A THREE-PRONGED STRATEGY FOR TECHNOLOGY CREATION, TRANSFER AND ABSORPTION*

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October 11, 1993

Abstract

The Computer Science Department of the University of Massachusetts, Amherst has developed a strategy for research, development, industrial interactions and technology transfer called the "Three Pronged Strategy (TPS)". The principal components within the Three-Pronged Strategy are: continuing programs of education and fundamental research in computer science within the Computer Science Department of the University of Massachusetts, Amherst; a program of focused, or "problem-driven" basic research within the Center for Real-Time and Intelligent Complex Computing Systems(CRICCS); and a program of applied research and development and technology transfer within the Applied Computing Systems Institute of Massachusetts (ACSIOM). In this report, we discuss the motivation and development of the TPS and our experiences to date. We describe each of the components of our strategy and suggest how these might be adapted to other environments.

Keywords: basic research; interdisciplinary, problem-driven research; applied research and development; industry/university collaboration; technology transfer; technology licensing; economic development; entrepreneurship

*Funding for some of the activities described herein is provided by the National Science Foundation under grants CDA-8922572, IRI-9208920, and EEC-9209623

1 INTRODUCTION

The Computer Science Department of the University of Massachusetts, Amherst has developed a strategy for research, development, industrial interactions and technology transfer called the "Three-Pronged Strategy (TPS)". We have developed this strategy in reaction to the confluence of several important factors effecting modern computing research. While this strategy is tailored to the particular environment in Massachusetts, we believe that the fundamental structure is one which can be adapted for use elsewhere. Our goals are to nurture and support fundamental basic research in computing; to address problem and application domains of importance to society and to contribute to the economic competitiveness of the United States.

The climate for academic research is changing rapidly. Many have called for modifications in the forty-year old compact between society and research universities. Society is demanding immediate results from science and engineering–results that will strengthen the nation's economy and competitive position in world markets. At the same time the public is questioning the impact on education of the post-WWII emphasis on research and questioning the ability of universities to manage public research funds. We have seen significant increases in Federal funding for the development of information technology. These Federal programs call for government, university, industry collaborations to solve important technical problems. However, in general, these programs make only minor reference to basic research and the development of human resources.

Clearly, computing research and computing technology development are interdependent. Our "world" of scientific inquiry is defined by the technology we create. Furthermore, as a community we are coming to agree that we must turn our research outward from those problem domains with which we are most familiar to the wide and growing set of applications where computing is a component of larger systems. We must do this because we have the expertise in the technologies that enable these applications and because these application domains will bring new constraints on our world of scientific inquiry and new opportunities for fundamental research.

Technology transfer has become synonymous with economic competitiveness in the political arena. We are told that while we remain the world leaders in basic research, we are not able to capitalize on this research as quickly as our competitors. We are rapidly loosing market share in many facets of the information technology industries. While this is clearly a complex issue with many dimensions, technology transfer is a key factor and it happens all too slowly today.

How can we maintain our basic research programs in an era of flat or declining resources? How can we move computing research into new problem domains? How can we speed up the transfer of knowledge and technology to our industries? We believe that the TPS framework provides an effective way to accomplish all of these diverse goals.

2 MOTIVATION

There are three main reasons why we began to define and develop the strategy we have come to call the Three-Pronged Strategy. First, we recognized that University research in computer science must develop and encourage industrial collaborations. It is necessary to carry out our work within the constraints of state-of-the-art technologies. Furthermore, we believe that it is time to consider computing problems within the context of large systems where computing is a component. Close industrial ties give us the access to current technology and application domain knowledge that we need to carry out our research. For a number of reasons industrial/academic collaboration is difficult–there are different reward systems in place, there are different goals and expectations for research and development, and there are different "cultures". Thus we needed to develop a strategy in which both industries and academia perceive a strong benefit.

Our fundamental goal is to define cooperative science paradigms, in which many researchers from many disciplines will develop the technology by which computers will benefit society in the next century. We accomplish this, not by abandoning the traditional academic approach to research, but by enhancing it through through transfer and evaluation mechanisms. Fundamental scientific issues are addressed within traditional basic research projects, via focused projects and through specific industry-based projects, each driving the other. These projects also serve as the mechanisms by which basic results are merged and transferred into application domains. The relationship is synergistic and complex. First, we do not address industry applications, but rather work with industry to isolate paradigmatic problems. These are abstractions of industry applications that pose the same intellectual problems but have smaller engineering or infrastructure requirements. Second, these paradigmatic problems are solved in the context of industry applications. This means that our research will always look ahead to more difficult problems; it will never be "inward looking," but will always be relevant outside the laboratory.

The second factor motivating the development of our strategy is our feeling that the climate for academic research is changing rapidly. We do not expect to see a large growth in Federal funding for basic research–we hope to see at least relatively level funding. We do expect a significant growth in funding for directed and applied projects in information technology. We felt that we needed to develop a strategy that protected and nurtured educational programs and basic research. Our strategy is designed to broaden the the funding base for basic research in the expectation of level or declining public funding. It is also designed to broaden the scope and adapt our programs to changing demographics and technology. The first is accomplished by creating a partnership we outlined above between traditional basic research and application-driven research and development. By constructing a mechanism for addressing problems of interest to industry and society that builds on basic research, we can make clear the benefit of the basic research to near- and

far-term industry problems. In encouraging the wide variety of collaborations necessary to address these focused problem domains, we enable researchers to adapt quickly to new opportunities of research and we are educating a new generation of students with broad experience in many interdisciplinary areas.

Finally, while the U.S. maintains a (narrowing) lead in many areas of basic science research, a pervasive weakness in our national economic system–reflected in the news headlines of the day, in employment figures, and in our standard of living–is our collective inability to transform basic research results into commercial products and services ahead of the international competition. Not only is technology transfer often cumbersome and haphazard between our major research universities and industry, but the same problem is manifested in the inability of many major corporations to capitalize on internal research and development projects by rapidly and effectively transferring new technology from one division of the same company to another division. The U.S. needs new models of technology transfer and commercialization capable of leapfrogging the international competition. The real challenge will be to develop innovative models for technology transfer that create economic development without compromising basic research. We believe we have a such a model–one that ties a technology transfer agent closely to the basic and focused research programs, but also administratively isolates this agent from having undue influence on the direction of the research programs. The technology transfer mechanism is a slave to the research programs. It is there to assist but not to mandate.

3 A THREE PRONGED STRATEGY

The Computer Science Department at the University of Massachusetts at Amherst has for the past four years worked towards the creation of a *new* model for a university, industry, government collaboration within which to conduct focused basic research on complex computing problems of significant interest to industry and of critical consequence to the national economy. The design of this national research collaboratory maximizes the application and commercialization of new technology from the labs, while preserving and strengthening the program of world class pure research on which the application depends.

The principal components within the Three-Pronged Strategy are: continuing programs of education and fundamental research in computer science within the Computer Science Department of the University of Massachusetts, Amherst; a program of focused, or "problem-driven" basic research within the Center for Real-Time and Intelligent Complex Computing Systems(CRICCS); and a program of applied research and development and technology transfer within the Applied Computing Systems Institute of Massachusetts (ACSIOM). We have developed this triad of organizations with separate but complementary functions and funding. This model comprises a continuum from pure research

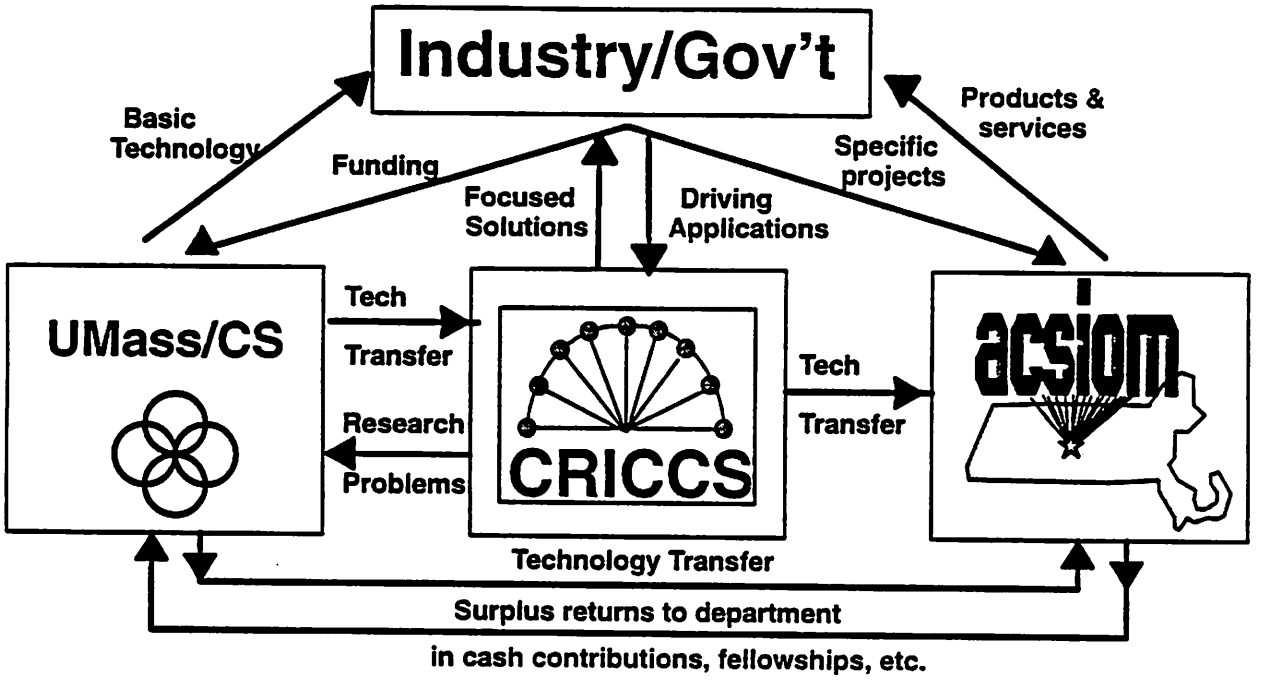

Figure 1: The Three-Pronged Strategy

to licensed products through which moves new technology, some percentage of our students, and participating industrial researchers. Feedback loops connect and enhance all of the programs. Companies are able to invest in long-term basic research and short-term applied research and development, realizing both an immediate return and a strategic long-term asset from their investment.

Each of the three entities is organized to focus its efforts and resources on its particular mission. The mission of the Computer Science Department is education and basic research, unconstrained by short-term industry needs. The mission of CRICCS is to explore research issues of interest to the Center's member companies and to produce new information technology of strategic importance to the participating companies. The role of ACSIOM is to develop and commercialize the technologies of the Department and CRICCS through industry collaboration and entrepreneurship.

The curricula and basic research agenda in the Computer Science Department is determined by individual faculty researchers. In contrast, the research agenda in CRICCS is steered by industrial advisory boards consisting of the member companies. ACSIOM's applied research agenda is market driven, and the corporation is governed by a board of directors. The three organizations also have a wide variety of often distinct funding sources and their own personnel. Functionally distinct and focused, the three elements of this model are complementary to the extent of being politically and economically interdependent over the long term.

3.1 The Computer Science Department

The Department of Computer Science at the University of Massachusetts recently celebrated its twenty-fifth anniversary. The Department has 31 tenure-track faculty, 10 research-track faculty, a number of postdoctoral researchers, 180 Ph.D. students, 190 undergraduate majors, a staff of over 50 administrative and technical staff and a significant educational and research computing infrastructure. There is an active program of research covering such areas as: operating systems; database systems; information retrieval; natural language processing, cooperative; distributed problem solving; real-time, distributed operating systems; real-time artificial intelligence; real-time communication networks; planning; special-purpose architectures; parallel computation; software engineering and programming languages; learning; robotic manipulation, navigation, and geometric reasoning; knowledge-based sensory processing; computation theory; person-machine interfaces; and intelligent tutoring systems.

The department has consistently ranked among the five most active research programs in computer science in terms of annual research expenditures. It currently has over $45M in active grants and contracts with an annual research budget of approximately $10M. The grant portfolio includes over 80 grants and contracts ranging from single-investigator NSF grants through large, multi-investigator DARPA contracts to specialized awards such as NSF/II and DoD/URI agreements. Computer science faculty are active industrial collaborators with a history of significant projects with major industries throughout the U.S.

An important goal of the Strategy is to insure the continuance of this diverse set of research activities. The other components of the TPS are designed to highlight the importance of this basic research program. In doing so, we are able to attract new sources of funding for individual projects and diversify the already broad portfolio of research grants and contracts. The TPS also benefits the basic research program by attracting facilities and infrastructure that benefits the broad goals of the department in research and education.

3.2 CRICCS

Computing researchers have been justly criticized for conducting basic research in relatively simple laboratory environments, ignoring issues raised by the complexity of current technology and systems. Closer ties with industry are needed if we are to bring that rapidly changing world into our laboratories. Also, while computers and computation systems are certainly objects of research, they must also be viewed as components of the social and economic mechanisms of our society. Computers are ubiquitous in educational,

medical and social services delivery systems; in information management and communications systems; in manufacturing and design; in defense, transportation, and all aspects of scientific research. For decades, we have directed our research *inward*–focusing on improving the environment in which we do our own work. To address the social and economic problems facing this nation and the world community, we must conduct our research in the context of large goals and large applications that are representative of the complex, computer-based systems on which our society depends.

In developing our strategy for research in the coming decades, we are driven by a vision of computing in the next century, in which computers, robots, and humans work cooperatively in large organizations. To realize this vision, we developed the Center for Real-Time and Intelligent Complex Computing Systems (CRICCS) in order to house in one center both undirected, basic research and focused projects involving researchers from a variety of scientific and engineering disciplines. CRICCS represents a style of research that: 1) identifies application domains; 2) models those domains to provide testbeds for experimental computing research; 3) builds collaborative, interdisciplinary research teams to address and solve the scientific problems; 4) transfers the results of our research back through our industrial partnerships into the original domains; 5) repeats this cycle to extend the results of our research into different application domains to test generality and discover new problem areas; and 6) develops and extends educational programs and curricula based on our research experience.

CRICCS coordinates university and industry research by establishing projects, laboratories and centers to support both basic scientific research and focused projects. Three university/industry collaboratories have been established to date within CRICCS, as described in the following sections. Over $23 million in new federal/state/industry support has been secured for these initial Centers. Additional focused programs are being developed within CRICCS.

Each of the CRICCS projects or centers benefits from and is supported by the general CRICCS administrative and technical infrastructure. However, each maintains its separate and distinct industrial membership. Member companies of any of the CRICCS projects and centers pay cash memberships ranging from $6,000 to $25,000 per year depending on the size of the company. There is also a mandatory in-kind personnel commitment required. This requirement insures active collaboration and is one of the fundamental keys, we believe, to successful technology transfer. Industry personnel work side by side with university researchers on the fundamental scientific issues of the centers. It is they who then return to their companies with the knowledge to develop practical applications of CRICCS technology. Frequent extended visits or exchanges of personnel are recommended where members cannot devote full-time personnel to the Center.

Another purpose of the interchange of personnel is to bring those with extensive expertise on industrial problem domains into the center to aid in modeling these domains and

developing realistic testbeds. Industries also contribute technology, systems and data. Within a given center or project, all industrial companies must share technology contributed to the center through appropriate licenses as they also share in all technology developed in the center or project through royalty-free, non-exclusive licenses granted by the University. Members of one center or project do not have access to contributed or developed technology within another center. All research in the center is unrestricted and expected to be published in the open literature. Members, however, have first access to the research and royalty-free licenses to any technology developed. We have found this arrangement to be most attractive to industry while maintaining a free and open research environment.

In addition to fairly intense face-to-face contact and collaboration, CRICCS organizes regular business meetings of the industrial advisory boards for each project or center, as well as technical meetings involving company's staff and center staff. The industrial advisory boards play a central role in setting the research agenda for each project and center. While the final decision on research projects remains the responsibility of each project's or center's director and the CRICCS director, the ability to strongly influence the direction of research is another attraction to potential industry members. Federal agencies funding the activities also have membership on the advisory boards and a voice in the direction of the projects.

Most projects and centers publish newsletters and provide short courses to member companies. Video Conferencing facilities have been installed to supplement telephone conferencing capabilities. An extensive outreach program for the New England region is planned for all CRICCS activities which will include regional conferences, workshops, professional development seminars, short courses, and industry roundtables. These will be held in the major industries centers of the region including Boston, Hartford, Nashua, Portland, and Providence.

3.2.1 Center for Intelligent Information Retrieval (CIIR)

The Center for Intelligent Information Retrieval (CIIR) at the University of Massachusetts at Amherst is one of the first centers to be funded by the National Science Foundation under its State/Industry University Cooperative Research Centers program. The two objectives of this center are to advance the science of information retrieval and to make new information retrieval technology available to industry and government. Initially, ten large corporations and small businesses representing medical, international trade, and legal domains, have joined this center. Additional companies will be invited to participate in and benefit from the center's advanced research and development program.

The research at CIIR focuses on the integration of techniques from information retrieval, natural language processing, case-based reasoning, and database systems. Advanced

text retrieval software is licensed immediately to member companies. This self-contained software package has a number of advantages compared to current technology and operates on a variety of platforms. This software will be enhanced and applied to member company retrieval needs. Other software that will be tailored to the needs of member companies include automatic category-assignment software, and an automatic abstracting (fact extraction) software package which has been recognized by the U.S. Department of Defense for its superior performance. Another important direction will be the development of advanced techniques for filtering and routing. Using these techniques, the computer system will route incoming streams of data based on profiles of individual user interests. A general goal within CIIR is to combine these and other advanced retrieval software components into an intelligent assistant for comprehensive information extraction, involving text and other forms of data located across a network of different computer systems. As part of this effort, researchers will be working on the integration of information retrieval and advanced database systems to provide "complex object" management. These techniques will be parallelized for improved performance and scaling with parallel processors.

3.2.2 Center for Autonomous, Real-Time Systems (CARTS)

The Center for Autonomous, Real-Time Systems was established in 1992 through NSF and DARPA funding. In addition, several major corporations are members of the center. CARTS has two laboratories: the Vision and Robotics Laboratory and the Real-Time Kernel Laboratory. Currently, the Real-Time Kernel Lab and the Vision and Robotics Lab support research on flexible manufacturing, in particular automated assembly. Preliminary studies are underway on other problem domains including process control and spill control applications.

In addressing automated manufacturing applications, we are primarily concerned with the extension and integration of dextrous manipulation and vision, and with cooperation among static and mobile robots and humans. Manufacturing automation has been quite successful in highly structured environments performing simple, repetitive tasks, such as paint spraying and spot welding. These applications are successful because the environment is carefully controlled to eliminate uncertainty. Necessarily, the robot systems in these applications are special-purpose in nature. They are brittle, primarily because of the inability of current perceptual systems to provide real-time information, and the inability of planning/control technology to incorporate uncertain evidence. Consequently, automation in the flexible (batch) manufacturing domain remains unrealized because, in most cases, the incremental cost of retooling for small volume production is prohibitive. Our research strategy for the manufacturing problem will focus initially on integrating real-time vision (specifically, the Image Understanding Architecture) with low-level reflexive robot control. We will focus on the fusion of information extracted

from active sensory exploration and on purposeful interaction with the environment. The demonstration of this baseline functionality will support future work on planning under uncertainty.

The three-year NSF/DARPA grant that established CARTS also includes funding for initial studies in two other areas. The spill control application domain involves managing events in an environment that is changing for the worse, such as an oil spill, a forest fire, and so on. Current robotics technology is probably sufficient to the task of moving around and mopping up the mess, but powerful planning and scheduling technology must be developed to do it intelligently and efficiently. Our initial research strategy will be to integrate the Spring real-time kernel with AI planners in existing simulations. Later once additional funding is obtained, this work will be extended to a simulated robotic environment, and finally, to our manufacturing testbed.

For the advanced process control application domain, we are seeking funding to construct an operational testbed controlled by a new (research driven) predictable real-time kernel integrated with real-time AI software. The expert systems technology, real-time AI processing and, eventually, vision processing, must adapt under strict time constraints to a nondeterministic environment to control complex processes whose behavior is not completely understood. The diagnosis of aberrant performance and inadequate models will be immensely valuable in improving performance, and an adaptive strategy for model updating, along with pattern recognition and neural network technology will be components of the strategy for an intelligent control system.

3.2.3 Project Pilgrim

Project Pilgrim was established in 1991 by a grant from Digital Equipment Corporation with significant matching monies from the University Board of Trustees. In 1992, Digital expanded the original scope of Project Pilgrim and several other industrial firms including Hewlett-Packard, IBM and GTE became members.

Project Pilgrim's original goal was to develop a consistent computing environment which encourages resource and information sharing across a variety of operating systems, hardware types, and network protocols. The Pilgrim environment is being initially deployed and used to support education, research, and administrative activities by a community of over 3,000 faculty, students, and staff in the Computer Science Department and the colleges of Natural Sciences and Mathematics and of Engineering. Core software technology for Project Pilgrim includes components of the OSF Distributed Computing Environment, selected services from MIT's Project Athena and OSF Motif.

Project Pilgrim has become one of the largest extant systems based on the OSF/DCE platform. Current plans are to address issues involved in extending the Pilgrim system

to networks of tens of thousands of workstations, servers, and specialized computing resources. In extended Project Pilgrim, we will study the environment's performance characteristics and attempt to develop a set of flexible management policies which promote resource sharing while respecting individual rights to exclusivity. The first generation environment will be used as a testbed for experimentation on more advanced distributed computing concepts under development at the University.

3.3 ACSIOM

The Applied Computing Systems Institute of Massachusetts Inc. (ACSIOM) is directed by a board which consists of university faculty and staff. ACSIOM's functions include the rapid development, commercialization, marketing, distribution, and support of the results of basic research; the provision of educational, training, and consulting services; the joint development with industry of proprietary applied technology; and the incubation of and assistance with new private start-up companies to enhance and market specific research "products".

ACSIOM is authorized by the University of Massachusetts Board of Trustees as the licensing agent for all technology created in the Computer Science Department and CRICCS, assisting member companies with embedding research results into their products and services. ACSIOM also serves to develop and license patents and other intellectual property for other departments and units within the five-campus University system. The University transfers its title to intellectual property to ACSIOM under a specific letter of understanding for each such property that defines the University's interests in the property. "Profits" from the development of these properties are returned to the university under an agreed-upon arrangement to be reinvested in research and scholarly activity.

University staff and faculty may work with ACSIOM to develop technology without conflict of interest, since ACSIOM is recognized by the Massachusetts Ethics Commission as an "agency" of the State. Furthermore, the University Board of Trustees has ruled that activities of University staff within ACSIOM are extensions of their University duties and allows additional compensation for such activities. Such activity is limited under "conflict of commitment" regulations to not interfere with normal job requirements.

ACSIOM is a private, not-for-profit corporation which also serves as a holding company for associated enterprises. ACSIOM Labs Inc. is a private, profit-making subsidiary, which is wholly owned by ACSIOM Inc. The purpose of ACSIOM Labs is to provide services to industry which are highly proprietary and which are more appropriately conducted by a profit-making company. ACSIOM Labs is eligible for technology development funds under the NSF Small Business Innovation and Research (SBIR) Program. Profits from ACSIOM Labs represent an income source to ACSIOM.

ACSIOM also holds an interest, in the form of either equity or royalties or both, in the new start-up companies which are created with its assistance. Several new start-ups have been incorporated recently. A total of eight private start-up companies have spun off from technologies developed at the University's Computer Science Department. These companies provide 140 full-time jobs for the Commonwealth and account for about $20 million annually in software sales. Approximately one third of this software revenue is from export sales.

ACSIOM draws most of its financial resources from its equity position in various companies, license fees, contracts and services. It is partially funded, however, by the State of Massachusetts under the NSF S/IUCRC grant that funds the Center for Intelligent Information Retrieval. In this capacity, ACSIOM serves as the technology transfer agent for CIIR, developing, licensing and distributing commercial versions of CIIR technology and working with CIIR member companies on "non-core projects" required by the NSF grant.

3.4 The Integrated Development Center

The State of Massachusetts is supporting the construction of a new 80,000 square foot building to house additional CRICCS shared laboratories and ACSIOM facilities and to provide leased space for member companies wishing to locate advanced development groups closer to the CRICCS labs. This facility will bring under one roof all of the components of our Three-Pronged Strategy: elements of the Department of Computer Science; CRICCS centers and projects; industrial visitors; ACSIOM; industrial research laboratories; and start-up companies. This facility should enhance the Strategy by bring all these elements into close proximity allowing for daily interactions.

4 CONCLUSIONS

The Three-Pronged Strategy has been under development for five years. The first step was to establish ACSIOM to house several ongoing activities supporting the maintenance and distribution of technology developed within the Department. Two software systems developed under an NSF CER (now II–Institutional Infrastructure) grant, a generic blackboard system for distributed AI applications (GBB) and a parallel implementation of Common Lisp. These systems were further developed within ACSIOM and have since formed the basis for two spin-offs: Blackboard Technology Group and Top Level Systems. Since its founding, ACSIOM has developed a large number of activities in technology commercialization, licensing, and industry applied research and develop-

ment. Currently, ACSIOM is expanding its activities to represent more departments and units of the University's five-campus system.

A significant effort was undertaken to obtain for ACSIOM the status as an "agency of the State". This allows ACSIOM to act as both an independent, non-profit 501(c)3 corporation and as a quasi-government agency. ACSIOM, then, is able to work closely with the University to develop and commercialize technology while providing the legal barriers necessary to maintain an appropriate distance from the University's educational and research programs. Another important aspect of ACSIOM is the ruling by the University Board of Trustees that ACSIOM activities are an extension of University activities. This allows University staff and faculty to move freely between ACSIOM and the University while maintaining a clear partition between the resulting activities.

ACSIOM has been quite successful in achieving its goal to be the primary technology transfer agent for the Computer Science Department. Technology transfer is a necessarily active process that involves day-to-day interaction between industry collaborators and university researchers. One measure of success of this process will be the extent to which industry members realize significant returns on the investment of their time and resources in the university/industry collaboration. To the extent that this technology transfer absorption and implementation is successful, economic development will take place and adequate resources will be available to basic research programs to continue to feed a healthy economic cycle.

The second part of the Strategy to be developed was CRICCS. The concept for CRICCS was developed in 1988 and was used as the basis for a number of proposals to various funding agencies. In 1990, the NSF CII program funded a five-year grant that provided the equipment and facilities for the first CRICCS laboratory. In 1991, the State funded the construction of the first industry/university laboratory for CRICCS–the CARTS laboratory. The State also funded a study which led to the current plan to construct the Integrated Development Center on campus–an 80,000 square foot building to house CRICCS, ACSIOM and industrial laboratories. This facility is expected to be available in 1995 with funding from the State and industrial sources. In 1992, the NSF and DARPA with additional industrial support funded the CARTS laboratory. Also in 1992, the NSF S/IUCRC Program with matching industrial and state funding established the CIIR laboratory. Finally, in the same year the expanded Project Pilgrim was moved under the CRICCS administrative structure.

CRICCS, with its strong focus on interdisciplinary research focused on industrial applications has been a successful attractor of industry participation. Currently, more than 20 large and small corporations are partners of various CRICCS laboratories. Dozens of industrial researchers are resident in CRICCS working closely with University researchers. We have already seen several examples of successful transfers of technology from CRICCS projects and centers back into products of the industrial partners. The

CRICCS model has attracted considerable attention and several new focused projects are under development.

Both CRICCS and ACSIOM have contributed substantially to the educational and research goals of the Department. The facilities and infrastructure that has been created for CRICCS and ACSIOM have benefited the Department. New collaborations have begun, encouraged by the environment that CRICCS provides. New education programs have been developed that are the direct result of CRICCS research and the interdisciplinary activities that go on in the Center.

There have been some problems in establishing this Strategy since it is new to the state and to industry. Existing state regulations were developed for typical state agencies and do not match, in all cases, the goals of an institution of higher education. It took a number of years to reach an agreement with the state agencies responsible for implementing and overseeing state regulations on the role of the University and ACSIOM in economic development. The current state administration is strongly committed to investment in and the encouragement of economic development, however, it took some time before the Governor and his secretaries understood the role that the University could play in their plans. This is an ongoing process. Most recently, we have received final approval for the Integrated Development Center from the State Office of Economic Affairs–a process that spanned two state administrations.

Industry is accustomed to two central means of industry/university collaboration–philanthropy and contract research and development. Industries were not accustomed to participating directly in the research and development and, particularly, were not accustomed to collaborating with other industries as well as university-based researchers. Attracting members to CRICCS was initially difficult but, as more members joined, more companies became interested. Some problems associated with adding new members remain. First, there is a concern that new industry members will have access to technology without the long-term investment of capital and staff participation that the original members have made. Second, there is a concern among existing industrial members about the addition of "competitors" to center membership. Both of these concerns have been addressed through the advisory board structure of the centers within CRICCS to the satisfaction of existing members, potential members and the funding agencies.

The Three-Pronged Strategy is a great success to date. While some facets of the strategy are peculiar to the environment in Massachusetts, we feel that the overall approach of closely coupling basic research, focused basic research, technology transfer, applied research and development and entrepreneurship is applicable to a wide variety of university/industry/government collaborations.