Summary Statement of Value Added to Industry and the Nation

Contents

1 Original vision and goals

In 1985 the main research theme and vision of ISR (originally the Systems Research Center) was the computer-aided design of complex automatic control and communication systems. This was to be accomplished through fundamental research that synergistically combined advances in three types of technology (VLSI, CAD, and AI) with sophisticated control and communication methodologies. The research plan included:

- In-depth investigation of the impact of VLSI, CAD, and AI;

- Fundamental research in modeling, optimization, computational and numerical methods

- Techniques for control systems, communication systems, and computer engineering;

- A set of five application thrust areas, including intelligent CAD of stochastic systems, intelligent servomechanisms, chemical process control, advanced automation and information processing in manufacturing systems, and telecommunication systems.

When ISR was founded, there was a clear need for a cross-disciplinary center to bridge the gap between control and communication research being undertaken in universities and control and communication practice occurring in industry. ISR's goal was to change the situation by:

- Bringing experiments and industrial interactions into the university and its education and research programs;

- Educating a new breed of engineer who would have a broad as well as a deep foundation, and an understanding of industrial practice;

- Bridging the gaps between disciplines; and

- Transferring technology to industry.

ISR and its original vision have evolved over the years. Our current vision is summarized in Section 3.

2 Value added

2A Impact on the field

Intelligent Control. There have been significant advances in the study of linear and nonlinear systems described by differential equation models, including methods for stability analysis, optimization, robust control, adaptive control, stabilization, tracking, and sensitivity minimizing controllers. ISR has been at the forefront of exciting developments in nonlinear control theory and design principles for nonlinear control systems.

Recently ISR has played a major role in a strong effort to model and understand hybrid models for heterogeneous systems involving both numeric and logical variables. Such models arise in many contexts, including multi-mode systems that are reconfigurable or have failure modes, disk drives, robotic systems and stepper motors. These models involve a close coupling between parts that are governed by differential equations and parts that are governed by models from computer science such as finite state automata. We have developed new analog models for hybrid systems at ISR, as well as a hybrid control formalism based on MDL, our device-independent motion description language. Our aim is to develop methodologies based on these advances which will lead to knowledge and tools for the control of heterogeneous systems.

Signal Processing and Communication. Communication and information processing are critical components of system operation. At the same time, the communication infrastructure of a system itself constitutes a subsystem that must be controlled. Although this coupling between control and communications has been widely recognized, there has been little progress in exploiting it to enhance overall performance. In large communication systems such as communication networks, control methodologies have been used to some degree. ISR has been a leader in this effort.

Networking and signal processing aspects of these systems traditionally have been pursued separately, despite the strong interaction between them. ISR has been at the forefront of current trends that have begun to combine signal processing techniques such as compression, with networking techniques such as broad-band switching, for joint design that integrates across traditionally separate network layers.

ISR has been a leader in the key area of hybrid satellite, terrestrial, and wireless telecommunication networks. There have been significant contributions to network performance evaluation and design, through the NASA-funded Center for Satellite and Hybrid Communication Networks and ISR's participation as a key partner in the Advanced Telecommunications and Information Distribution Research Program (a Federated Laboratory of the Army Research Laboratory).

Furthermore, ISR has initiated the full exploitation of this coupling between communication and control by considering the impact of communication technology on control design. Instances in which the coupling has yet to be fully exploited include control strategies' reliance upon sensor technology and data fusion, the effects of signal compression techniques on servo loop bandwidth, and the use of hierarchical signal representations (such as progressive coding and compression) both for adaptive network flow control and for improved operation of control systems in general.

Systems Integration Methodology. There is a need for a rational methodology for solving problems of systems integration. There is a considerable body of knowledge on object-oriented programming and object-oriented databases, and there has been progress in describing products with higher level codes.

However, no methodologies exist for representing processes in an object-based manner at a higher level of abstraction. These are not just computer science or software issues. They require, for example, a close coupling with research on modeling. ISR has been a leader in the development of fundamentals for heterogeneous databases and deductive databases. Complexity has been studied for some classes of models, but quantitative theories of model complexity for heterogeneous systems do not exist.

The use of feedback to manage system complexity has been studied extensively, but systematic efforts to make quantitative comparisons between architectures for heterogeneous systems have been lacking. ISR has been at the forefront of research on optimization and trade-off analysis based on linear and nonlinear optimization. This has culminated in widely used tools such as CONSOL and FSQP.

Progress on mixed integer-nonlinear programming has been made at a number of universities. However, there is a clear need for tools and methodologies for analyzing tradeoffs between conflicting specifications and performance metrics for complex heterogeneous systems. ISR has been a leader in AI planning (including heterogeneous planning), and is now beginning to combine these methods with optimization-based techniques to perform tradeoff analysis for heterogeneous systems.

2B Impact on industry

Strategic partnerships with the industrial community are critical to ISR's success and continuing evolution. 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 ISR and those industries.

Companies can participate in ISR activities as industrial partners; as members of ISR centers or consortia; by sponsoring research or participating in joint research; or by sponsoring fellowships and participating in educational programs. More than 100 companies have benefited from participation in ISR programs since the Institute's inception.

Examples of ISR's impact on industry

Workshop on Barriers to Systems Integration. On Dec. 8, 1994, the Institute for Systems Research hosted an industrial workshop to identify the barriers that stand in the way of industry's ability to do systems integration. Participants from a wide range of U.S. industries were invited to work together to identify those that were common across their industries and, hence, would provide the greatest payoff if overcome. The working groups identified 41 specific barriers that interfered with the ability to do systems integration and which cut across industry boundaries. The participants concluded that they were facing a number of common issues and that inadequate resources were being devoted to addressing these issues. The results of the workshop were published in a report to the National Science Foundation entitled "Systems Challenges for the Next Decade," which was widely distributed.

DirecPC™. ISR researchers collaborated with Hughes Network Systems engineers to develop a low-cost, hybrid (terrestrial and satellite) network service that could deliver data from the Internet to users at rates up to 160 kilobits per second. Satellite technology makes it possible for DirecPC™ to provide this high data rate immediately without waiting for incremental upgrades to cable or telephone plants. Users equipped with a 9600 BPS modem now can experience a 40-fold increase in speed receiving material. Hughes took the technology commercial in November 1994 and markets this product to businesses and computer enthusiasts. The University of Maryland Office of Technology Liaison recognized DirecPC™ as the top physical science invention disclosed in 1994.

Smart tool post for precision machining. Smart materials are critical for creating structures that can sense and react to their environment. This project explored the application of smart materials in machine tools for vibration compensation. ISR worked with three industrial partners (Martin Marietta Laboratories, Lockheed and AVX) to design a tool post for precision machining. A product prototype of the tool post has been fabricated at ISR to demonstrate the systems engineering approach for product development. ISR is now working with its industrial partners for commercialization of the smart tool post product.

2C Impact on engineering education and the engineering workforce

ISR's cross-disciplinary research and learning environment is unparalleled at other U.S. universities. The Institute's research teams successfully join faculty and students from 11 academic departments with working engineers in industry and government to address the larger, systems-level problems associated with engineering technology. Together, they integrate control, communications, and computation with physical and process knowledge. The results are better systems and products, as well as methodologies and tools for systems analysis and design.

Real world engineering projects typically require the systems-level cooperation of experts from several engineering disciplines. Today, systems-level considerations are recognized as being paramount in the design of new products.

Systems engineering differs qualitatively from other engineering disciplines. Whereas other disciplines concentrate on using knowledge of the real world (e.g., electrical circuits, materials, robotics), systems engineering finds its focus in constructs of analysis and synthesis for problems involving multiple aspects of the real world. In other words, systems engineering focuses on **methods** to solve problems, not the solution of the problems *per se.*

ISR's broad range of educational programs is closely linked with its research objectives, facilitating the rapid transfer of advanced research and industrial applications

into the educational process. ISR's hands-on, cross-disciplinary learning opportunities span pre-college to postgraduate education.

For working engineers, ISR has been active in generating industry-relevant short courses. In 1996 ISR faculty members conducted a four-part short course on systems engineering at the NASA Goddard Space Flight Center. During 1993 and 1994 ISR began an effort in distance education that resulted in a series of short courses on systems engineering being delivered to 10 United Technologies sites via interactive compressed video. In addition, ISR began offering a Professional Masters of Engineering in Systems in Fall 1994. It is an applications-oriented, methods-focused, part-time graduate program designed primarily for working engineers.

2D Development of important facilities

Once ISR was funded by NSF with significant university support, founding Director John Baras undertook a key effort to help secure ISR's long-term viability. He established a leading-edge center for telecommunications within ISR, the NASA Center for the Commercial Development of Space (CCDS). Now known as the Center for Satellite and Hybrid Communication Networks (CSHCN), it brought together a spectrum of ISR skills in cross-disciplinary systems research in a coherent way. This allowed ISR's expertise in systems research to be focused on an emerging growth industry and application. This applications focus added an important intellectual dimension, namely the opportunity to reveal systems research needs from the perspective of an application. Today, CSHCN includes a consortium of participating companies.

The CALCE Electronics Packaging Research Center was also established. Due to its success, it has now been spun off and is independently funded as an NSF state/industry/ university cooperative research center.

Additional important facilities have been developed in the past three years. These are summarized in section 5B.

2E Impact on the research/education culture at the University of Maryland and Harvard University

Research

The Institute for Systems Research is an instrument of change at both Maryland and Harvard, particularly concerning attitudes about cross-disciplinary research, education and interaction with industry. ISR is a new type of institute that stresses truly cross-disciplinary research and working in teams consisting of university and industry members.

ISR has been held up as a model for combining cross-disciplinary research, education and public service by the Deans of Engineering and Computer, Mathematical and Physical Sciences, the Provost and the President of the University of Maryland, as well as by the University of Maryland System Blue Ribbon Committee on Research and Public Service.

The value system among faculty (both inside and outside ISR) has been changed as a result of ISR's influence: working with industry and working in cross-disciplinary teams are now regarded as key elements of a faculty member's responsibilities. Indeed, these factors are taken into account in promotion, tenure and merit raise decisions; the ISR director has an official role in these processes for faculty with joint appointments in ISR.

Since ISR's inception, there has been a distinct improvement in the extent to which engineering systems research at Maryland and Harvard is relevant to industry and in the tendency of faculty and students to work in teams that include industry. Many of ISR's projects now involve faculty from a number of the 11 departments affiliated with ISR. In addition, the choice of research directions has increasingly been influenced by relevance to industrial needs.

Interactions of faculty and students are enhanced by the co-location of the primary offices of most ISR faculty in ISR space and by a student office policy that places students from different departments in the same office. Bringing together faculty and students from different departments has broken down departmental barriers.

ISR has become a highlight of engineering at the University of Maryland, integrally connected to almost one third of its portfolio of engineering research. Furthermore, ISR is regarded as—and is encouraged to be—the primary leader for cross-disciplinary initiatives in the College of Engineering.

Education

The Institute for Systems Research has implemented a comprehensive education program that spans the spectrum from post-doctoral researchers to high school students. These programs have had a profound effect on the engineering education provided by the University of Maryland and Harvard and their influence has spread well beyond those campuses.

Graduate education. The most substantial effects ISR has had on engineering education at the University of Maryland and Harvard have come at the graduate level. These effects come from the cross-disciplinary nature of ISR's faculty and research and ISR's establishing the M.S. in Systems Engineering (MSSE).

The goals of the MSSE program are to:

• Provide broad exposure to a wide range of systems engineering principles, including software tools for modeling and optimization, decision and risk analysis, stochastic analysis and human factors engineering;

- Instill an understanding of the financial and management issues associated with complex engineering systems; and

- Provide a deep understanding of one particular application area.

The MSSE curriculum was designed with substantial industry input; furthermore, it represented the first multi-college graduate degree program at the University of Maryland involving the engineering college. Subsequent programs that followed the MSSE model include an M.S. in Telecommunications and a proposal for an M.S. in Manufacturing. ISR faculty have played key roles in the development of both of these programs.

Undergraduate education. ISR has affected undergraduate education at the University of Maryland and Harvard primarily through curriculum innovation and exposure to research.

The development of **the Walking Machines course** at the University of Maryland is an archetypal example of an ISR innovation involving both curriculum enhancement and undergraduate involvement in research. This senior-level course uses a three-year cycle to investigate all the issues associated with designing and building a walking robot with navigational capabilities; different semesters focus on issues such as control, power, gear mechanisms and signal processing.

The course has been designated a "capstone design course" in both electrical and mechanical engineering—the only course at the University of Maryland to be so designated in two different departments. Moreover, the "Walking Machines" course is part of a combined undergraduate/graduate effort to create a research testbed for robotic design; undergraduates get direct involvement in ISR-related research.

At the end of each course, an autonomous robot "grand prix" is held according to international rules. In 1997, the winning team from Maryland traveled to Tokyo and competed against more than 100 mostly Japanese robots. The Maryland robot "Lancelot" won, and its creators became instant media celebrities. They appeared on the front page of *The Washington Post*, on *Good Morning America*, on public television, and in many other news outlets. The team leader, Assistant Professor Gregory

Walsh, holds a joint appointment with the Department of Mechanical Engineering and ISR.

ISR administers the innovative, cross-disciplinary **Gemstone undergraduate honors program**, originally conceived by William Destler, Dean of Maryland's A. James Clark School of Engineering. Gemstone addresses two of the most common criticisms of modern undergraduate education—the lack of an integrative experience to provide a context for learning, and the failure to provide meaningful interactions between students in different disciplines.

As freshmen, students form teams and spend their next three years analyzing and investigating important societal problems from various disciplinary perspectives. Now going into its third year, the program has attracted 461 students with average SAT scores of 1440. The Gemstone concept is helping Maryland stake out a national presence as an innovator in undergraduate education. ISR was chosen to administer the program because of its experience and reputation in bringing together faculty and students for cross-disciplinary research.

Changes in freshman engineering design courses are another example of the influence of ISR on undergraduate curriculum. Working with the NSF-sponsored Engineering Coalition of schools for Excellence in Education and Leadership (ECSEL), ISR faculty have been instrumental in revising the University of Maryland course. It is now centered on a real engineering design project undertaken by small teams of students. The enthusiasm generated by this course has already resulted in a substantial reduction in engineering student attrition. In 1997 Associate Professor Guang-ming Zhang (ME/ISR) took over the leadership of ECSEL at Maryland, succeeding Thomas Regan, Associate Dean of the A. James Clark School of Engineering, who subsequently became director of the overall ECSEL coalition.

Undergraduate research has been supported primarily through two programs. The **Research Experience for Undergraduates** (REU) program has been sponsored by NSF since 1987. It offers stipends to undergraduates from other universities to come to ISR to work on research projects over the summer. More than 113 students from 50 different schools have conducted research at ISR under this program. ISR operates the **Systems Undergraduate**

ISR education figures since 1985

Degrees granted to ISR-affiliated students

	Maryland	Harvard
PhD	238	19
MS	410	—
BS	129	1

Current ISR graduate students (Maryland)
PhD 152   MS 129

Other research participation
Postdocs 64
Undergraduate 246

MS in Systems Engineering (est. 1987)
Graduates 49
Current students 25

Gemstone undergraduate honors program (est. 1996)
Total freshmen entering the program 461

Young Scholars (est. 1991)
High school students participated 146
Now at the University of Maryland 33

Research Fellowships (SURF) program using state funds. This program pays a stipend to undergraduates at the University of Maryland who work on ISR research projects, either during the summer or the academic year. ISR has supported 53 students in the SURF program since 1991.

The REU and SURF programs are not the only means by which undergraduates participate in ISR research. ISR has dramatically increased the number of undergraduate students conducting systems-related research at the University of Maryland. Dozens of students have taken "projects" courses during which they worked on research and development tasks under the guidance of ISR faculty and graduate students.

Outreach to pre-college students. ISR has administered an NSF Young Scholars program since 1991. Each summer, up to 25 pre-senior high-school students spend six weeks at ISR, taking ENES 100: Introduction to Engineering Design, the course described earlier in this section; spending several afternoons each week in an ISR-affiliated laboratory; and attending a wide array of seminars, field trips and workshops. The Young Scholars program has been extremely successful, praised by students, parents and teachers alike.

Additional information about ISR's impact on educational culture is found in section 5C.

3 Current vision and goals

ISR and its original vision *(see section 1)* have evolved over the years. Founding Director John Baras used ISR's successes, including the establishment of CSHCN, to obtain institute status for the ERC and permanent funding from the state of Maryland. This achievement solidified ISR's role in the college and university, assured long-term financial and administrative support for ISR pursuits, provided a stable basis for creating new centers and programs, and won the confidence of outstanding ERC faculty.

NSF's ERC investment in fundamental systems research themes has flourished. Eight major programs and centers have been established at ISR in the past three years. In addition, ISR's research applications have broadened and its industrial support and participation base have increased. These activities have all contributed to ISR's

achievement of fully self-sustaining status and graduation from the NSF ERC program.

Today ISR is a global leader and innovator in the integrated design and control of complex engineering systems.

At the heart of ISR's research agenda is a drive to advance and exploit fundamental methodological tools for solving systems engineering problems, including intelligent control; modeling and optimization; communications and signal processing; computing; operations research; human factors; reliability and risk assessment; and systems integration. These **systems tools** form the foundation for ISR's collaborative research and teaching. ISR's research has substantially advanced the state of art in these areas, motivated and clarified by the Institute's experience in applications-focused research projects.

By taking the systems level approach to engineering problems, ISR is able to deliver revolutionary rather than incremental improvements in engineering systems. ISR has produced enabling technologies for a variety of applications important to U.S. global competitiveness, including manufacturing processes, consumer products and very large scale engineering systems such as hybrid communication networks. In the process of developing these solutions, ISR has also made important contributions to basic research and education.

ISR's mission is to develop, demonstrate and teach methodologies for the solution of complex, heterogeneous, and dynamic problems of engineering technology and systems. Its current strategy is to:

- Advance and exploit core skills of systems engineering;

- Illustrate methodologies in specific application domains which benefit industry and government;

- Construct and disseminate educational vehicles for systems engineering methods, tools and applications;

- Identify and nurture programs and centers aimed at key components and realizations of the mission; and

- Use industry and government partner and advisory structures to facilitate mission and strategy.

4 Chart: Advances in the past three years

Year	Type	Advance	Impact	Significance
1996	Knowledge	Foundations of Hybrid Systems	New analog models and methods for analog/digital hybrid systems; device-independent language for motion commands, feedback laws, and execution times; integration of planning and nonholonomic control.	Can provide basis for control and optimization of hybrid systems; basis for portability, reuse and open control software; motion description language (MDL) software tool.
1996	Knowledge	Nonlinear Analysis and Design	New results in modeling and control of interconnected mechanical systems; invention of bifurcation control laws.	Extends control theory to much broader classes of systems arising in applications.
1996	Knowledge	Models and Algorithms for Sound Processing	Models of spatiotemporal response of the auditory system and auditory cortex; new algorithms for speech processing.	Applications to speech analysis and recognition; applications to prediction of faults in mechanical systems and to understanding learning processes in natural and artificial systems.
1996	Knowledge	Foundations for Optimization-Based Engineering Design and Trade-off Analysis	Accommodate challenges of real problems through formulation of multi-objective optimization framework; new optimization algorithms involving feasible iterates, addressing semi-infinite problems.	Provides structured methodology for complex systems optimization problems, where thousands of parameters, objectives, and constraints are involved.
1996	Knowledge	Object-oriented (OO) Systems Modeling and Graphical User Interfaces (GUI)	Methods for incorporating constraints in OO databases; treemap approach for information visualization for hierarchical data; fast queries in OO databases.	The confluence in ISR of leading-edge expertise in database structures and user interface design has led to the development of powerful new tools for network visualization and management, with major implications for telecommunications.
1996	Knowledge	Design and Planning System for Concurrent Engineering	Information technology has been used to create a unique concurrent engineering environment for design and manufacturing of electronics products. The developed system consists of an object-oriented database, a cost evaluation module, a quality evaluation module and a process planning module. It is capable of analyzing a given process plan based on the system's knowledge and user input and is able to critique the plan in terms of cost, quality and manufacturability.	ISR researchers from engineering, computer science, and business have teamed skills to produce a suite of methods for concurrent product design and manufacturing planning. Such advances are increasingly requires for systems integrators, where a premium is placed on rapid design, efficient development processes, and early assessment of manufacturability and cost.
1996	Technology	Producibility and manufacturability of high power surveillance transmit/receive (T/R) modules	High Power Surveillance Transmit/Receive modules are an integral part of the latest active aperture surveillance radar antenna arrays being developed and manufactured by Northrop Grumman ESSD. Since 1991 ISR has worked with engineers at ESSD to develop an expert software system to optimize design configuration and manufacturing processes for the production of High Power T/R modules.	This computer-based system exploits ISR's systems expertise in design and planning for concurrent engineering. It has been installed at ESSD and is currently being used as a consultation tool to management and engineers seeking the most cost-effective approach to producing T/R modules while maintaining high quality.
1996	Technology	Next generation network management system	ISR and Hughes Network Systems (HNS) have been participating in a collaborative research and development effort to develop the next generation network management product for satellite and hybrid network configuration management. The project incorporates ergonomically designed graphical user interfaces tailored to the network configuration management function and advanced object-oriented database structures.	The close collaboration between HNS and ISR, a consequence of ISR's industrial partners program and its initiation of the Center for Satellite and Hybrid Communication Networks, has driven the design concept incorporating object-oriented programming methodology to associate data with functions, permit customization and provide an open architecture environment. Hughes Network Systems strongly believes that the resulting network management product will help the company maintain a strong, long-term position relative to foreign competitors, improve its exports and increase its revenues by tens of millions of dollars. Software tools and graphical widgets for network representation have been productized and licensed.
1996	Technology	Algorithms and Circuits for Sound Processing	Application to sound localization	Patent on cochlear filter bank which processes sound as does mammalian auditory system, with potential implications for sound localization.

Year	Type	Advance	Impact	Significance
1996	Education	Industrial Workshop: Model Based Sensing and Control in Semiconductor Manufacturing	ISR sponsored an industry-university workshop (38 participants) to address available and needed technology and the pathways for implementation of intelligent process control. Participants included Texas Instruments; SEMATECH; Motorola; LAM Research; Sandia National Laboratories; NIST; Air Products and Chemicals, Inc.; Applied Materials; IBM; Integrated Systems, Inc.; NSF; Northrop Grumman and Science Applications International Corp.	The workshop served effectively to educate both ISR and industry people, to bring together ISR's skills in control, modeling, operations, and experiment, and to initiate the substantial ISR research programs now in place for semiconductor manufacturing applications.
1996	Education	Gemstone: Cross-disciplinary undergraduate honors program	The innovative, interdisciplinary Gemstone undergraduate honors program addresses two of the most common criticisms of modern undergraduate education—the lack of an integrative experience to provide a context for learning, and the failure to provide meaningful interactions between students in different disciplines. Now entering its third year, the program has attracted 461 students, with average SAT scores of 1440.	Gemstone is a model for interdisciplinary education, bringing together students from all disciplines into teams which address issues with broad social, economic, and political aspects together with strong technological contexts. Gemstone already has gained national attention for the University of Maryland, which increasingly is being seen as a leading innovator in undergraduate education. Because of its leadership and tradition in cross-disciplinary research and education, ISR was the obvious and natural home to make Gemstone a success.
1997	Knowledge	Advanced Systems Approaches for Semiconductor Manufacturing	Critical assessment of transferrability of run-to-run control between process and equipment versions and generations, identifying robustness of control algorithms as critical.	Advanced theoretical control methods provide value in spite of measurement and model error, and collaboration with experimental expertise enables identification of impact in equipment specifications.
1997	Knowledge	Hybrid Shop Layout	ISR has developed a master plan for hybrid shop layout that is expected to yield $300,000 cost savings during the first phase of implementation at Northrop Grumman. In the company's manufacture of radar assemblies, over 10,000 parts are produced in a job shop facility that comprises 160 work centers arranged in a functional layout. The shop layout causes high part traffic and, consequently, large production cycle times.	ISR exploited its skills in logistics and systems to benefit Northrop Grumman, a prime industrial partner. Researchers adopted a three-stage redesign: 1) a set of manufacturing cells was determined based on the inter-resource traffic and the expected savings in material movement was computed; the most promising of these cells was selected for implementation; 2) a layout that maximized the flow in a common direction was derived for the machines in each of the previously selected cells—a variety of cellular arrangements were examined; and 3) a time-phased implementation plan was derived in order to decide which cells should be implemented, the time at which the implementation will take place and the final layout of machines and cells on the facility shop floor; the goal was to maximize the total benefits over time while keeping the machine relocation costs within budget constraints. A software package that performs all of the above design modules is being developed.
1997	Knowledge	Variant and Generative Planning	Theoretical framework for analyzing hierarchical task network planning; formalized techniques for reuse of plans.	These methods are attractive and applicable to combine and exploit both existing and new plans for applications including manufacturing and defense.
1997	Technology	Control Designer's Unified Interface (CONDUIT)	CONDUIT is a state-of-the-art designer's assistant for use in the design and evaluation of aircraft control systems. It assists the designer in setting up control system design problems in the computer, in evaluating the controller's performance with respect to the aircraft handling quality-qualities criteria, and in optimizing the design.	CONDUIT is currently being used by U.S. aircraft manufacturers in approximately one half-dozen aircraft control system design projects. It is expected that CONDUIT will be used in the design of virtually all aircraft control systems designed in the United States.
1997	Technology	Wavelet-Based Multiresolution Local Tomography	The algorithm reconstructs the wavelet coefficients of an image from Radon transform data. It uses the properties of wavelets to localize the Radon transform and can be used to reconstruct a local region of the cross-section of	Use of the algorithm could significantly reduce the amount of radiation exposure necessary, for example, in mammograms and other x-rays. It allows reconstruction of a local region with only 12.5 percent of full exposure data. Previous

Year	Type	Advance	Impact	Significance
			a body, using almost completely local data which significantly reduces the amount of exposure and computations in X-ray tomography.	attempts reduced exposure only to 40 percent for the same case. The algorithm was featured in a 1998 National Cancer Institute lung cancer detection workshop. It is considered a novel possible technology when coupled with ISR's new image processing ideas.
1998	Knowledge	Progressive coding and compression for images use on the Internet	Advanced techniques of signal processing have been combined with systems optimization of communication networks and protocols to provide high-speed, robust methods for Internet transmission applications.	ISR has brought together the normally separate disciplines of signal processing and network design/operation. This is critical for the Internet, which greatly exploits the variety and complexity of advanced and hybrid communications networks, but must still assure robust signal processing over heterogeneous networks.
1998	Knowledge	Integrating Product Dynamics and Process Models	Expands operational methods for semiconductor manufacturing to include factory/market dynamics and individual process behavior.	By bringing together ISR skills in operations research, control, logistics, and industry/experiment, new systems benefits are identified which promise to improve factory management and capital costs.
1998	Technology	Software Tools for Optimization-Based Engineering Design and Trade-off Analysis	Implement knowledge base for advanced optimization methods in algorithms and software; disseminate; commercialize; and apply to industry problems.	Interactive software tools CONSOL and FSQP have been developed and disseminated worldwide, and can be interfaced with any dynamic simulator for trade-off exploration. Northrop Grumman has incorporated CONSOL into PROTO-OPT, an advanced graphical optimization-based control system design software. At Northrop Grumman's Electronic Sensors and Systems Division (ESSD), CONSOL is being implemented to design a line-of-sight stabilizer for an airborne camera. At General Electric, FSQP is incorporated in Engineous for design optimization and automation, yielding a 10-to-1 productivity savings for the company. Texaco is using FSQP in its process control software, now being commercialized, for nonlinear constraints and feasible iterate. FSQP is in use in 56 countries; CFSQP at more than 600 sites; FSQP at more than 400 sites. A nonexclusive license to CFSQP source code has been granted to Cadence for use in its Resolve Optimizer for Analog Artist.
1998	Technology	Artificial intelligence planning techniques for a new version of Great Game Products, Inc.'s Bridge Baron	The new version of Bridge Baron incorporates advanced AI planning techniques based on Hierarchical Task-Network (HTN) planning to develop alternative strategies, and evaluation of these alternative strategies.	Bridge Baron provided a highly visible and challenging test of the effectiveness of the HTN planning techniques. Bridge Baron won the world championship for contract bridge computer programs in 1997.
1998	Education	Simulator-Based Educational Tools	Dynamic simulation methods and advanced user interfaces and software development approaches have provided a new vehicle for education and training as software tools available to a broad learner base, anytime and anywhere. The software architecture supports rapid module authoring, with minimal software knowledge required by the domain experts.	ISR computer science and engineering faculty have collaborated on modules for manufacturing applications, now used in a graduate course and further intended for industry training. In addition, a supportive authoring architecture has been constructed to facilitate module development and deployment. Additional modules have been readily generated for the hydrology of the Nile River (now used in an undergraduate world course) and for traffic management training (in Civil Engineering), demonstrating the broad applicability and flexible authoring characteristics of the approach.

The Institute for Systems Research

5 ISR's impact in the past three years

5A Overall impact on industry

ISR has had a profound influence on industry during a time of two fundamental and important changes.

First, industry has identified and emphasized a growing need for systems engineering due to increased technological complexity, emphasis on competitive manufacturing, and business forces that place a premium on systems-level design, realization, metrics, rapid time to market and quality.

Second, these pressures have driven corporations to transform the character of their investment in university research from relatively open-ended fundamental work to more directed, coherent, strategic initiatives.

Accordingly, ISR began emphasizing sponsored joint research with corporations, as long as that research is consistent with ISR's overall theme. It also began forming research consortia to diffuse the cost of research while at the same time ensuring corporate participation in that research. The NSF core funding, in this regard, has served as an excellent source of "seed money" to encourage industry to join these consortia.

ISR also began forming and joining consortia to pursue third party sources of funding to underwrite the cost of research; these have included funding from federal agencies as well as state programs such as the Maryland Industrial Partnerships (MIPS). As a result, ISR's collaborations with industry have increased and deepened.

ISR and its industrial partners promote the growth of American industrial competitiveness by accelerating the rate at which fundamental engineering advances are applied by industry.

5B New facilities developed

ISR's success has led to the establishment of several cross-disciplinary centers and programs.

• The Center for Auditory and Acoustic Research (CAAR) investigates the auditory system and acoustic signal processing to develop, implement and evaluate mathematical models and algorithms for wide-ranging software and hardware applications.

• The National Center of Excellence in Aviation Operations Research (NEXTOR) investigates data analysis, ground delay program enhancements, CDM and collaborative routing.

• The Center for Dynamics and Control of Smart Structures (CDCSS) couples elastomechanics and fluid mechanics with electro-physical influences such as piezo-electric effects, magnetostrictive effects, and electrocapillary forces. CDCSS also studies the use of large arrays of MEMS actuators and sensors to control fluids and structures.

• The Advanced Telecommunications and Information Distribution Research Program (ATIRP) is helping to advance the Army's digital initiative through wireless battlefield digital communications, tactical/strategic interoperability, information distribution and multimedia concepts research.

• The Center for Engineered Learning Systems (CELS) is constructing new software-based educational approaches to provide effective, broadly available learning environments.

• The Collaborative Agent Technical Systems (CATS) project is developing a formal, tangible definition of agent programming and researching the software needed to implement this communication system.

• The Integrating Product Dynamics and Process Models (IPDPM) program is developing new operational methods that enable efficient semiconductor manufacturing operations throughout the wafer fab life cycle.

• ISR is participating in NSF's $22.5 million program for research in Learning and Intelligent Systems (LIS), an interdisciplinary program to advance the understanding of how learning occurs in humans, animals and artificial systems. The goal of ISR's portion of the project is to investigate time coding in the central nervous system, specifically the auditory system of the barn owl.

These programs embody integrated systems research approaches, some aligned more toward application areas and others toward advancing fundamentals in systems research.

5C ISR's impact on the research and education culture of the engineering school and the university

Section 2E provides significant details on this topic. Additional information is provided here.

In the past three years, ISR has continued its role as the protagonist for cross-disciplinary, systems-directed research at the University of Maryland because of its intellectual leadership and the growing importance of systems engineering.

ISR's research agenda has evolved into a federation of centers and major research programs under the Institute umbrella and supported by staff and funding. Currently with eight such large activities, ISR is now focusing on how a synergistic relationship can be structured among ISR, its centers and large programs. The arrangement must recognize and support the thematic and structural diversity of the centers as well as the pervasiveness of fundamental systems methodologies throughout the centers.

The notions of concentrating on major, enduring themes of systems research and realizing them through applications testbeds is consistent with the ERC organizational concept.

ISR has achieved excellence and recognition for its contributions and talent in key areas central to systems research. These have leveraged additional benefits through new associations with other disciplines and research areas in the College of Engineering, information technology, and a host of external representatives from industry, government, and academia.

The College Park campus provides profound faculty resources to underwrite such initiatives, while research needs assessments and agendas on the national scene highlight directions of high potential. ISR's educational activities have remained a very high priority. With focus on systems research as seen from the perspective of both core systems skills and systems applications, the educational experiences of students and postdocs directly involved in ISR's research programs continue to deliver substantial and unusual value as these alumni move into careers in industry, government and academia.

The educational program has been maintained in several forms. The M.S. in Systems Engineering, as well as the corresponding Professional Master's degree, are already part of the university's degree programs; furthermore, dramatic demand for systems engineering education will provide a strong incentive for current efforts to revise, improve, and disseminate these unique programs.

Similar excitement stems from ISR's Gemstone program at the undergraduate level; this has not only captured tremendous attention across the campus and nation, but it has stimulated thinking within ISR about mechanisms to bring systems educational experiences to a broad spectrum of undergraduates, both inside and outside engineering.

Significant portions of ISR's educational programs from pre-college to continuing education have continued, providing rich new insights to students about the nature of engineering, the importance of cross-disciplinary viewpoints, and the central role of systems engineering and thinking. Some of these (e.g., Young Scholars, REU, and the Masters' programs in systems) are now established vehicles.

ISR is encouraging and supporting major developments in its systems engineering education programs along several directions, including construction of modular components accessible over the Internet and usable for customized short courses; increased emphasis on case studies and the application of systems engineering tools; collaboration with industry and government practitioners of systems engineering; and development of a graduate certificate program in systems engineering which would accompany advanced degrees in conventional engineering disciplines.

Past successes of ISR as an ERC provide a sound platform for significant further growth in the future, with emphasis in three directions: (1) systems research; (2) systems engineering education; and (3) expansion of ISR's contributions to new domains of systems engineering. This exciting future could not have happened without the combined visions of leaders in ISR and NSF. ✍

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