allocation between source and channel coding was developed for application over fading channels and yielded end-to-end performance improvements by up to 4 dB.

In a related work, we have examined the design and application of rate-compatible trellis codes designed for (Rayleigh) fading channels.

## Research Plan

We have demonstrated how these codes could be used in conjunction with tree-structured vector quantization to adaptively optimize mean-square error performance over fading channels.

We have also developed a medium access protocol (MAC) for wireless ATM systems that uses time division multiple-access with frequency division duplex and supports CBR, VBR and ABR as well as delay-sensitive and delay-insensitive services. We have investigated the effects of bandlimiting on a Markovian VBR video model due to wireless channel or receivers with limited bandwidth reception capability; an appropriate truncated Markovian model was developed and did allow us to analyze and optimize connection admission control (CAC) schemes in multi-hop multicasting networks. We developed and analyzed optimal power control schemes for multi-rate CDMA networks for multimedia wireless (PCS) communications; these power control schemes account for the channel propagation characteristics and different transmission rates and equalize the other-user interference while meeting the BER requirements of the different traffic types. In related work, we found ways to accurately evaluate the coverage areas for CDMA cellular networks with soft and hard handoff. The effects of power control, shadowing, fast channel fading and the propagation features of the medium were taken into consideration. Soft handoff and diversity reception at the mobile were shown to extend by a significant factor the area covered by the CDMA base station.

Finally, work continued on the use of Spatial Domain Multiple Access (SDMA) for wireless communication which cleverly combines signal processing and network control.

The SDMA scheme uses an antenna array at the base station to create a separate beam pattern for each user, thus allowing multiple users on the same channel.

We have developed several novel techniques for simultaneous diversity combining and decoding, as well as for blind equalization and identification.

**Performance evaluation and network control.** Fundamental advances in the past year include the development of buffer asymptotics for the so-called Cox traffic model—this is a very versatile class of statistical models for traffic which exhibit short- and long-range dependencies; demonstration of the inadequacy of the Hurst parameter as a sole parameter of self-similarity for the purpose of queueing performance; application of ordinal optimization techniques to the solution of the voice admission control problem in voice-data integrated networks; evaluation of cell loss probability in crossbar switches with input queueing and finite buffers; large asymptotics for crossbar switches with input queueing; efficient schemes for integrating voice and data traffic in a heterogeneous satellite / terrestrial network using TDMA in the satellite network and CDMA in the terrestrial subnetwork; near-optimal admission schemes for voice and multi-priority data traffic for networks of LEO and MEO satellites; tools for fast performance evaluation, sensitivity analysis and design optimization of multi-link networks with combined circuit-switched / packet-switched multimedia traffic; and the use of search theory to heuristically generate paging algorithms which outperform existing paging algorithms; and the pioneering use of SDMA for network control. ⌘

## Systems Integration Methodology

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Systems integration is central to the ISR vision. Due to competitive needs, complex heterogeneous engineering systems are being configured in a modular fashion. This allows, in the design stage, modules to be developed in parallel, thus reducing development time while improving quality, lowering cost and facilitating technology insertion. In the stage of dynamic control or operation, modularity induces higher performance, reliable fault tolerant control and improved adaptation. However, it can be difficult to decide how to divide the design or control task into modules and how to integrate their operation. Interoperability of modules that involve different functionalities, technologies and design principles, calls for systems integration at the stages of design and control. Thus our focus goes well beyond integration of computer modules (the focus of other systems integration efforts).

There are basic research challenges in unifying the methodologies of control, communication and

computing to develop models for complex systems that are comprehensive and cut across the boundaries imposed by differences in implementation (e.g., analog vs. digital, electrically vs. mechanically steerable antennas) or in the formulation of models. Integration of models based on first principles with models constructed from empirical data on poorly understood processes is a basic problem. Command language based user interfaces and standards based inter-module connections must be incorporated in the scientific foundations of integration of heterogeneous modules. Developing a quantitative theory of model complexity incorporating the required heterogeneity is a major challenge. Developing integration of heterogeneous data for decision making in heterogeneous domains is a key challenge for the thrust.

## ISR's unique contributions

The ISR has a worldwide reputation for its fundamental systems level research and for bringing the results of this research to practice. We have achieved many important results including mathematical foundations for VLSI algorithms and their implementation in high-performance circuits, consistent estimation of system complexity metrics and optimization-based nonlinear control. Collaborations involving computer scientists have led to major advances in database technology and algorithms with applications to manufacturing and communication network management, AI planning techniques using connectionist and reactive approaches with applications to robotics and system fault management, a new theoretical framework for analyzing hierarchical task network (HTN) planning, new theoretical foundations for heterogeneous databases and deductive queries and a wide range of signal processing and understanding algorithms (particularly in speech and vision) and their real-time implementations. The unique environment of ISR also provides a fertile ground for cross-fertilization leading to fundamental discoveries in new methodologies for systems integration which are not being developed elsewhere in the depth and breadth attempted at ISR.

## Technical approach

Object-oriented software and object-based system representation provide a language which can link models across disciplines and levels of detail. System modules and algorithms, for example, are represented as data objects. This approach provides tools for abstraction, hides heterogeneity, encapsulates domain-specific knowledge in object models and connects knowledge domains via object interactions. The system model is then contained in an object-oriented database (OODB). Communication between disciplines is a major obstacle to effective environments for systems integration; the object-oriented approach helps to bridge this gap and provides a tight link between disciplinary engineers.

A key question we will address is how to compare and design system architectures for heterogeneous modular systems. The architecture of control and communication systems from a fundamental perspective has not been systematically studied. This involves information processing architectures, control/actuator architectures and decision making architectures. We will use studies of information patterns, control complexity measures and communication protocol overheads to devise descriptions of systems architectures and methods to control architectures.

We will advance trade-off analysis to a systematic methodology using quantitative and analytical techniques and algorithms, from the empirical and ad hoc stage that it exists right now. At several national workshops this has been identified as a major obstacle for effective systems integration.

## Key advances within the past year

### Modeling and Complexity

We have continued the study of complexity metrics for systems consisting of hidden Markov models (HMM) (as approximations to continuous models) and finite state automata (FSA) modules. This relatively simple class is important for the problems of systems integration that we are currently investigating: virtual factories and heterogeneous communication networks. We also investigated complexity metrics for hybrid systems models, in particular as they relate to applications of the thrust methodology in semiconductor manufacturing processes and heterogeneous communication networks. HMM and FSA models are also essential for intelligent control systems. We further developed our results linking model complexity to learning, control complexity and intelligence. Certain quantitative frameworks for analyzing model complexity vs. performance were developed. In particular we have made strong connections with approximate dynaming programming approaches, AI planning and differential game methodologies.

We have extended our object modeling to include both large heterogeneous networks and virtual manufacturing of electromechanical systems. In particular we have developed interfaces between our object models and the legacy databases used so widely in industry. In particular this includes the development of efficient middleware systems.

In our virtual factories project, we have developed and implemented hybrid (Object-oriented and

Relational) representations of the various data that exist in an enterprise from parts, processes to labor, accounting and materials. We have initiated the development of different views of the data as appropriate for the different parts of an enterprise. We developed a new information model that captures the capabilities and performance of a manufacturing plant and implemented it in the same OO database.

**Object-Oriented Databases and Graphical User Interfaces.** We continued the development of efficient graphical user interfaces linked to Object-oriented Databases for system modeling and monitoring. We developed a new GUI model that allows the browsing of non-hierarchical data by user developed partial orders. This was successfully applied to the network management of large full mesh connected networks, allowing browsing based on subnetworks, network elements as well as performance attribute values specified by thresholds. We developed novel methods for resolving the display lock problem presented when distributed databases are browsed with GUIs from different workstations. The method was successfully demonstrated in the configuration management of a large hybrid network. We also investigated the problem of efficient storage of time series data for fast recovery and age-based granularity. We developed new algorithms for fast approximate matching in multimedia databases based on image content. We have initiated work to investigate and extend such methods for manufacturing information networks and for system architecture component browsing.

### Planning and Trade-Off Analysis

We have developed various design critiquing methods for distributed manufacturing. We continued the development of a novel multi-criterion optimization framework for the trade-off analysis and process selection in the manufacturing of T/R modules and more general electromechanical components and systems. Motivated by this multi-criterion optimization problem we have initiated a systematic effort to expand CONSOL by the inclusion of discrete variable optimization. We have initiated a systematic effort for the development of efficient and fast algorithms to perform multi-criteria mixed integer continuous optimization. In addition we have developed the interface to an OO database for such problems. We also initiated the integration of multi-criteria optimization with AI constraint-based reasoning for the development of trade-off systems.

By combining these results with our recent developments on heterogeneous databases and hybrid knowledge bases—which make it possible to integrate multiple information sources—we will be able to integrate multiple planning systems for manufacturing and other systems applications.

**Heterogeneous Planning.** The challenge has been to overcome the complexity of domain-independent approaches to AI planning. Our approach is based on two components: use developments in hybrid knowledge bases to integrate a number of information sources and use AI planning techniques for hierarchical task network (HTN) planning.

We developed the first provably sound and complete HTN planning algorithm and have implemented it in the system "Universal Method deComposition Planner" (UMCP). UMCP is used as a testbed to evaluate various planning strategies and their effects on performance. We focused on understanding and evaluating the effects of "commitment strategies" on the efficiency of HTN. We studied and compared the following commitment strategies: (1) Delay variable bindings as much as possible; (2) Commit to variable bindings as soon as possible; (3) Select whether to delay variable bindings or commit them by estimating the No of branches to be created in the search tree. Our results demonstrate that method (3) plans more efficiently over a broader range of planning domains. We used these developments in the process planning module in EDAPS (Electromechanical Design and Planning System).

**Integration and querying of heterogeneous databases.** There is no uniform framework for integrating/querying heterogeneous data. We developed a general purpose mathematical structure (MEDIA-ABSTRACT) that captures the "core" part of different types of media data. We developed a single query language for querying a multimedia DB system. We developed update methods and efficient indexing structures for the content of multimedia DBMSs. A formal logical model theory was developed for multimedia reasoning. We showed that the algorithm is efficient: elementary queries are answerable in quadratic time (worst case); Boolean queries in polynomial time. A System called MACS for reasoning with media-abstractions was created jointly with Topographic & Eng. Center, Ft. Belvoir. The latter was used for terrain reasoning applications. Our approach showed that a very small class of linear constraints (difference constraints) can be used to represent temporal, spatial, QoS, jitter, delay jitter and cell loss probability constraints. Based on this we developed a very efficient dynamic programming algorithm to schedule Multimedia Presentations to the temporal/spatial/quality constraints in the specification. We plan to pursue applications to network management related constraints.

## Research Plan

We investigated the problem of distributed concurrent display of heterogeneous data. This involved problems with consistency, concurrency and performance of the GUI and its link to the OODB. Time performance is critical; client data caching. The critical problem is to generate consistent and up-to-date views of the database. We developed an external display schema over the DB schema. We used display classes encapsulating the desired user interface functionality. The graphical elements of the GUI, are instances of display classes: display objects. We introduced display cache as an additional level in the memory hierarchy. We introduced relaxed correctness and a non-restrictive form of shared locks which we called display locks.

**Focused Research Projects**

**EMSYS: Design and Planning of Complex Electro-Mechanical Systems.** We initiated the development of an industry-University consortium in this area, based on a careful integration of the following projects.

*EDAPS: Electromechanical Design and Planning System.* The vision is to develop an integrated system for designing and planning the manufacture of microwave transmit / receive modules. Specific features include:

- Integration of commercial electronic and mechanical CAD packages such as EESof (Hewlett Packard) and Microstation Modeler (Bentley Systems)
- Integration of electronic and mechanical process planning
- Hierarchical Task Network (HTN) planning techniques from AI. Plan-based design evaluation (in progress)

*EXTRA: ExpertT/R Module Analyst.* The vision is to develop an IPPD automation tool for electro-mechanical products that will integrate product and process design phases into a single system environment and will help designer with best overall decisions including manufacturing considerations. Specific features include:

- Integration of legacy, relational, object-oriented DB's enterprise-wide for product data management
- Process representation and characterization for quality and cost assessment
- Multi-objective optimization for trade-off analysis

*HERMES: Heterogeneous Reasoning & Mediator System.* The vision is to create a system for the intelligent interchange of diverse heterogeneous information and provide for integration at both the systems and semantic levels. Specific features include:

- The ability to run on a distributed platform across the Internet
- To provide remote access to and integration of distributed heterogeneous database systems and other software systems
- To integrate many commercial and third-party packages DBASE, PARADOX, ObjectStore, Ingres, flat files, images, video, spatial databases, newswires, path planning systems, face recognition systems

*IMACS: Interactive Manufacturability Analysis and Critiquing System.* The vision is to achieve DFM by evaluating manufacturability of CAD designs during the design phase. Specific features include:

- Include in the domain machines parts and 3-axis vertical machining center
- To recognize machining features automatically from the CAD model
- To generate and evaluate alternative operation plans
- To provide feedback about machining operations, setups, cost and time

*OSPAM: Optimal Selection of Partners in Agile Manufacturing.* The vision is to create a system to design for manufacture by multi-enterprise partnerships including optimal assignment of production tasks to partners. Specific features include

- The retrieval of similar designs already developed by partners
- The detection of infeasible design attributes. The evaluation of design manufacturability with respect to production capabilities of potential partners
- The formation of optimal partner networks
- To perform all tasks early in the design cycle.

**Network Management.** A noteworthy feature of the proposed fault management system is that it will have learning capabilities. The challenge here is to develop systems for Integrated Network Management of heterogeneous communication networks. Network management has been identified by our industry partners as a key market differentiator. Our approach includes the following key ingredients:

- Represent the network via on object-oriented database

- Develop advanced GUIs linked to the OOBD for the network
- Invoke dynamic queries from GUI
- Embed constraints in OODB
- Embed multi-criteria optimization and AI search in OODB
- Integration of configuration, fault and performance management
- Our approach offers the following advantages:
- Exploits hierarchical data structures
- Scales up to large networks (300,000 nodes and larger)
- Develops “performance objects” for performance management
- Allows multi-resolution performance data storage
- Utilizes link to simulations
- Can handle full mesh graphs via selected subnetwork hierarchies

Our system supports two types of user queries: Queries on a single object (such as utilization of a particular link at sometime, buffer capacity at a given node, delay and error rate over a specific link); Queries across objects (such as aggregate delay over a specific virtual circuit).

It is impractical to store information gathered over a period of time with the same granularity. We have developed a scheme that uses three levels of granularity and automatically reduces precision as information gets older. We use three processes, one for each level of granularity. We have implemented this scheme in a distributed performance model. We also developed a new efficient browser for mesh connected graph networks.

We designed a Mesh Network Browser which explores various partial orders created by the operator. The Browser is used to invoke dynamic queries in the OODB representation and allows selection and display across subnetwork or node hierarchy. Selection capabilities are based on network element menu, on subnetworks, on filtering of network elements using specific assignable attributes.

The Browser is directly connected to the OODB representing the network for continuous network monitoring and management. We also developed and implemented a Wheel Widget Performance Data Display for simultaneous and efficient utilization of several performance metrics (e.g. utilization, VPI, capacity, throughput).

### Plans for the future

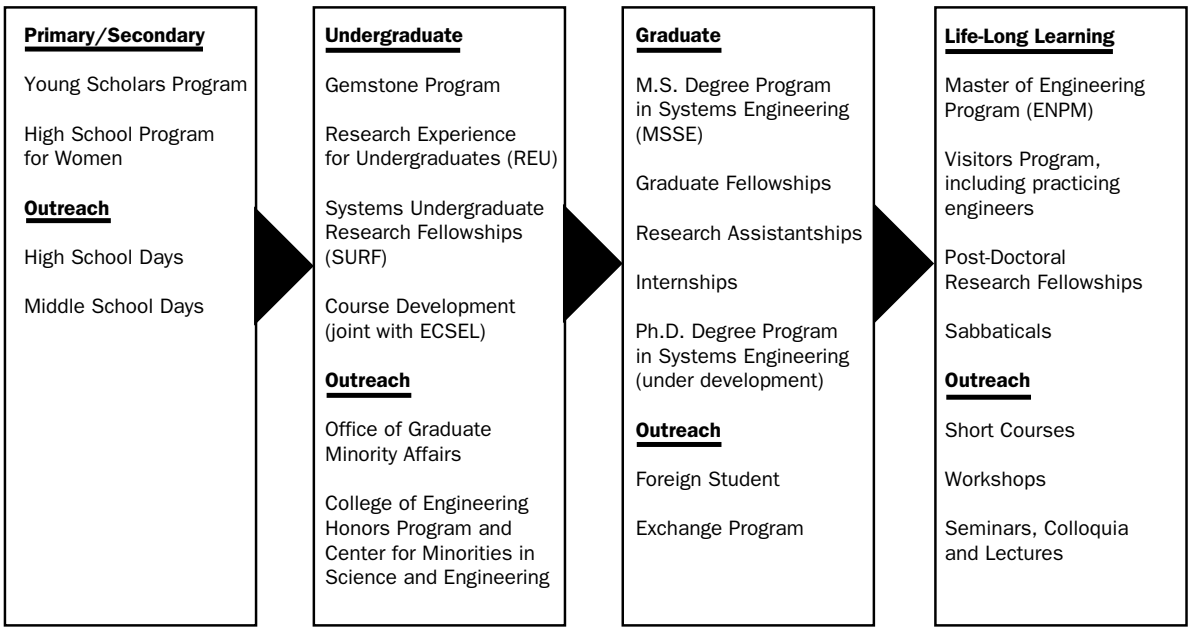
- Modify and simplify information models for plants, parts, processes vs. planning complexity.
- Develop a universal framework for integration of heterogeneous databases and of application software running on them.
- Develop a process modeling framework for manufacturing electromechanical parts.
- Integration of various systems for integrated product / process design (EDAPS, ACIS, EXTRA, etc.) Extend multi-objective optimization method for trade-offs and integrate with AI planning methods.
- Extend fast computation of trade-off curves.
- Develop further partner selection problem (technical, strategic etc. attributes).
- Develop a domain integration tool kit (heterogeneous database techniques).
- Develop heterogeneous, fast planning algorithms.
- Automate configuration, performance and fault management in our framework for network management.
- Integrate process control with manufacturing / production scheduling and management in automotive factories, semiconductor factories and microelectronic / consumer products factories.

## Education Program Plan

The ISR is committed to educating a "new breed" of systems engineer for U.S. industry and academia and has implemented a wide array of innovative educational programs. These programs form an *educational continuum* (see *Figure 2 below*), an educational development path that encourages pre-college students to enter science and engineering, educates a new generation of systems engineers at the university level and provides opportunities for practicing engineers to keep abreast of technology. Industrial participation keeps the focus of the education program squarely on the dynamic, long-term needs of industry.

The ISR has established a reputation among ERCs both locally and nationally for the aggressive innovation of its educational programs. These programs—and their close ties to the ISR's research mission—represent a real step forward in educating a "new breed" of systems engineer.

**Figure 2 ISR Education Programs: A Strategically Integrated Path**




### Inventory of Programs

**Pre-College Activities.** In each of the past five summers, our Young Scholars program has brought a new group of high-potential high school students to campus. The six-week program is designed to encourage our brightest young minds to consider science and engineering as a career path. Participants enroll in a three-credit freshman class, "Introduction to Engineering Design," and participate in research and design projects in the ISR's labs, field trips to industry and government labs and seminars on careers, communication skills and ethics. A total of 96 students have now participated in the program. Sixty-one of the participants are now pursuing studies in science or engineering and 24 have chosen the University of Maryland at College Park. In spring 1996, the ISR was awarded a two-year grant to continue the Young Scholars program. This summer's program will include 25 students.

For the past two years, ISR has participated in the Prince Georges' County South Eastern Consortium for Minorities in Engineering (SECME) Program. In conjunction with other units within the A. James Clark School of Engineering, we have coordinated campus tours of laboratories, which introduced more than 200 middle and high school students each year to higher education studies and careers in engineering and science.

In the Summer Study in Engineering for Women High School Students program, an ISR faculty member has brought students into his lab to provide them with hands-on laboratory experience. The program is designed to encourage women to pursue careers in engineering. Last year, the ISR brought these students together with Young Scholar participants for various career seminars and field trips.

**Undergraduate Programs.** In the last year, 56 undergraduates participated in ISR research. During the summer the NSF's Research Experiences for

Undergraduates (for students from other universities) and the ISR-funded Systems Undergraduate Research Fellowship (for UMCP students) programs were combined to maximize the student-to-student and faculty-to-student interaction. A graduate student assisted the faculty supervisor by holding weekly meetings, scheduling field trips and seminars and evaluating participants' weekly progress reports. At the end of the program, each student prepared a final report, which were combined to form an ISR technical report. In an effort to continue to provide research opportunities for undergraduates, the ISR will continue to seek various fundings opportunities (e.g., NSF Supplemental awards for undergraduates, corporate sponsorship, etc.).

We are particularly excited about the new Gemstone Program, administered by ISR, which began in Fall 1996. This program, which was conceived by Dean William Destler of the A. James Clark School of Engineering and endorsed by the deans of all the other colleges at UMCP, brings together teams of undergraduate students — from engineering, business and management, the social sciences and the humanities — who will spend four years analyzing and investigating some of the major societal problems of our time (e.g., electronic privacy in the internet era, energy-efficient transportation, etc.). Gemstone scholars will take a sequence of 3-credit courses examining the implications of technological innovation from scientific, economic and sociological perspectives. Teams will meet regularly with faculty mentors to keep the project on track, to define and focus the investigation and to maintain the multidisciplinary threads. We admitted 112 freshmen into the Gemstone program in Fall 1996, and anticipate adding about 100 per year. Gemstone participants will be awarded a baccalaureate degree with a special Gemstone designation. Core funding for the Gemstone Program has been provided by AT&T and General Electric and additional support is provided by IBM through the IBM-Total Quality Program at UMCP.

**Graduate Programs.** The ISR's graduate programs attract outstanding students from universities across the U.S. and throughout the world. The interdisciplinary nature of ISR brings together students from every engineering discipline and from computer science, math and business; in the last year 315 graduate students (from four colleges and eleven departments) engaged in ISR research projects. The ISR provides students with a rich cross-disciplinary environment that extends beyond the traditional classroom—combining fundamental research, rigorous course work and laboratory experiences enhanced by industrial interaction; thus they obtain a deep education in their "core" areas and a thorough understanding of industry's problems.

The ISR hosts graduate exchange students from L'Ecole Nationale Supérieure des Télécommunications in France for six-month internships. Their work has resulted in joint publications with ISR faculty and software development that directly supports ISR strategic goals and is transferred to U.S. industry. In the past funding for this exchange program was split between the ISR and funds available to individual faculty. We expect that this exchange program will continue with faculty fully funding the internships.

The ISR facilitates the rich cross-disciplinary environment in many ways. Sharing offices and lab experiences guarantees that students from a wide variety of departments come into contact with one another. There are speaker and seminar programs that provide ISR students and faculty with continuous exposure to outstanding researchers and practitioners from industry and academia. The ISR sponsors a small number of ISR Fellowships for exceptional graduate students. It is aggressively seeking corporate support for both undergraduate and graduate student fellowships. In addition, we have created Systems Fellowships for outstanding graduate students, which provide the ISR faculty an opportunity to fully fund an ISR Fellow through their individual grants and contracts. Students nominated for these fellowships must be evaluated by the ISR Education Program Committee and meet the criteria for ISR Fellowship selection.

One of ISR's main education programs is its innovative M.S. in Systems Engineering (MSSE), a degree program designed and implemented by the ISR in cooperation with its industrial partners. There are 40 students currently enrolled in MSSE. This interdisciplinary program emphasizes technically challenging course work in fundamental principles of systems engineering and related business and financial issues. Relevance to practical systems engineering problems is maintained through case studies, projects, an optional M.S. thesis and in-class presentations and seminars by industrial representatives. This academic program will continue to be supported by the ISR's state budget.

The Master of Engineering Program, designed for the practicing engineer, was implemented in the Fall 1995 semester; several options, including Systems Engineering, are offered. Currently, there are 25 students enrolled in the Systems Engineering option of the new Master's degree program. Students in this non-thesis program follow the same core course requirements as for the MSSE. The program is an applications-oriented, methods-focused, part-time program designed to assist engineers in the development of their professional careers and to provide technical expertise needed in business, government and industrial environments. A portion of the tuition

fees generated from this program helps to support the MSSE course offerings.

In spring 1996, the ISR offered four short courses, developed from critical elements of the MSSE core courses, for practicing engineers at NASA / Goddard in Greenbelt, Maryland. ISR faculty taught these courses and resources were generated from course registration. The ISR plans to continue to develop and offer short courses to industry and government agencies in the future.

## Future Plans

The ISR will continue its efforts to augment the traditional focus of engineering education, train a new generation of engineers, place emphasis on new methods of education and learning and reach beyond the university to retrain and update practitioners. New systems engineers will be educated in an environment that will best enable them to be effective in industry or in creating similar environments in other universities. The ISR has identified four priority areas in which it will establish new initiatives over the next five years. These goals were formulated as part of the ISR's strategic plan submitted to UMCP administrators and they enjoy enthusiastic support at all levels of the college and university. Descriptions of those four goals follow.

**Create Innovative Methods to Enhance Cross-disciplinary Undergraduate Education.** The ISR is the embodiment of cross-disciplinary engineering. Since its establishment in 1985, its activities have focused on cross-disciplinary approaches to designing and controlling large complex systems; the resulting environment — with its emphasis on multi-departmental teams and problems that arise at the interfaces between disciplines — has had a profound effect on graduate student education at UMCP. There has also been a strong impact on the *undergraduate* programs; curriculum development and increased opportunity to conduct research are only two areas in which the undergraduate population has benefited from the ISR.

To increase and broaden our impact on undergraduate students, we will continue to work closely with the ECSEL education coalition. Some of the ways we intend to accomplish this goal are:

- Develop large projects that include teams of undergraduates from several departments and colleges. An example is the "Walking Machine" project that was developed by ISR faculty from electrical and mechanical engineering; undergraduates from these departments have designed all the various subsystems necessary for a walking robot — including control and navigation, power, gear mechanism and voice recognition.
- Use technology to incorporate more complex (and more realistic) problem-solving into undergraduate courses. Ready access to powerful workstations permits material learned in many courses to be incorporated into a single assignment; a good example of this was the recent addition of a project on noise-whitening filters in quadrature-amplitude modulation (QAM) in a junior-level probability class. This addition — carried out by an ISR faculty member — gave students a concrete example regarding the importance of probability in digital communication system design. ISR faculty have undertaken a similar effort in the junior-level signals and systems course at UMCP; more such innovations are planned.
- Continue efforts in multi-departmental curriculum reform. With faculty from eleven departments at UMCP, the ISR is in a unique position to coordinate "islands" of common interests that exist throughout the university. For example, there are four departments at UMCP that offer a senior-level course in control systems; a similar situation exists regarding computers and computation. ISR faculty have made efforts to coordinate course content in these areas. We intend to introduce multi-departmental "demonstration sections" that will bring together students from different programs to observe and learn about technology of common interest. The goal is to give undergraduates a greater awareness of the way similar problems arise in disparate fields and a better understanding of the threads that tie those fields together.

**Use Technology to Bring Engineering Education to Working Engineers.** Enhancing U.S. competitiveness is central to the ISR's mission and "lifelong learning" is an important tool in enhancing competitiveness. While ISR faculty have for years delivered on-site short courses to their industrial partners, it is our intention to dramatically extend the scope of this activity through the use of interactive compressed video. Our first efforts in this vein came in Fall 1993 and Spring 1994 when we distributed short courses in systems engineering to multiple sites of United Technologies; feedback from United Technologies was very positive and we are currently working with the University of Maryland Instructional Television (ITV) system to prepare a broad array of courses to be made available in this format.

Our ultimate goal is to be able to deliver instruction directly to the desktops of practicing engineers. Once this has been accomplished, we will have installed the infrastructure necessary to fully integrate our research and education programs with industry.

**Enhance the Diversity of the ISR Population.** The ISR has an outstanding record of enhancing diversity in its programs. For example:

- Of the 96 Young Scholars over the last five years, 42 (44%) were women and 19 (20%) were African-American or Hispanic.
- Of the 49 REU participants over the last five years, 16 (32%) have been women and 21 (42%) have been African-American.
- Of the 40 students enrolled in the MSSE program during Fall 1995, 8 (25%) were women and 7 (18%) were African-American or Hispanic.

We have not been as successful in attracting and retaining women and minority students in the M.S. and Ph.D. programs of our constituent departments; of the 315 graduate students currently affiliated with the ISR, only 49 (16%) are women and only 17 (5%) are African-American or Hispanic. Our goal is to build on our successes and become a focal point of diversity enhancement in the A. James Clark School of Engineering at UMCP—especially as it applies to graduate education. We intend to pursue funding opportunities that will let us aggressively recruit women and minority graduate students in engineering and support them while they pursue advanced degrees. And "support" refers not only to financial support: our goal is to create an infrastructure that will bring these new graduate students into the "research community" of which the ISR is a part.

The educational programs of the ISR fulfill two vital aspects of the ERC mission: to disseminate the research and techniques developed at the Institute and to educate a "new breed" of engineer. The existing programs carry out those goals extraordinarily well; we intend to maintain and expand those successful programs while simultaneously undertaking the exciting new challenges set forth above. ⌘

# Industrial Collaboration and Technology Transfer Plan

**Industrial Partnership Program.** The ISR is building on its highly successful Industrial Partnership program. During the past 11 years, the number of patents and copyrights issued to the Institute has increased, the amount of intellectual property licensed to industry has grown and the level of industrial participation in the activities of the Institute has expanded significantly. Furthermore, the ISR's industrial collaboration has served as a model for others to emulate; the ISR has spun-off two very successful academic/industry research consortia—the CALCE Electronics Packaging Research Center, which is now independently funded as an NSF State/Industry/University Cooperative Research Center and the Center for Satellite and Hybrid Communication Networks, a NASA and industry-funded research center. Both of these centers remain closely affiliated with the ISR and share its administrative resources and research facilities.

Not only is the ISR building on its past relationships with industry, it is also reaching out across the nation to play an increasing role in the national agenda. The issue of systems research is an increasing part of the national agenda and the ISR is assuming its rightful place of leadership in this national forum.

The goal of the ISR's Industrial Partnership Program is to promote the growth of American industrial competitiveness by accelerating the rate at which fundamental engineering advances are applied by industry. The ISR achieves this goal by continuously and actively engaging industrial partners in every level of activity in the organization and, by doing so, promoting the rapid exchange of information between the ISR and those industries.

A company can be involved in the activities of the ISR in many ways—as a member of the ISR's Research Advisory Council, as a member of its Industrial Affiliate Program, as a Research Affiliate, or as a member of a research consortium. The ISR's current industrial partners are listed in *Table 1* at right. The ISR has also engaged its industrial partners in its education program and, in 1993-4, piloted a distance education program with one of its affiliates. The ISR provides many mutually beneficial services for its industrial affiliates. For example, the ISR hosted a two-day workshop by Silvaco International, a developer of semiconductor CAD software, Feb. 19 and 20, 1996. The ISR hosted a similar workshop for TD Technologies to train ISR students and industrial representatives in its SLATE software in the fall of 1995.

**Table 1 Industrial Participation**

| | Industrial Affiliates | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sustaining Partner | Sponsor Associates | Member, Research Advisory Council | Member, CCDS Satellite & Hybrid Comm Sys | Member, Chemical Process Systems Lab | Member, Neural Net Club | Research Affiliate | Small Business | Medium-Sized Business | Fortune 500 | Foreign-Owned Business | Number of years of support |
| Advanced Micro Devices | | ● | | | | | ● | | ● | | | 1 |
| Air Products | | | | | ● | | | | ● | | | 5 |
| Ascent Logic | | ● | | | | | | ● | | | | 2 |
| AT&T Bell Labs | | | | | | ● | | | ● | | | 8 |
| Bellcore | | | | | | ● | | | ● | | | 1 |
| Bentley Systems | | ● | | | | | | ● | | | | 1 |
| Bethlehem Steel | | ● | | | ● | | | | ● | | | 1 |
| BFGoodrich | | | ● | | ● | | | | ● | | | 2 |
| British Petroleum | | | | | ● | | | | | | ● | 5 |
| Chevron | | | | | | ● | | | ● | | | 5 |
| COMSAT | | | | ● | | | | | ● | | | 5 |
| CTA | | | | | | ● | | ● | | | | 2 |
| Dow Chemical | | | | | ● | | | | ● | | | 2 |
| E.I. Dupont de Nemours | | ● | | ● | ● | | | | ● | | | 11 |
| EPRI | | | | | | ● | | | ● | | | 2 |
| ETRI | | | | | | ● | | | ● | | | 1 |
| Exxon | | ● | | ● | | | | | ● | | | 11 |
| Fisher Controls | | | | | ● | | | | ● | | | 2 |
| General Motors | | | | | | ● | | | ● | | | 1 |
| Gensym | | ● | | | ● | | | ● | | | | 2 |
| GTE | | | | | | ● | | | ● | | | 1 |
| Honeywell | | | ● | | ● | | | | ● | | | 4 |
| Hughes Space & Comm. | | | | ● | | | | | ● | | | 4 |
| Hughes Applied Info Systems | | | | | | ● | | | ● | | | 2 |
| Hughes Network Systems | | | | ● | | ● | | | ● | | | 4 |
| IBM | | | | | | ● | | | ● | | | 1 |
| ICI | | | | | ● | | | | ● | | | 4 |
| Integrated Systems, Inc. | | | | | ● | | | | ● | | | 3 |
| Jade Simulations | | ● | | | | | | ● | | | | 4 |
| Lawrence Associates | | | | | | ● | | ● | | | | 1 |
| Lockheed Martin | ● | | ● | ● | | ● | | | ● | | | 11 |
| Loral | | | | ● | | | | | ● | | | 1 |
| LTV Steel | | | | | ● | | | | ● | | | 5 |
| MITRE | | | | | | ● | | ● | | | | 3 |
| Mitsubishi Kasei | | ● | | | ● | | | | ● | | ● | 2 |
| Mobil | | | | | ● | | | | ● | | | 9 |
| Motorola | | | | | | ● | | | ● | | | 1 |
| Nat. Ctr. for Manufac. Science | | | ● | | | ● | | | | | | 2 |
| NeuralWare | | ● | | | ● | | | ● | | | | 2 |
| Northrop Grumman | ● | ● | ● | | | ● | | | ● | | | 11 |
| Pavilion Technologies | | ● | | | ● | | | ● | | | | 1 |
| Praxair | | | | | ● | | | | ● | | | 4 |
| Rhone-Poulenc | | | | | ● | | | | ● | | ● | 10 |
| Rohm & Haas | | | | | ● | | | | ● | | | 2 |
| Setpoint, Inc. | | ● | | | ● | | | ● | | | | 1 |
| Silvaco | | ● | | | | | | ● | | | | 1 |
| Superconducting Technologies | | | | ● | | | | ● | | | | 4 |
| TD Technologies | | ● | | | | | | ● | | | | 1 |
| Texaco | | ● | | ● | | | ● | | | ● | | 3 |
| Texas Instruments, Inc. | | ● | ● | ● | | | ● | | | ● | | 6 |
| Trillium Network System | | | | ● | | | | ● | | | | 2 |
| TRW | | | | ● | | | | | | ● | | 8 |
| Unilever | | | | | | ● | | | | | ● | 4 |
| United Technologies | | | ● | | | | | | | ● | | 2 |

## Industrial Collaboration and Technology Transfer Plan

**Research Advisory Council**. The Research Advisory Council (RAC) is composed of ten senior systems scientists and engineers from across U.S. industry. The current members are listed in the table below. The RAC provides top down oversight of the strategic vision and research agenda of the ISR. The Director corresponds with the RAC throughout the year on important issues and convenes the council at least once annually in College Park. By involving these senior level executives in this advisory capacity, the ISR ensures that both the objectives of the ERC program and the long term needs of industry are being met.

**Table 2 Research Advisory Council**

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**Industrial Affiliate Program**. The Industrial Affiliate program is for those companies that provide unrestricted cash or in-kind grants to the Institute. To acknowledge their special contributions, these industrial affiliates are afforded special privileges within the Institute and increased access to its facilities. The ISR has three levels of participation in this program. A Sustaining Partner provides $200,000 per year for three years; a Sponsor provides $100,000 per year for three years: and an Associate provides $25,000 per year. Sustaining Partners and Sponsors are invited to have a member sit on the Research Advisory Council.

**Research Affiliates**. The greatest interaction with industry takes place as the result of industry becoming directly involved in the research of the ISR. A firm is designated a Research Affiliate when it either sponsors research at the Institute or participates in a joint research project with the ISR. This participation can take place individually or as a member of a research consortium. It has been the ISR's experience that the most successful industry / university rela-

tionships and technology transfer result from collaborative research projects. For example, Westinghouse uses collaboratively developed manufacturing software for cycle-time reduction, with particular application to the company's optimal facility design for antenna assembly and for producability, cost and quality evaluation of electro-mechanical assemblies. Hughes Network Systems will market DirecPC™, a low-cost satellite and terrestrial network service that can deliver data from the Internet to the user at much faster rates; this product resulted from joint research with the ISR.

These collaborative projects also serve to expand the industrial base of the ISR. For example, in 1993, the ISR, in collaboration with two of its sustaining partners, Westinghouse and Martin Marietta and NIST, won a $500,000 Army contract to use emerging product description standards to facilitate product design and partner selection in an agile manufacturing environment. The follow-on plans for this highly successful project include the original industrial partners, plus extend the industrial base to the automotive industry through General Motors and Detroit's Focus Hope and include a software vendor, CTA, which plans to commercialize the results.

This year, the ISR , with industrial partners Sanders (a Lockheed Martin company), Bellcore, GTE and Motorola, won an award to participate in the Army Research Laboratory's $46 million Advanced Telecommunications and Information Distribution Research Program. It will bring more than $5 million in funding to ISR over the next five years. The ISR hosted more than 100 members of the federated laboratory consortium working on the program March 4 and 5 at the University College Conference Center on campus.

The state of Maryland has been a strong supporter of both the NSF's ERC program and the ISR's industrial partnership program. Not only does the state permanently support the operations of the Institute, thus ensuring that the NSF funds are highly leveraged, but it also will provide matching funds for industrial research conducted at the university. Since 1985, the ISR and 19 of its industrial partners have participated in 22 of these Maryland Industrial Partnerships (MIPS) valued at over $4 million.

One of the key features of our Research Affiliate program is the involvement of students in relevant research that is conducted in partnership with industry. The ISR encourages its students to work with industry and each semester the ISR has a number of students who are conducting research at industrial sites. A key feature of the ISR's Industrial Fellowship Program is that Fellows spend summers doing research at the industrial site. The results of this interaction are ISR graduates who are highly sought after by industry.

**Consortium activities**. Participants in consortia organized by the ISR become involved in the ISR's programs within the subject area of the consortium and further extend the reach of the ISR's Industrial Partnership Program. For example, the Center for Satellite and Hybrid Communication Networks (CSHCN), composed of four universities and 13 industrial partners, is one of seventeen NASA Centers for the Commercial Development of Space. The industrial members of the Chemical Process Systems Laboratory (CPSL) sponsor joint research in the control of chemical and petroleum refining operations and the Neural Network Club brings together sixteen national and international companies to conduct research into the use of neural networks in the process industry.

**Summary of plans for the future.** As previously discussed, the ISR plans to build into the future on the already strong foundation laid during its first years of operation. Immediate plans include building on the model of the Neural Network Club by establishing a Network Management Club that deals with networking issues across all industries.

A key aspect of the ISR's plans for the future is to assume an increasing position of leadership in systems research in the national forum and to assist companies in developing systems and control methodology as a corporate strategic technology. The ISR took its first step on this path on Dec. 8, 1994, when it hosted a national industrial workshop to address the "Systems Challenges of the Next Decade." The purpose of the workshop was to identify the barrier issues to systems integration that exist across U.S. industry and to establish a national research agenda to overcoming those barriers. The results of that workshop were distributed in a report to the National Science Foundation and other federal policy agencies and were incorporated into the ISR's strategic research plan.

On May 16, 1996, the ISR held a followup workshop entitled "Model Based Sensing and Control in Semiconductor Manufacturing: How Do We Get from Here to There?" at the University of Maryland at College Park. The purpose of the workshop was to consider the status and prognosis for sensing, modeling, control and their integration for semiconductor manufacturing, focusing on two key questions:

- What technical elements and approaches to their integration are required to achieve the promise of model-based sensing and control?

- What realistic implementation pathway can be envisioned to move from today's paradigm to one of intelligent process control?

The workshop was attended by key leaders from industry, government and academia. It was a small workshop in order to facilitate communication and the free exchange of ideas among the invited participants. A copy of the agenda is shown in the table below.

The workshop was very successful and establishes the ISR as a strong presence in the application of control and systems concepts in semiconductor manufacturing. This workshop builds on the supplemental award granted to the ISR and the Center for Advanced electronic Materials Processing at North Carolina State University. A key organizer and participant in the workshop was Gary Rubloff from NCSU. He will be joining the University of Maryland faculty on July 1, 1996, with a joint appointment in the ISR and the Department of Materials and Nuclear Engineering.

It is the ISR's intention to continue these workshops to ensure that it is receiving close and continuous feedback on its systems level research objectives and to ensure that the results of its research are rapidly communicated to industry.

**Table 3 May 1996 Industrial Conference Schedule**

**Model Based Sensing and Control in Semiconductor Manufacturing:**
**How Do We Get from Here to There?**
Sponsored by the Institute for Systems Research at the University of Maryland at College Park
May 16, 1996

**Introduction and Opening Remarks**
Steven I. Marcus
Director, Institute for Systems Research

***Status and Prognosis***

**State of the Art in Sensing and Control in Semiconductor Manufacturing**
Jimmy Hosch
Texas Instruments/Sematech

**Elements of Process Control Solutions for Implementation in Semiconductor Manufacturing**
John Gragg
Motorola

**Break**

**View from the Equipment Suppliers**
Kevin Uram
LAM Research

**Discussion—Issues Review/Refinement**

**Working Lunch with Discussion**

***Process and Equipment Modeling***

**Process Modeling and Process Control in MOCVD and MBE Growth of Compound Semiconductors**
Peter Esherick
Sandia Albuquerque

***Sensors***

**Sensing and Simulation for Process Optimization, Control and Environmentally-Conscious Manufacturing**
Gary Rubloff
University of Maryland/ISR and NCSU

**Thermo-Electro-Mechanical Structures: Opportunities in Sensing and Control for Manufacturing**
Michael Gaitan
NIST

**Break**

***Model-Based Control***

**Modeling and Sensor-Based Control for Silicon Processing**
P.S. Krishnaprasad
University of Maryland/ISR

**Run-to-Run Control: Methods and Applications in Plasma Etching**
Evanghelos Zafiriou
University of Maryland/ISR

**Discussion: Assessment and Models for Success**

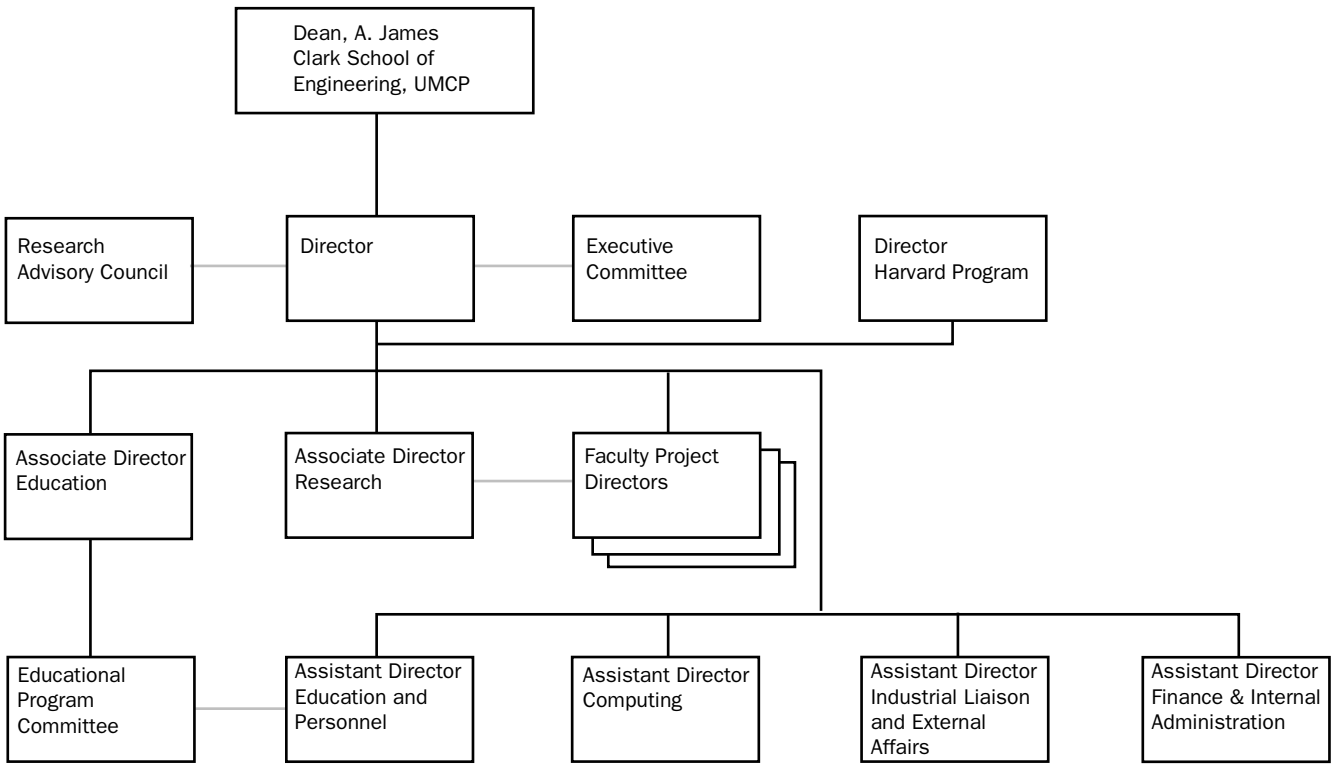
# ISR Infrastructure: Leadership, Management and Team

## Center Leadership and Management

The ISR is an interdisciplinary organization with programs in systems research and education. The Institute involves faculty and students from the Departments of Electrical, Chemical, Mechanical, Aerospace, Civil and Materials and Nuclear Engineering, Computer Science, Mathematics, Physics, Zoology and the College of Business and Management at the University of Maryland, as well as the Division of Applied Sciences at Harvard University. The ISR is a permanent research institute at the University of Maryland under the direction of Steven I. Marcus, Professor of Electrical Engineering.

The administrative operations of ISR fully support the research and education mission of the Institute and contribute significantly to ISR's success. The figure below shows the overall organizational structure of the Institute and demonstrates the integration of administrative and mission functions. The Institute follows the financial processes and procedures prescribed by the University and the University of Maryland Foundation in all financial transactions. The Institute's operating budget is subject to the annual review and approval of its Executive Committee. There is close and ongoing coordination between the Director and the Director of the Harvard Programs, as well as close collaboration between the Maryland and Harvard teams in the Intelligent Control thrust and the Control Networks project. The Institute fosters cross-disciplinary team research by organizing team projects and by conducting rigorous reviews of its research. The research program is reviewed by both the Executive Committee (internal) and the Research Advisory Council (external) to ensure that the program is consistent with the objectives of the ERC program and the Strategic Plan of the Institute.

**Figure 3 Organization of the ISR for FY96**



# ISR Infrastructure: Leadership, Management and Team

## Organization of ISR Personnel and Research Environment

The ISR personnel includes University faculty, research scientists, visiting scientists from other academic institutions, research associates (post-doctoral researchers), graduate and undergraduate research students, visiting engineers and scientists from industry and R&D laboratories, as well as staff.

The ISR continues to maintain extremely high standards for its "new breed" of faculty. They are required to have an outstanding cross-disciplinary background, promise for innovative research, strong interest and ability to collaborate with industry and the ability to be innovative in their approach to educating students. This fiscal year ISR had 55 distinguished faculty participating in research; 38 hold joint appointments with departments at the University of Maryland. Attesting to the quality of our faculty, 15 of the faculty are NSF PYIs or NYIs, 12 are Fellows of IEEE, APS, ASME, or AIChE, one is a member of the National Academy of Engineering and several have received prestigious technical awards for their work. Biographical sketches are included in this report.

The ISR is committed to increasing the involvement of women, under-represented minorities and disabled persons in the faculty and student body in engineering. It actively recruits the highest caliber persons from these categories to participate in ISR's research and education programs. Last spring ISR selected a tenured, female faculty member from the Zoology Department to join as an Affiliate Faculty member to work with other ISR faculty in the area of biologically motivated intelligent control. In addition, ISR plays a leadership role in the School of Engineering to search for women and minority candidates at all levels. We previously took the lead and offered a workshop on "How to Conduct a Successful Hiring Search," and anticipate conducting the workshop again. In our own programs (the M.S. Program in Systems Engineering, Research Experience for Undergraduates and Young Scholars), we have been very successful in attracting members of these groups. ⌘

# ISR Infrastructure: Center Headquarters, Equipment and Facilities

In FY 1996, the University of Maryland made available to ISR an additional 3,000 square feet of laboratory and office space, bringing the total to 30,000 square feet in two buildings on the UMCP campus. In addition, Harvard has made available 4,000 square feet for activities at that site, renovating two floors of a laboratory building. The provision of generous office and laboratory space has enabled ISR to be the primary office location for faculty and students from 10 departments, fostering frequent contact and interaction within this unique community.

Over 9,000 sq. ft. at UMCP is dedicated to nine laboratories, including Intelligent Servo Systems, Systems Integration, VLSI Systems, Communication and Signal Processing, Computer Aided Control Systems Engineering, Computer Integrated Manufacturing and Neural Systems. Another 900 sq. ft. is dedicated to a teaching lab open to ISR graduate and undergraduate researchers. Other affiliated labs include Human Computer Interaction, Space Systems and Advanced Design and Manufacturing.

ISR's computing environment includes several high-end graphics workstations, powerful computing engines and a carefully planned software library. A well-balanced upgrade policy has enabled us to increase our capabilities tenfold in terms of speed and capacity. This has also resulted in our complete migration to open systems and a client-server technology.

The powerful network of Unix workstations that embraces the concepts of distributed computing and a distributed file system encourages the use of new analytical software and techniques to increase the productivity of our researchers and staff and has introduced students to the advanced tools used by leading industries. Some of the tools that constitute ISR's software library are Matlab, Signal Processing Workstation, Bones, Opnet, MatrixX, Octtools, Mentor Graphics and a variety of database and mathematical packages. Supplementing this array is the latest in systems engineering and design software from industrial partners such as Ascent Logic Corp., Integrated Systems Inc. and Jade Simulations. ISR also has specialized hardware ranging from ASIC testers and logic analyzers in the VLSI Design Lab to the advanced machining and rapid mechanical prototyping tools in the Advanced Design and Manufacturing Lab. To complement the powerful capabilities of this software library, ISR's faculty and students have ready access from every workstation to state of the art in parallel supercomputing on the CM5 from Thinking Machine Corp. at the University of Maryland. ⌘

## ISR Infrastructure: Financial Support and Strategic Financial Planning

NSF funding is phasing down, however continued strong state and university support is being used to leverage additional industry, state agency and federal government moneys to maintain the diversified funding base of the Institute. Total annual support to the Institute from all sources for FY 96 was about $12,000,000.

Salary and benefits for faculty and staff positions are funded exclusively from State and University sources, as is the cost of general operations. In addition to specific research funding provided by industry, NSF and other federal and state agencies, State and University moneys also provide nearly $800,000 per year as matching to designated research initiatives of the faculty and Institute.

Federal funding is directed almost exclusively to the costs of basic research in integrated design and control of complex engineering systems, providing salary and equipment support to professional, post graduate and graduate student researchers. Targeted educational programs for talented high school and undergraduate students also receive directed support from NSF.

The ISR continues to leverage support for its research efforts in agreements that increase its research capability without the need for additional financial support. For example, in FY 1995, ISR signed three Cooperative Research and Development Agreements (CRADAs) that provide access to AT&T and federal laboratory research and facilities.

Using these and other well established contacts with numerous federal agencies, state programs and industry, ISR will continue to explore mission and applications oriented research opportunities of mutual interest. The income from industry and other federal sources shown in the chart above is based on ISR's FY 95 funding from these sources. In addition, efforts will continue to form consortia of teams of ISR faculty, outstanding faculty from other universities, industries and federal agencies to pursue programs of national importance, such as the Center for Satellite and Hybrid Communication Networks, an ISR affiliated NASA-sponsored program.

As it transitions to self-supporting ERC status, the ISR's state funding will continue at approximately its current level and other federal support will remain strong. In addition to developing targeted funding around consortia and research projects, a key issue for the ISR is how to increase industry funding and how to develop additional funding to seed research and fund post-docs and fellowships. ⌘

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## Dana S. Nau

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## Mark A. Shayman

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## Ben A. Shneiderman

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## Guangming Zhang

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Eyad H. Abed received the S.B. degree from the Massachusetts Institute of Technology in 1979 and the M.S. and Ph.D. degrees in 1981 and 1982, respectively, from the University of California at Berkeley, all in Electrical Engineering. He has been with the Department of Electrical Engineering at the University of Maryland since 1983, where he is presently a Professor and holds a joint appointment with the Institute for Systems Research. Dr. Abed is a recipient of the Presidential Young Investigator Award from the National Science Foundation, the O. Hugo Schuck Best Paper award from the American Automatic Control Council, the Outstanding Systems Engineering Faculty Award of the Institute for Systems Research and the Alan Berman Research Publication Award from the Naval Research Laboratory and two teaching awards from the University of Maryland. He serves on the Advisory Editorial Board of *Nonlinear Dynamics*.

Dr. Abed's past research includes contributions on the following subjects: control of nonlinear systems exhibiting bifurcation and chaos; singular perturbation analysis and reduced-order modeling; nonlinear stability and stabilization; linear robust stability; gas turbine jet engine dynamics and control; electric power system dynamics and control; tethered satellite control; aircraft control; and radar system dynamics. He is also investigating the use of nonlinear dynamics in communication systems and signal processing applications.

## Raymond A. Adomaitis

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After receiving his Ph.D. from IIT in 1988, Dr. Adomaitis became a postdoctoral research associate in the Chemical Engineering Department of Princeton University.

He accepted a postdoctoral Fellowship at the University of Maryland in 1990, joined the research faculty in 1992 and became an Assistant Professor in 1995.

He has also held short-term appointments at Los Alamos National Laboratory and the Institute for Mathematics and Informatics at the Lithuanian Academy of Sciences in Vilnius, Lithuania.

Dr. Adomaitis is a member of the AIChE, AIAA and SIAM. He is one of the organizers of the 1995 workshop "Noninvertible Dynamical Systems: Theory, Computation, Applications," has served as a panel member for the 1994 ARO workshop "Intelligent Turbine Engines for Army Applications," chaired the sessions "Nonlinear Dynamical Problems in Process Control," (1993 ACC), "Rotating Stall II," (1995 SPIE), "Microelectronics and Thermal Process Control," (1995 ACC) and is a referee for numerous journals, one book and several proposals. He is currently serving on a number of University of Maryland academic service committees.

He is currently advising one B.S. and two Ph.D. students and is co-advising two Ph.D. students; all are involved in modeling and model reduction research for intelligent materials manufacturing processes. He has been a member of eight Ph.D. thesis committees and one M.S. committee.

Dr. Adomaitis' research interests include systems modeling methodologies for simulation and control of materials manufacturing processes and aircraft propulsion systems. This research aims to develop a modeling framework which gives reduced order models, suitable for analysis and model-based control, consistent with the high-fidelity dynamic simulations. This research encompasses aspects of computational fluid dynamics, bifurcation analysis, parallel computing techniques, nonlinear control and nonlinear signal processing.

## Mark Austin

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Dr. Austin received his Master of Science and his Ph.D. degrees in Structural Engineering from the University of California, Berkeley, in 1982 and 1985, respectively. He received his Bachelor of Engineering in 1980 from the University of Canterbury, New Zealand.

Dr. Austin was a Research Assistant at the University of Canterbury, New Zealand, from November 1980 to July 1981. From 1982 through 1985, he was a Research Assistant at the University of California, Berkeley and from 1985 through 1987 he was a Research Engineer at the same institution. He has worked as a faculty member at the University of Maryland since 1987. For the period 1989–1991, Dr. Austin received the NSF Research Initiation Award.

In 1989, Dr. Austin was a member of the ASCE Maryland Section Seismic Provisions Review Committee. He is currently a reviewer for NSF and *ASCE Journal of Structural Engineering*. Dr. Austin is affiliated with the American Society of Civil Engineers, the New Zealand Society of Earthquake Engineering, the Association of Computing Machinery and the American Institute of Aeronautics and Astronautics.

Dr. Austin's research interests are in the areas of computer-aided design of civil engineering structures, numerical algorithms for multibody dynamics and control and earthquake engineering.

## Michael O. Ball

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Michael Ball received his BES in Engineering Science and MSE in Operations Research from Johns Hopkins University in 1972 and his Ph.D. degree in Operations Research from Cornell University in 1977.

Dr. Ball joined the University of Maryland faculty in 1979 as an Assistant Professor and in 1984 he became Associate Professor in the College of Business and Management. In 1988, he became a Professor in the College of Business and Management and in 1990 he received a joint appointment with that College and the Systems Research Center. Dr. Ball is a member of the Operations Research Society of America, the Mathematical Programming Society, the Society for Industrial and Applied Mathematics and IEEE. He is associate editor for *Networks and Operations Research Letters* and has been area editor for optimization for the journal *Operations Research* and associate editor for *IEEE Transactions on Reliability*.

Dr. Ball held several industrial positions from 1973 to 1978, at companies including the U.S. Environmental Protection Agency, Network Analysis Corp. and Bell Laboratories. Since 1979 he has consulted with a variety of private companies and government agencies, including the Federal Aviation Administration, Sprint, CACI, Inc., the United States Postal Service, the Military Airlift Command and United Parcel Service.

Dr. Ball's research interests are in the areas of network optimization and network reliability analysis, particularly applied to the design of telecommunications networks, transportation systems and manufacturing systems. He has published extensively on these topics in a variety of journals. His research has been funded by the U.S. Department of Transportation, the U.S. Army Research Office, NSF, IBM, United Parcel Service, Westinghouse, Loral and Hughes Networks Systems.

## John S. Baras

**Lockheed Martin Chair in Systems Engineering, Professor, Electrical Engineering and the Institute for Systems Research**

John S. Baras received the BS in Electrical Engineering from the Nat. Tech. Univ. of Athens, Greece, in 1970 and the M.S. and Ph.D. degrees in Applied Math. from Harvard University in 1971 and 1973.

Professor Baras was the founding Director of the ISR from 1985 to 1991. Since August 1973 he has been with the Electrical Engineering Department and the Applied Mathematics Faculty, at the University of Maryland, College Park, where he is currently a Professor holding a permanent joint appointment with the ISR. In February 1990 he was appointed to the Lockheed Martin Chair in Systems Engineering. Since 1991 Dr. Baras has been the Director of the Center for Hybrid and Satellite Communication Networks (a NASA Center for the Commercial Development of Space).

Among his awards are: a 1978 Naval Research Laboratory Research Publication Award, the 1980 Outstanding Paper Award of the IEEE Control Systems Society, 1983 and 1993 Alan Berman Research Publication Award from NRL. Professor Baras is a Fellow of IEEE. 1991 Outstanding Invention of the Year Award from the University of Maryland for the invention of a Low Complexity CELP Speech Coder (with Y.H. Kao). 1993 and 1995 Alan Berman Research Publication Award, from the Naval Research Laboratory. 1994 Outstanding Invention of the Year Award from the University of Maryland for the invention of "A System Design for a Hybrid Network Data Communications Terminal Using Asymmetric TCP/IP to Support Internet Applications" (with A. Falk, D. Freidman, B. Johnson, T. Ephremides, T. Kirkwood, N. Suphasindhu and D. Dillon). 1995 Award for Outstanding Performance for Analysis, Engineering and Implementation of a Novel, Actively Controlled Toolpost for High Precision Machining by SMS Team. November 1995, Outstanding Contributions to Seniors Award, from the Vice President for Student Affairs and the Senior Council. January 1996, Outstanding Paper Award, "ATM in Hybrid Networks" presented at Design SuperCon 1996 Conference, Santa Clara, CA. April 1996, MIPS Research Award of Excellence for Outstanding Contributions in Advancing Maryland Industry for work done with Hughes Network Systems (with A. Falk).

He has served in the following: Board of Governors of the IEEE Control Systems Society, IEEE Engineering R&D Committee; Aerospace Industries Association advisory committee on advanced

sensors; IEEE Fellow evaluation committee, the planning committee for the Montgomery County Maryland Information Technologies Center. He is currently serving on the editorial board of *Mathematics of Control, Signals and Systems*, the editorial board of *Systems and Control: Foundations and Applications*, the editorial board of *IMA J. of Mathematical Control and Information*, the editorial board of *Systems Automation- Research and Applications* and he is the managing editor of the series *Progress in Automation and Information Systems* from Springer-Verlag.

Professor Baras' main research interests include stochastic systems, real-time parallel architectures for nonlinear signal processing, object-oriented network management systems, satellite and hybrid communication networks, expert and symbolic systems for control and communication systems synthesis, distributed parameter systems, planning and optimization, real-time architectures for intelligent control, mathematical foundations of vision, intelligent manufacturing of smart materials.

## Carlos A. Berenstein

**Professor, Mathematics and the Institute for Systems Research**

Carlos Berenstein received his Licenciado en Matematicas in 1966 from the University of Buenos Aires. In 1969 and 1970 he was awarded his M.S. and Ph.D. degrees from New York University.

Carlos Berenstein was an Instructor at the University of Buenos Aires 1964 to 1965 and a Research Fellow at CNICT (Buenos Aires) in 1966. He worked as an Assistant Professor at Harvard University from 1970 to 1973 and a Research Fellow from 1975 to 1976. He served as Assistant Professor at the University of Maryland from 1973 to 1975 and later as an Associate Professor from 1976 to 1980. He became full Professor at the University of Maryland in 1980 and in 1985 joined the Systems Research Center as a research faculty appointment. Since 1995 he has held a permanent position in the Institute for Systems Research, awarded for outstanding contributions to system science.

He has held Visiting Professor positions at Scuola Normale Superiore (Pisa), Brandeis University, IMPA (Rio de Janeiro), University of Kiel, Université P. et M. Curie (Paris), Université de Paris (Orsay and Paris IV), Ecole Polytechnique, Univ. de Bordeaux and Bar Ilan University. Dr. Berenstein was the Director of the Center for Applications of Mathematics at George Mason University from 1990 to 1991.

Dr. Berenstein received a Sloan Foundation Graduate Fellowship, from 1967 to 1970 and the Founder's Day Award of New York University in 1971. He received a grant from the U.S. Army Research Office in Durham and has received continuous support from the NSF since 1973 He is currently supported by NSA. The Argonne Universities Association also awarded Dr. Berenstein a "Special Year" grant. In 1989, Dr. Berenstein received the National Academy of Science Travel Award to Soviet Union and in 1990, he received the Hironaka Fellowship and was a Visiting Professor at the Research Institute of Mathematical Sciences in Kyoto, Japan from June to July in 1990.

He also has received grants to travel to Israel by the Binational Science Foundation and in 1995 was the only American in the Annual Taniguchi Conference in Katata, Japan.

Professor Berenstein's research interests lie in the theory and applications of complex variables, convolution equations, complexity and linear systems. Particularly interesting recent applications are to medical tomography and non-destructive evaluation.

Berenstein has written five books, edited another six and written more than 100 research articles.

## Roger W. Brockett

**An Wang Professor of Electrical Engineering and Computer Science, Division of Applied Sciences, Harvard University**

Roger Brockett received his B.S. in 1960 from the Case Institute of Technology. There he was awarded an M.S. degree in 1962 and Ph.D. in 1964. From 1963 to 1967 Dr. Brockett was an Assistant Professor of Electrical Engineering at Massachusetts Institute of Technology and an Associate Professor in the same department from 1967 to 1969. From there he became a Gordon McKay Professor of Applied Mathematics at Harvard University and was named to the An Wang Chair in Electrical Engineering and Computer Science in 1989. He has held a variety of consulting positions from 1965 to the present, including work at Lincoln Laboratory, Martin Marietta Co., U.S. Army Material Command, Scientific Systems, Inc., U.S. Army Night Vision Laboratory and General Electric Corporate Research Labs.

Dr. Brockett is a member of the National Academy of Engineers, a fellow of the IEEE and member of the AMS, SIAM, Sigma Xi and Tau Beta Pi. He has been a member of the IEEE Control Society Advisory Committee (1972–1975), Automatic Control Group's Information Dissemination Committee (1966–1969) and Program Chairman for the Joint Automatic Control Conference (1971).

He has held a Guggenheim fellowship for the study of mathematical system theory, was awarded

the American Automatic Control Council's Richard E. Bellman Control Heritage Award in 1989 and the IEEE Field award in Systems Science and Engineering in 1991.

Dr. Brockett's research interests are in system theory, robotics and computer vision.

## M. Scott Corson

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Dr. Corson is an expert in distributed communication protocols, having developed distributed algorithms for achieving highly adaptive, multipath routing; medium access for multi-receiver communication systems; reservation-based multicast routing in mobile networks; and self-organizing, scaleable, reliable multicast transport in high-speed networks. Concepts developed from his work on scaleable, reliable multicast are being incorporated into the ARPA-sponsored Real-Time Information Transfer and Networking (RITN) project to support Distributed Interactive Simulation and the STOW '97 demonstration. He is currently working with Hughes Network Systems on a project to extend IP multicast over the asymmetric DBS system for inclusion in the DirecPC product. He is currently a co-chair of the Mobile Mesh Networking BOF group within the Internet Engineering Task Force (IETF). The group's goal will be to standardize an IETF protocol for routing in mobile, multihop packet radio networks.

He is also an expert in object-oriented software and programming. He is currently managing development of an integrated tactical and strategic network simulation and management capability for the Army Research Laboratory, for use in a possible follow-on to the Force XXI effort, as well as developing new routing technologies for possible inclusion in future mobile Army communication networks. The testbed is CORBA-compliant and will consist of a object-oriented hierarchical simulation framework to permit the fast performance evaluation of large communication networks.

## Wijesuriya P. Dayawansa

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Dr. Dayawansa received his Master of Science in Electrical Engineering from Clarkson University in Potsdam, NY in August 1982 and his Doctor of Science in Systems Science and Mathematics from Washington University in St. Louis, MO, in August 1986. He received his Bachelor of Science in Electrical Engineering from University of Peradeniya in Sri Lanka.

Dr. Dayawansa was an assistant professor in Mathematics at Texas Tech University from September 1986 till August 1989. Since then he has been in the Electrical Engineering and the Institute for Systems Research at the University of Maryland at College Park as an assistant professor until Aug. 15, 1992 and as an associate professor since then. Dr. Dayawansa has published over 20 papers in books and in refereed technical journals and over 20 papers in refereed conference proceedings. He has served in the program committee of the IEEE Conference on Decision and Control in 1990.

He is a member of the IEEE, AMS and SIAM and has served as an associate editor of the *SIAM Journal on Control and Optimization*, a corresponding editor of the *Journal of Mathematical Systems, Estimation and Control* and the *IEEE Transactions on Automatic Control*.

Dr. Dayawansa's interests are in the area of mathematical theory of nonlinear control systems, control theory of smart material actuators and sensors and robotics.

## Anthony Ephremides

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Anthony Ephremides received his B.S. degree from the National Technical University of Athens (1967) and M.S. (1969) and Ph.D. (1971) degrees from Princeton University, all in Electrical Engineering. He has been at the University of Maryland since 1971 and currently holds a joint appoint-appointment as Professor in the Electrical Engineering Department and the Institute of Systems Research. He is co-founder and co-director of the NASA Center for Commercial Development of Space on Hybrid and Satellite Communications Networks established in 1991 at Maryland as an off-shoot of the ISR. He was a Visiting Professor in 1978 at the National Technical University in Athens, Greece and in 1979 at the EECS Department of the University of California, Berkeley. During 1985–86 he was on leave at MIT and ETH in Zurich, Switzerland.

He is the President of the Board of Governors of the Information Theory Group of the IEEE. He has been an Associate Editor on *Estimation of the IEEE Transactions on Automatic Control* and is now the Associate Editor for *Queueing Networks*. Dr. Ephremides is also the President of Pontos, Inc., a private consulting firm and a Member of the Advisory Scientific Committee of the University of Crete. He was the organizer of the 1983 IEEE Workshop on Multi-User Information Theory and Systems and has taught several short courses on the subject under

continuing engineering programs in the United States and abroad. He was the General Chairman of the 1986 IEEE Conference on Decision and Control in Athens, Greece. He has also been the Director of the Fairchild Scholars and Doctoral Fellows Program, an academic and research partnership program in Satellite Communications between Fairchild Industries and the University of Maryland. He won the IEEE Donald E. Fink Prize Paper Award (1992). He has been the President of the Information Theory of the IEEE (1987) and served on the Board of the IEEE (1989 and 1990).

Dr. Ephremides' interests are in the areas of communication theory, communication systems and networks, queueing systems, signal processing and satellite communications.

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In 1989 he received the Presidential Young Investigator Award by the National Science Foundation. He has received three awards for teaching excellence from the department of Computer Science (1987, 1992, 1996).

His research interests include physical data base design and searching methods for medical, multimedia and spatial data.

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Dr. Farvardin was the Associate Editor for *Quantization, Speech/Image Coding* of the I*EEE Transactions on Communications* during 1986–1990 and is currently Associate Editor for *Source Coding* of the *IEEE Transactions on Information Theory*.

Professor Farvardin was the recipient of the Allen B. Dumont Prize as a graduate student in Electrical, Computer and Systems Engineering at RPI. He received the 1987 George Corcoran Award for outstanding contributions to Electrical Engineering Education at the University of Maryland. In 1987, he received the Presidential Young Investigator Partnerships Award of Excellence (with J. Jájá) and in 1993 he received the Outstanding Systems Engineering Faculty Award from the Institute for Systems Research, University of Maryland.

He was the faculty advisor for a team of students which received the 1996 Texas Instruments DSP Solutions Challenge 1996 Award for the American Division.

Dr. Farvardin's research interests include information theory, digital communications and signal processing with application to speech/image coding and transmission in particular for wireless communication systems.

## Michael C. Fu

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Dr. Fu received his Ph.D. and M.S degrees in applied mathematics from Harvard University in 1989 and 1986, respectively. He received S.B. and S.M. degrees in electrical engineering and an S.B. degree in mathematics from the Massachusetts Institute of Technology in 1985. Since 1989, he has been at the University of Maryland at College Park, in the College of Business and Management.

Dr. Fu is a member of IEEE and the Institute for Operations Research and the Management Sciences (INFORMS). He is an Associate Editor of the *INFORMS Journal on Computing and IIE Transactions*. He was on the Program Committee for the Spring 1996 INFORMS National Meeting, in charge of contributed papers. In 1995 he was awarded the Maryland Business School's annual Allen J. Krowe Award for Teaching Excellence. He has authored or co-authored more than 30 journal articles and conference proceedings.

## Thomas E. Fuja

**Associate Professor, Electrical Engineering and the Institute for Systems Research**

Thomas Fuja received his undergraduate education at the University of Michigan, graduating with a B.S.E.E. and a B.S.Comp.E. in 1981. He pursued his graduate studies at Cornell University, receiving an M.Eng. and a Ph.D. in 1983 and 1987, respectively.

In 1982–83 Dr. Fuja worked at AT&T Bell Laboratories in Holmdel, N.J.—first in the Satellite Communications Department and later in the Loop Transmission Laboratory. Since August 1987 he has been a member of the faculty at the University of Maryland, where he holds a joint appointment in the Department of Electrical Engineering and the Institute for Systems Research. Dr. Fuja was promoted from Assistant Professor to Associate Professor with tenure effective August 1993. He currently serves as Associate Director for Education in the Institute for Systems Research.

Dr. Fuja has been very active in the IEEE Information Theory Society—serving as the Society's treasurer from 1989 to the present and organizing and chairing sessions at technical conferences. In 1989 Dr. Fuja received the National Science Foundation's Presidential Young Investigator award. In 1991 he received the George Corcoran Memorial Award for teaching and educational leadership in electrical engineering at the University of Maryland.

Dr. Fuja's research interests lie in many different aspects of digital communication systems—particularly in coding theory and applications and information theory. Most recently he has become interested in the channel coding problems associated with transmitting compressed speech and video signals over wireless channels.

## Evaggelos Geraniotis

**Professor, Electrical Engineering and the Institute for Systems Research**

Evaggelos Geraniotis received the Diploma (with highest honors) in Electrical Engineering from the National Technical University of Athens, Athens, Greece, in 1978 and the M.S. and Ph.D. degrees in Electrical Engineering from the University of Illinois at Urbana-Champaign in 1980 and 1983, respectively. From September 1982 to August 1985 Dr. Geraniotis was an Assistant Professor of Electrical and Computer Engineering at the University of Massachusetts, Amherst. Since September 1985 he has been with the University of Maryland, College Park, where he is presently Professor of Electrical Engineering and a joint faculty member of the Institute for Systems Research. Dr. Geraniotis has received several awards including the Ministry of Education of Greece First National Prize in 1973 and an Alan Berman Naval Research Laboratory Publication Award in 1990. He is a Senior Member of the IEEE and has served as officer of the Washington D.C./ Northern Virginia Chapter of the Information Theory Society. From February 1989 to December 1992 he was Editor for *Spread-Spectrum* of the *IEEE Transactions on Communications*.

Dr. Geraniotis' research has been in communication systems and networks with emphasis on the traffic and channel modeling, performance evaluation and design of: multi-access protocols for mobile, satellite, cellular and optical networks; multi-media (video, voice and data) integration schemes for wireless networks, optical networks, high-speed ATM networks and hybrid satellite/terrestrial networks. He has also been conducting research on spread-spectrum and anti-jam communication systems; on schemes for interception, feature-detection and classification of signals; on radar detection and discrimination; and on distributed detection, estimation, multi-sensor correlation and data fusion.

## James A. Hendler

**Associate Professor, Computer Science and the Institute for Systems Research**

James A. Hendler is an Associate Professor at the University of Maryland, in the Department of Computer Science and the Institute for Systems Research. Dr. Hendler heads the Autonomous Mobile Robotics Laboratory, an ISR-affiliated laboratory.

In 1978, Dr. Hendler received his B.S. degree in computer science (specializing in artificial intelligence) from Yale University. Between 1978 and 1983, Hendler worked in the areas of artificial intelligence and human factors engineering, first as a research programmer for Yale University's Artificial Intelligence Project and then as a member of the technical staff at Texas Instruments Incorporated. In addition, he continued his studies, earning two Master's Degrees, one in 1982 from Southern Methodist University's Psychology Department (specializing in experimental psychology) and one in 1983 from Brown University's Computer Science Department. He received his Ph.D. in 1985 working with Dr. Eugene Charniak at Brown University. The Ph.D. work centered on expanding the abilities of AI planning systems.

Dr. Hendler has been a consultant teaching LISP and AI and working in the expert systems area for Smart Systems Technology, Gould Corp., Lisp Machines Incorporated, Symbolics Incorporated,

IBM, OAO and ARD Corp. He is the author of the book *Integrating Marker-Passing and Problem Solving: An activation spreading approach to improved choice in planning* (Lawrence Erlbaum Associates, 1987," is the editor of *Expert Systems: The User Interface* (Ablex, 1987), *Readings in Planning* (Morgan-Kaufmann, 1990; with J. Allen and A. Tate) and *Massively Parallel AI* (AAAI / MIT Press, 1994; with H. Kitano). He also serves as the Artificial Intelligence area editor for the international journal *Connection Science* and is an associate editor of the *Journal of Experimental and Theoretical AI.* He is currently writing a textbook entitled *AI Planning Systems* to be published by Morgan-Kaufmann. Dr. Hendler was the recipient of a 1995 Fulbright Foundation Research Fellowship.

## Jeffrey W. Herrmann

**Assistant Professor, Mechanical Engineering and the Institute for Systems Research**

Dr. Herrmann earned his B.S. in applied mathematics from Georgia Institute of Technology and as a National Science Foundation Graduate Research Fellow from 1990 to 1993, he received his Ph.D. in industrial and systems engineering from the University of Florida. His dissertation investigated production scheduling problems motivated by semiconductor manufacturing. He held a post-doctoral research position in the Institute for Systems Research from 1993 to 1995. He has worked on applied research projects with Harris Semiconductor, Westinghouse Electronic Systems Group, Martin- Marietta, Black & Decker and other manufacturers in the state of Maryland.

His publications cover topics in production scheduling, manufacturing facility design and design evaluation and partner selection for agile manufacturing. His current research interests include the design and control of manufacturing systems and the integration of product design and manufacturing system design.

## Joseph Jájá

**Director, Institute for Advanced Computer Studies and Professor, Electrical Engineering and the Institute for Systems Research**

Joseph JáJá received his B.S. degree with high distinction in Mathematics from the American University of Beirut in 1974. He was awarded his M.S. and Ph.D. degrees in Applied Mathematics by Harvard University in 1976 and 1977, respectively. Dr. JáJá worked as a Teaching Assistant from 1976–77 at Harvard University. He served as an Assistant Professor of Computer Science from 1977–82 and as an Associate Professor of Computer Science from 1982–82 at the Pennsylvania State University. In 1983 he became an Associate Professor of Electrical Engineering at the University of Maryland and joined the Systems Research Center as a research faculty appointment in 1985. He was promoted to full Professor in 1987. He served as the ISR Associate Director for Research from 1988 to 1994. He has been the Director of the Institute for Advanced Computer Studies since July 1994.

Professor JáJá's current research interests are in the areas of high-performance computing and VLSI signal processing.

## P.S. Krishnaprasad

**Professor, Electrical Engineering and the Institute for Systems Research**

P.S. Krishnaprasad received his Ph.D. degree from Harvard University in 1977. He was on the faculty of the Systems Engineering Department at Case Western Reserve University from 1977 to 1980. He has been with the University of Maryland since August 1980, where he has held the position of Professor of Electrical Engineering since 1987 and a joint appointment with the Institute for Systems Research since 1988. At Maryland, Krishnaprasad is also a member of the Faculty of the Applied Mathematics Program. He has held visiting positions with Erasmus University (Rotterdam); the Department of Mathematics, University of California, Berkeley; the University of Groningen (the Netherlands); the Mathematical Sciences Institute at Cornell University; and the Mechanical and Aerospace Engineering Department at Princeton University. He has been an active participant in the research programs of the Institute for Systems Research, a collaborative center between the University of Maryland and Harvard University engaged in research in systems problems in engineering.

Dr. Krishnaprasad's research interests lie in the broad area of geometric control theory and its applications. He has contributed to the understanding of parametrization problems in linear systems, the Lie algebraic foundations of certain nonlinear filtering problems pertaining to system identification, the Lie theory and stability of interconnected mechanical systems (e.g., spacecraft with elastic attachments, spinning rotors and fluid-filled cavities) and symmetry principles in nonlinear control theory. He has also investigated mathematical problems in the kinematics and control of robot manipulators, the real-time control of flexible robot arms with end-point sensing, tactile perception and the development of symbolic algebraic tools for design and control. In the last several years, his interests have drawn him to: problems of modeling, design, motion planning and control, arising in mobile robotics (legged and wheeled vehicles,

autonomous underwater vehicles and autonomous aircraft); geometric methods in nonlinear dynamics; wavelet analysis for signals and systems; intelligent control architectures, in part inspired by biological paradigms such as central patterns generators and neural networks; the technology of smart materials such as piezo-electric and magnetostrictive materials for use in actuation and sensing; problems of integration of actuators and sensors in control networks; and modeling, simulation, monitoring and control in semiconductor manufacturing processes, such as rapid thermal chemical vapor deposition and chemical mechanical polishing / planarization.

A central interest in geometric control theory, geometric mechanics, Lie groups and distributed parameter systems, guides the technical approaches taken to attack problems in the above areas. Additionally, this work is also linked to the experimental efforts in the Intelligent Servosystems Laboratory where the current projects include; experiments in positioning, vibration suppression and impact control of a flexible arm; mechanical manipulation with a modular hand; nonholonomic robot design; 3–D solid modeling and graphical animation; a hybrid motor prototype; and motor networks. In the area of semiconductor processing, experimental efforts are being explored with collaborating University and Industry partners.

Dr. Krishnaprasad was on the Editorial Board of *Systems and Control Letters*.

He is a reviewer for IEEE, the National Science Foundation, SIAM journals and others. His professional society memberships include the AIAA and the AMS. He is an Elected Fellow of the IEEE.

P.S. Krishnaprasad was elected a Fellow of the IEEE in 1990 for his contributions to geometric and nonlinear control and engineering education.

## K.J. Ray Liu

**Associate Professor, Electrical Engineering and the Institute for Systems Research**

Dr. K.J. Ray Liu received his B.S. degree from the National Taiwan University in 1983 and his Ph.D. degree from the University of California, Los Angeles, in 1990, both in electrical engineering.

Since 1990 Dr. Liu has been with Electrical Engineering Department and the Institute for Systems Research of University of Maryland at College Park. He is the director of the Digital Signal Processing Laboratory.

His research interests span all aspects of high-performance computational signal processing including parallel and distributed processing, fast algorithm, VLSI and concurrent architecture, with applications to image / video, radar / sonar, communications and medical and biomedical technology. He has published more than 100 papers in these areas.

His research has been supported by the National Science Foundation, the National Institutes of Health, the Office of Naval Research, the Army Research Laboratory and companies such as Westinghouse, Watkins Johnson, Allied-Signal and Micro Star.

Dr. Liu was the recipient of the 1994 National Science Foundation Young Investigator Award in recognition of being one of the nation's most outstanding and promising young faculty in science and engineering. He was awarded the IEEE Signal Processing Society's 1993 Senior Award for a paper of exceptional merit published in the IEEE Transactions on Signal Processing. Dr. Liu received the George Corcoran Award in 1994 for outstanding contributions to electrical engineering education and the Outstanding Systems Engineering Faculty Award in 1996 in recognition of outstanding contributions in research, both from the University of Maryland.

He also received numerous awards including Finalist for Invention of the Year from the University of Maryland, the Research Initiation Award from the National Science Foundation, the University Fellowship and the Hortense Fishbaugh Memorial Scholarship from UCLA, the President Research Partnership from the University of Michigan, the Achievement Award from the Taiwanese-American Foundation, the Service Award from the Mei-Hwa Chinese School and the Book Coupon Award and Prof. Feng Memorial Scholarship from National Taiwan University.

Dr. Liu is an Associate Editor of *IEEE Transactions on Signal Processing*, an editor of the *Journal of VLSI Signal Processing* and a member of the Design and Implementation of Signal Processing Systems Technical Committee of the IEEE Signal Processing Society. He has been in program committees and served as session chairman of numerous international conferences and workshops.

## Armand M. Makowski

**Professor, Electrical Engineering and the Institute for Systems Research**

Armand M. Makowski received the Licence en Sciences Mathematiques from the Universite Libre de Bruxelles in 1975, the M.S. degree in Engineering-Systems Science from UCLA in 1976 and the Ph.D. degree in Applied Mathematics from the University of Kentucky in 1981. In August 1981, he joined the faculty of the Electrical Engineering Department at

the University of Maryland at College Park, where he is presently a Full Professor.

He has been affiliated with the Institute for Systems Research, one of the NSF Engineering Research Centers, since its establishment in 1985; he is currently its Associate Director for Research. He is also a co-founder of and active participant in the Center for Satellite and Hybrid Communication Networks, a NASA center for the development and commercialization of space.

Over the past few years, he has held visiting positions at the Technion (Israel), INRIA (France), the IBM T.J. Watson Research Center (Hawthorne) and AT&T Bell Laboratories (Murray Hill). Armand Makowski was a C.R.B. Graduate Fellow of the Belgian-American Educational Foundation for the academic year 1975–76; he is also a 1984 recipient of the NSF Presidential Young Investigator Award.

Dr. Makowski's research interests broadly lie in applying advanced methods from the theory of stochastic processes to the modeling, design and performance evaluation of a variety of engineering systems, with particular emphasis on communication systems and networks. Recent activities include the use of asymptotic methods for the performance evaluation of switching systems, long-range modeling for multimedia applications in high-speed networks and stochastic control formulation of resource allocation issues in wireless networks (e.g., handoffs and paging). He is also currently involved in several industry-sponsored projects dealing with ATM technology.

## Steven I. Marcus

**Director, Institute for Systems Research and Professor, Electrical Engineering**

Dr. Marcus received his Ph.D. and S.M. from the Massachusetts Institute of Technology in 1975 and 1972, respectively. He received a B.A. from Rice University in 1971. Prior to becoming the Director of the Systems Research Center in 1991, Dr. Marcus held the L.B. (Preach) Meaders Professorship in Engineering at the University of Texas at Austin from 1987 through 1991. He was at the University of Texas at Austin from 1975 until 1991, serving as Associate Chairman of the Electrical Engineering Department from 1984 through 1989.

Steven Marcus is a Fellow of IEEE, the recipient of The Werner W. Dornberger Centennial Teaching Fellowship in Engineering in 1982–83 and 1983–84 and the recipient of the University of Texas Engineering Foundation Award in 1976, 1977, 1980, 1982 and 1986. Dr. Marcus is a member of SIAM, AMS and Operations Research Society of America. He is an Editor of the *SIAM Journal on Control and Optimization* and Associate Editor of *Mathematics of Control, Signals* and *Systems*, *Journal on Discrete Event Dynamic Systems* and *Acta Applicandae Mathematicae*. He has authored or co-authored more than 100 articles, conference proceedings and book chapters.

Dr. Marcus' research interests lie in the areas of control and systems engineering, stochastic systems and discrete event systems.

## Thomas J. McAvoy

**Professor, Chemical Engineering and the Institute for Systems Research**

Thomas J. McAvoy received his B.S. in Chemical Engineering from the Brooklyn Polytechnic Institute in 1961. He received M.A. and Ph.D. degrees in Chemical Engineering from Princeton University in 1963 and 1964, respectively. In 1960 and 1961, Thomas McAvoy worked for the Diamond Alkali Co., Newark and for the M.W. Kellogg Co., New York, in a Computer Applications Group in 1962. In 1964 he worked for Electronics Associates Inc., Computation Center, Princeton. From 1970 to 1971, Thomas McAvoy served in a Research Apprenticeship at Delft University of Technology in Delft, Netherlands. He taught from 1964 to 1980 at the University of Massachusetts, Chemical Engineering Department. In 1980 he began teaching at the University of Maryland, Chemical Engineering department and received his research faculty appointment to the Systems Research Center in 1985.

Professor McAvoy earned the Allied Foundation Award for Excellence in Undergraduate Education in 1982 and received the Donald P. Eckman Education Award in 1987. He was on the Editorial Board for *Instrumentation Technology* from 1983 to 1987, Editorial Board *I&EC Research* from 1989–92, Associate Editor for *Automatica* from 1991–1993, is currently North America Editor for *Automatica* and was a Co-Chairman in 1986 for *Chemical Process Control III*.

Dr. McAvoy's interests are in the areas of neural networks, process control, smart sensing and waste water control.

## Linda Milor

**Assistant Professor, Electrical Engineering and the Institute for Systems Research**

Dr. Milor received her BS degree in Engineering Physics and her Ph.D. degree in Electrical Engineering from the University of California, Berkeley. Her thesis work was on reducing the production testing time of analog circuits.

While a graduate student she conducted research at Bell Laboratories and at IBM. In 1990 she received a joint appointment as an Assistant Professor for the

Electrical Engineering Department and the Institute for Systems Research at the University of Maryland at College Park. She has also spent a year working at Advanced Micro Devices studying yield forecasting, performance prediction and failure analysis.

Dr. Milor's research interests include circuit design, computer-aided integrated circuit design, computer-aided integrated circuit manufacturing, statistical modeling, yield modeling, circuit performance modeling and failure analysis. She has published papers related to testing of mixed signal circuits and yield analysis of circuits using statistical modeling.

## Ioannis Minis

**Associate Professor, Mechanical Engineering and the Institute for Systems Research**

Dr. Minis received his M.S. in mechanical engineering from Clarkson University (1983) and his Ph.D. in mechanical engineering from the University of Maryland (1988). He received his undergraduate degree in mechanical engineering from the National Technical University of Athens, Greece (1982).

He has been with the University of Maryland for 12 years, most recently in a joint appointment with the Department of Mechanical Engineering and the Institute for Systems Research. From 1988 to 1995, he was an assistant professor in the Department of Mechanical Engineering at the University's Baltimore County and College Park campuses. From 1984 to 1988, he was a research fellow and assistant instructor in the Mechanical Engineering Department at the College Park campus.

Dr. Minis is the 1993 recipient of the Earl E. Walker Outstanding Young Manufacturing Engineer Award of the Society of Manufacturing Engineers. He also received the best paper award in the area of Engineering Database Management: *Use of PDES in Group Technology Applications for Electronics,* at the 1992 ASME International Conference on Computers in Engineering.

Dr. Minis' research interests are in the areas of production systems, concurrent engineering and machining dynamics and control.

## Prakash Narayan

**Professor, Electrical Engineering and the Institute for Systems Research**

Dr. Narayan received his Master of Science degree in Systems Science and Mathematics and his Doctor of Science degree in Electrical Engineering from Washington University in St. Louis, MO, in May 1978 and August 1981, respectively. He received his Bachelor of Technology in Electrical Engineering in August of 1976 from the Indian Institute of Technology in Madras, India.

He has been with ISR since 1985 and holds a joint appointment with the Institute. Since 1991, Dr. Narayan has also been a member of the NASA Center for Satellite and Hybrid Communications at the University of Maryland. He has held the position of Visiting Professor at the Swiss Federal Institute of Technology (Zurich), the Technion (Haifa, Israel), the University of Bielefeld (Bielefeld, Germany), the Mathematical Institute of the Hungarian Academy of Sciences (Budapest, Hungary), the Laboratory for Dynamical Systems and Bioengineering (Padova, Italy) and the Indian Institute of Science in Bangalore.

Dr. Narayan has served as a consultant to Bell Communications Research, Morristown, N.J. He is a reviewer for several IEEE Transactions, NSF and other publications and organizations.

Dr. Narayan's interests are in the areas of information theory, communication networks and statistical signal processing.

## Dana S. Nau

**Professor, Computer Science and the Institute for Systems Research**

Dana Nau is a professor at the University of Maryland, in the Department of Computer Science and the Institute for Systems Research (ISR). He is also affiliated with the Institute for Advanced Computer Studies (UMIACS) and the Department of Mechanical Engineering. In ISR, he is co-leader of the EMSYS (Electro-Mechanical Systems Design and Planning) project and co-leader of the Systems Integration research thrust. His research interests include AI planning and searching techniques and computer-integrated design and manufacturing.

Dr. Nau received a B.S. in applied mathematics from the University of Missouri at Rolla in 1974. He received an A.M. (in 1976) and Ph.D. (in 1979) in Computer Science from Duke University, where he was an NSF graduate fellow and a James B. Duke graduate fellow. He has had summer and/or sabbatical appointments at IBM Research, NIST, the University of Rochester and General Motors Research Laboratories. He has been on numerous program committees, review panels and editorial boards and has been the Academic Co-Director for AAAI's Special Interest Group on Automated Manufacturing (SIGMAN). He has co-edited two books and has published more than 150 refereed technical papers. Copies of recent papers and summaries of current research projects are available at http://www.cs.umd.edu/users/nau.

Dr. Nau has received a NSF Presidential Young Investigator Award (1984–89), an IBM faculty development award (1984–86), an honorable mention award in the Texas Instruments 1987 call for papers on AI for industrial automation, an honorable mention for AAAI's best paper award (1991), ISR Outstanding Systems Engineering Faculty award (1993–94) and a best-paper award at the ASME 1995 Computers in Engineering Conference. In 1996 he was made a Fellow of the American Association for Artificial Intelligence (AAAI).

## Nicholas Roussopoulos

**Professor, Computer Science and the Institute of Advanced Computer Studies**

Dr. Roussopoulos received his B.A. degree in Mathematics from the University of Athens in 1969. He received an M.S. degree and a Ph.D. in Computer Science from the University of Toronto in 1973 and 1977, respectively.

Dr. Roussopoulos served as a lecturer in Mathematics for the Greek Army from 1969–1970. From 1971–1976, he was a Research and Teaching Assistant for the Department of Computer Science, University of Toronto. He became a Researcher for the IBM Research Lab in San Jose, California, from 1976–1977. In 1977 he joined the Department of Computer Science, University of Texas at Austin as an Assistant Professor. In 1981 he became Assistant Professor at the Department of Computer Science at the University of Maryland, Associate Professor in 1985 and Full Professor in 1991.

He served on the Space Science Board Committee on Data Management and Computation, (CODMAC), from 1985 until 1988. He was the General Chairman of the ACM International Conference on Data Management 1986. He is an elected trustee of the VLDB Endowment since 1990.

He has also organized and chaired a series of Workshops for the VHSIC Engineering Information System program.

He also serves on the editorial board of two international journals, *Information Systems* and *Decision Support Systems*.

Dr. Roussopoulos' research is in high performance database systems, mobile databases, client-server database architectures, distributed database systems, geographic information systems, network management information systems, database design and management, engineering information systems, software engineering databases and artificial intelligence databases.

Dr. Roussopoulos has published over 80 refereed papers in journals and conferences.

## Shihab A. Shamma

**Professor, Electrical Engineering and the Institute for Systems Research**

Shihab Shamma received his B.S. degree in 1976 from Imperial College, in London, U.K. He received his M.S. and Ph.D. degrees in Electrical Engineering and an M.A. in Slavic Languages from Stanford University in 1977 and 1980.

He has been a member of the University of Maryland faculty since 1984 when he started as an Assistant Professor in the Electrical Engineering Department. He became an Associate Professor in 1989 and a Professor in 1995. He has been associated with the Systems Research Center since its inception in 1985 and received a joint appointment in 1990. Previously, Dr. Shamma worked at the National Institutes of Health and Stanford University.

Dr. Shamma's research interests include biological aspects of sound and speech analysis and computational neuroscience in general.

## Mark A. Shayman

**Professor, Electrical Engineering and the Institute for Systems Research**

Mark Shayman graduated Summa Cum Laude from Yale University with a B.A. in Molecular Biophysics and Biochemistry in 1975. He received his S.M. in Applied Mathematics from Harvard University in 1977 and Ph.D. in Applied Mathematics from Harvard in 1981. From 1981–1986 he was a faculty member in the Department of Systems Science and Mathematics, Washington University, St. Louis, Missouri. Since 1986, he has had a joint faculty appointment in the Electrical Engineering Department and the Institute for Systems Research (ISR) at the University of Maryland where he currently holds the rank of Professor. Within ISR, Dr. Shayman is Graduate Director of the M.S. in Systems Engineering Program and is a member of the Center for Satellite and Hybrid Communication Networks (CSHCN), a NASA Center for the Commercial Development of Space.

Dr. Shayman received the Donald P. Eckman Award in 1984 from the American Automatic Control Council (U.S. member organization in International Federation of Automatic Control) for outstanding contribution to the field of control by a young researcher in the United States. He was granted the Presidential Young Investigator Award in 1985 from the National Science Foundation. Dr. Shayman received the George Corcoran Award for contributions to electrical engineering education from the Electrical Engineering Department and the Outstanding Professor Award from the Graduate

Student Association of the Electrical Engineering Department of the University of Maryland, both in 1988. He has served as Associate Editor of *IEEE Transactions on Automatic Control* and is currently Chair of the Technical Committee on Control Theory of the IEEE Control Systems Society.

Dr. Shayman's research interests are in the control of discrete event systems with application to communication network management.

## Ben Shneiderman

**Professor, Computer Science**

Dr. Shneiderman is head of the Human-Computer Interaction Laboratory and Member of the Institute for Systems Research, all at the University of Maryland at College Park. He has taught previously at the State University of New York and at Indiana University. He regularly teaches popular short courses and organizes an annual satellite television presentation on "User Interface Strategies" seen by thousands of professionals since 1987.

In 1995, he received an Honorary Doctorate of Science from the University of Guelph, Ontario, Canada.

Dr. Shneiderman is the author of *Software Psychology: Human Factors in Computer and Information Systems* (1980) and *Designing the User Interface: Strategies for Effective Human-Computer Interaction* (1987, second edition 1992), Addison-Wesley Publishers, Reading, MA. His 1989 book, co-authored with Greg Kearsley, *Hypertext Hands-On!*, contains a hypertext version on two disks. He is the originator of the Hyperties hypermedia system, now produced by Cognetics Corp., Princeton Junction, NJ. In addition he has co-authored two textbooks, edited three technical books, published more than 180 technical papers and book chapters. His 1993 edited book Sparks of Innovation in Human-Computer Interaction collects 25 papers from the past 10 years of research at the University of Maryland.

Ben Shneiderman has been on the Editorial Advisory Boards of nine journals including the newly formed ACM Transactions on Computer- Human Interaction and the ACM Interactions. He edits the Ablex Publishing Co. book series on "Human-Computer Interaction." He has consulted and lectured for many organizations including Apple, AT&T, Citicorp, GE, Honeywell, IBM, Intel, Library of Congress, NASA and university research groups.

## Nicholas D. Sidiropoulos

**Assistant Research Scientist,**
**The Institute for Systems Research**

Dr. Sidiropoulos was appointed to his present position as Assistant Research Scientist, Institute for Systems Research, University of Maryland at College Park, in January 1996. He is also an Adjunct Professor, Dept. of Electrical Engineering, University of Maryland, since January 1995. From August 1994, to January 1996 he was a Post-Doctoral Research Associate, Institute for Systems Research, University of Maryland at College Park.

His research expertise is in statistical and nonlinear signal processing, optimization and image processing.

His efforts have focused on several problems in optimal filtering, estimation and detection, regression, coding, deconvolution and, more recently, medical imaging.

He has completed work leading to a patent disclosure on the problem of automatic computer-aided selection of window—and—level (dynamic range) parameters for the optimal display of X-rays and other types of very high contrast resolution medical images on filmless radiology workstations. Among other distinctions, he has been the recipient of a Fulbright fellowship (1988–1989) and a teaching award from the IEEE student chapter of the University of Maryland (Fall 1995).

Dr. Sidiropoulos earned a Ph.D. in Electrical Engineering in August 1992 at University of Maryland at College Park and an M.S. in Electrical Engineering in May 1990 at the University of Maryland at College Park. He earned a diploma in Electrical Engineering (highest honors) in July 1988 at the Aristotelian University of Thessaloniki, Greece.

Dr. Sidiropoulos is a member of IEEE, a member of the Technical Chamber of Greece and a registered P.E. in Greece. He is a reviewer for *IEEE Trans. Signal Processing, IEEE Trans. Image Processing, Journal of Visual Communication and Image Representation* and the *Journal of Mathematical Imaging and Vision*.

## V. S. Subrahmanian

**Assistant Professor, Computer Science**
**and the Institute for Systems Research**

V.S. Subrahmanian received his M.S. (1987) and Ph.D. (1989) in computer science from Syracuse University where he was a teaching / research assistant during 1985–89. In 1989, he joined the University of Maryland as an Assistant Professor in Computer Science. In 1993, he received NSF's Young Investigator Award.

Dr. Subrahmanian's work is on the declarative, computational and implementation aspects of reasoning with uncertainty, inconsistency, non-monotonicity and numeric computation in logic programming and deductive databases. He is working on the development of a theoretical foundation for a logic programming / deductive database system incorporating these features. The theoretical foundation is based on characterizing the meaning of such programs in terms of model-theoretic semantics and in terms of fixed-point theory. The fixed-point theory is complicated by the fact that the operators being studied are non-monotonic. He is also developing techniques to compute the alternative semantical constructs developed by us. As one of his intended domain of applications is real-time control systems, it is important that these query processing techniques be very fast at run-time and that they be easily "updatable" in the sense that new information reflecting changes in the environment lead to quick re-evaluation of appropriate queries. He has developed fast, incremental computation techniques for query processing under such circumstances.

## Leandros Tassiulas

**Assistant Professor, Electrical Engineering**

Leandros Tassiulas (S'89, M'91) was born in 1965, in Katerini, Greece.

He obtained the Diploma in Electrical Engineering from the Aristotelian University of Thessaloniki, Thessaloniki, Greece in 1987 and the M.S. and Ph.D. degrees in Electrical Engineering from the University of Maryland at College Park in 1989 and 1991 respectively.

From September 1991 to June 1995 he was an Assistant Professor in the Department of Electrical Engineering, Polytechnic University, Brooklyn, NY.

Since July 1995 he is an Assistant Professor in the Department of Electrical Engineering, University of Maryland at College Park.

His research interests are in the field of computer and communication networks with emphasis on wireless communications and high-speed network architectures and management, in control and optimization of stochastic systems and in parallel and distributed processing.

Dr. Tassiulas received an NSF Research Initiation Award in 1992 and an NSF Faculty Early Career Development Award in 1995.

He co-authored a paper that won the INFOCOM '94 best paper award.

## Andre L. Tits

**Professor, Electrical Engineering and the Institute for Systems Research**

Andre L. Tits was born in Verviers, Belgium on April 13, 1951. He received the 'Inginieur Civil' degree from the University of Liege, Belgium and the M.S. and Ph.D. degrees from the University of California, Berkeley, all in Electrical Engineering, in 1974, 1979 and 1980, respectively.

Since 1981, Dr. Tits has been with the University of Maryland at College Park. Currently, he is an Professor of Electrical Engineering and he holds a permanent joint appointment with the Institute for Systems Research. He has held visiting positions at the University of California, Berkeley, at the Lund Institute of Technology, at INRIA, at the Catholic University of Louvain at Louvain-la-Neuve, Belgium and at the Australian National University.

Dr. Tits received a 1985 NSF Presidential Young Investigator Award. He is a member of the Institute of Electrical and Electronics Engineers, of the Mathematical Programming Society, of the Society for Industrial and Applied Mathematics and of the Association des Ingenieurs sortis de l'Institut Montefiore.

Dr. Tits is an Associate Editor of *Automatica* (the IFAC journal) and an Associate Editor At Large of the I*EEE Transactions on Automatic Control*.

Dr. Tits' main research interests lie in various aspects of optimization-based system design and robust control. The former include theoretical questions in numerical methods for optimization, novel ideas and software for interactive optimization-based design and application of the above to the design of electrical, chemical and mechanical systems. Current projects include the development of a fast feasible algorithm for semi-infinite optimization and the development of graphical tools for exploration of design tradeoffs. Dr. Tits recent work in robust control has dealt with both parametric and dynamic uncertainty, including contributions to the computation of the structured singular value.

## Lung-Wen Tsai

**Professor, Mechanical Engineering and the Institute for Systems Research**

Dr. Lung-Wen Tsai received his B.S. degree from the National Taiwan University in 1967, M.S. degree from the State University of New York at Buffalo in 1970 and Ph.D. degree from Stanford University in 1973.

From 1973 to 1978 he worked for Hewlett-Packard Co. as a research and development engineer and from 1978 to 1986 he worked for the General Motors Re-

search Laboratories as a senior research engineer, staff research engineer and then senior staff research engineer. Dr. Tsai joined the University of Maryland in 1986 as an Associate Professor and became a Full Professor in 1990.

Dr. Tsai is a registered professional engineer in the State of California, a Fellow of ASME and a member of SAE. He is a well-known researcher in the field of Mechanisms and Machine Theory and Robotics. He has published numerous papers in prestigious journals and conference proceedings. Dr. Tsai is the recipient of several prestigious awards including the 1985 ASME Melville Medal, the 1986 General Motors Campbell Award, the 1988 SAE Arch Colwell Award and the 1993 AMR South Pointing Chariot Award. He is the holder of seven U.S. patents and one pending application.

Dr. Tsai's research interests include design methodology, design automation, kinematics and dynamics of mechanisms, automotive engineering, robot manipulators and other intelligent servomechanisms.

## Evanghelos Zafiriou

**Associate Professor, Chemical Engineering Department and the Institute for Systems Research**

Evanghelos Zafiriou received his Diploma in Chemical Engineering from the National Technical University in Athens, Greece, in 1983, where he was the recipient of several awards, including the Technical Chamber of Greece award for having the highest GPA of any NTU student during his senior year. He obtained the Ph.D. degree, also in Chemical Engineering, from the California Institute of Technology, in 1987. He then joined the University of Maryland as Assistant Professor and was promoted to Associate Professor with tenure in 1991. He is the co-director of the Chemical Process Systems Laboratory at ISR.

In 1990 he received the Presidential Young Investigator award from NSF and he has obtained full industrial matching funds.

Dr. Zafiriou has lectured at several short courses for industry nationally and internationally on topics including model predictive control, robust process control and neural networks. In addition to numerous papers, he has co-authored a book on *Robust Process Control* (Prentice-Hall, 1989). He has organized several sessions and meetings on these topics, including, in June 1994, a Workshop of the Int. Federation of Aut. Control on the Integration of Process Design and Control, for which he served as General Chair and Int. Program Committee Chair, as well as Proceedings Editor.

He is a member of the AIChE, IEEE, ACS and SIAM and a panel member and proposal reviewer for five NSF Programs and the ACS. He has served as guest editor for two archival journals and is a reviewer for over a dozen journals.

Dr. Zafiriou's interests are in robust and nonlinear process control, control-relevant identification and run-to-run and feedback control in semiconductor manufacturing.

## Guangming Zhang

**Associate Professor, Mechanical Engineering and the Institute for Systems Research**

Dr. Zhang received M.S. and Ph.D. degrees in Mechanical Engineering from the University of Illinois at Urbana-Champaign in 1983 and 1986 respectively. He also received a M.S. and B.A. degrees from Tianjin University, The People's Republic of China, in 1981 and 1966 respectively. Dr. Zhang has been on the faculty at the University of Maryland since 1989. From 1988 through 1989, Dr. Zhang was a Visiting Research Associate at the Knowledge-Based Engineering Systems Research Laboratory in the Department of Mechanical and Industrial Engineering at the University of Illinois at Urbana-Champaign. He was an Associate Professor at the Beijing Institute of Printing in The People's Republic of China from 1986 to 1988.

Dr. Zhang holds memberships in the following professional associations: American Association for Artificial Intelligence, American Society of Mechanical Engineers, Society of Manufacturing Engineers, Women in Engineering Program Advocates Network, American Society of Quality Control. He received the 1992 ASME Blackall Machine Tool and Gage Award. He was the recipient of the 1993 E. Robert Kent Outstanding Teaching Award from the College of Engineering.

Dr. Zhang's research interests include manufacturing systems, dynamics of mechanical structures, quality engineering, dynamics of machine tools and machining of advanced engineering materials.

## Margaret Brumfield

**Assistant Director for Finance and Internal Operations**

Margaret Brumfield has been with the Institute since 1987. She plans and manages all financial and internal administrative matters of the institute and its associated Centers (CALCE Electronic Packaging Research Center and Center for Satellite and Hybrid Communication Networks), including its total budget of $12 million from state, government and industry sources. She has organized the financial affairs of the institute through the creation and management of a computer-based parallel accounting system and has overseen the development of a computer-based data management system for payroll, inventory, proposal development and facilities utilization. Additional facets of her work include the management of ISR space and facilities and supervision of six employees who perform accounting, payroll, facilities management, inventory tracking and proposal submission activities.

Ms. Brumfield has over 25 years of professional experience in a variety of positions involving financial and administrative management, budgeting, organization and management analysis, contracting and statistical analysis. Before joining ISR, she was senior business affairs specialist with the Corp. for Public Broadcasting. She has also held positions with the U.S. Department of Commerce Office of International Marketing and the U.S. Department of Labor. Ms. Brumfield is a graduate of the University of Maryland, having received a Master of Public Policy degree in Public Sector Financial Management and a Bachelor of Science degree in Economics.

## Susan L. Frazier

**Assistant Director for Education and Personnel**

Ms. Frazier's responsibilities include managing faculty, student and staff affairs. She serves as the personnel and equity officer for the Institute, coordinating recruitment efforts for faculty, post-doctoral appointments and visitors and advising the Director on personnel related issues. She also coordinates administrative and technical staff recruitment and search processes, monitors affirmative action activities and develops visa documentation for employees. She manages the ISR education programs, including the Post-Doctoral Fellowship program and graduate, undergraduate and high school student participation in research and education. She supervises development efforts to solicit funds to support the programs and outreach activities to attract women and minority students to the ISR programs.

Ms. Frazier has been with the Institute since April 1986. Prior to that time, she was a Program Analyst in the Office of the Chancellor at the University of Maryland at College Park, where she was employed for 10 years. Ms. Frazier is a graduate of the University of Maryland; she received her Bachelor of Arts degree in Sociology.

## Amar Vadlamudi

**Assistant Director for Computing and Laboratory Facilities**

As Assistant Director for Computing and Laboratory Facilities, Mr. Amar Vadlamudi coordinates and manages all of the Institute's computing activities. His objectives in this endeavor are to provide a state of the art computer system for research; to teach faculty, students and staff the use of the systems and supported software; to generate revenue through proposals involving software development and outreach functions; and to present a coherent picture of ISR computing to supporting government agencies and industrial affiliates.

The Assistant Director for Computing and Laboratory Facilities plans and manages administrative support for labs; ensures the development of necessary ISR hardware and software capability; maintains productive relations between ISR and vendors; manages software licensing for ISR; recommends and supervises the procurement of computer equipment and outside computer services; coordinates network planning and development; develops and maintains research software; represents ISR on campus committees; provides leadership in key technologies; interfaces with other units within the University; initiates and manages a software club and bulletin board system; assists in the implementation of an outreach to medium and small companies; and assists in the educational outreach functions of ISR.

Mr. Vadlamudi worked under the direction of Dr. Joseph Jájá in the VLSI Systems Laboratory of ISR in 1992 as part of his master's degree program. He subsequently received a Master of Science degree in Electrical Engineering from the University of Maryland at College Park. In 1993 he joined ISR General Computing Staff as a Computer Systems Specialist and maintained and supported the Institute's UNIX computer networks and software environment. In 1994, he became the Institute's Assistant Director for Computing and his broad knowledge in engineering and computer science, as well as his familiarity with the Institute's research activities, enabled him to manage a highly skilled technical team and to assist faculty with specialized equipment needs for their research.

Mr. Vadlamudi is currently involved with the introduction of technologies such as ATM, multicasting and distributed object databases into ISR computing environment.