Report by the Subcommission on Research

Subcommission Members

John Laird, Professor of Electrical Engineering and Computer Science; *Co-chair*
Farnam Jahanian, Associate Professor of Electrical Engineering and Computer Science; *Co-chair*
Brian Athey, Assistant Professor of Cell and Developmental Biology and of Art and Design
Dan Atkins, Professor of Information and of Electrical Engineering and Computer Science
David Featherman, Director, Institute for Social Research and Professor of Psychology and Sociology
James Penner-Hahn, Associate Vice President for Research and Professor of Chemistry
Eric Rabkin, Professor of English Language and Literature
Douglas Richstone, Professor of Astronomy
B. Alan Taylor, Professor and Chair of Mathematics

Assisted by Gary Krenz, Special Counsel to the President

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Introduction

This is a report of the findings and recommendations of the Presidential Information Revolution Commission (PIRC) Subcommission on Research. It is based upon reading, knowledge from the committee members, and foremost, from extensive discussion with many members of the University community. This process has yielded a consensus that we are at a point of significant challenge, but also significant opportunity. The University should aggressively invest and build leadership in a broad set of integrated technical and social initiatives to understand and use information and communication technology (ICT) more profoundly to serve the mission of knowledge creation, dissemination, application, and preservation in the University and society at large.

This subcommission has focused on the "information revolution" in the context of the research mission of the University. It realizes, however, that much of the infrastructure investment required is common to the service and learning/teaching missions as well, and that information and collaboration offer the potential to better support integration and synergy between them. We have, however, tried to focus primarily on the knowledge-creation mission of the University and to propose recommendations to move us in the right direction within an ongoing iterative process of discovery, adoption, use, and evaluation. It is our hope that this report will help inform the nature and extent of the financial, human, and organizational investments that should be made to enable the University of Michigan to be a leader in both contributing to and prospering in the age of the "information revolution."

Like other areas of fundamental research (for example, mathematics, language, statistics, and molecular biology), information and communication technologies require pursuit in two crucial, complementary ways: research about ICT and research using ICT. Perhaps more than any other research area, however, ICT plays this dual role ever more centrally in virtually every discipline. In the last forty years, the explosive growth of knowledge in ICT has led to new fields (e.g., computer science), new interdisciplinary domains (e.g., complex systems), and advances of all sorts within existing fields (e.g., computational linguistics). The rate of such knowledge growth will doubtless increase for the foreseeable future. The University of Michigan can and must play a key role here or consign itself to a secondary position in American education. As a large, socially and intellectually diverse institution with outstanding theoretical and practical strengths (think of our Medical School and our Hospital), the University has special obligations and opportunities. It can best serve itself, its faculty and students, and the world, by stimulating research of each kind (both by and about ICT) and their inevitable synergies. If it does not, the University will find itself at a competitive disadvantage across all fields of research, relinquishing its role as one the leading research universities. With a coordinated approach to theory and practice of ICT across research areas, we could make the University of Michigan into a major living laboratory in defining the research university of the future.

Background and Vision

University-based research has been central to the creation of the information revolution and digital information technology has been increasingly central to the activities of the University. Beginning in the 1950s, building-size computers first served business and administrative needs and mathematical analysis, primarily in science and engineering. With the advent of integrated circuits and optical communications, Moore's Law took effect and the raw performance of computers (at a fixed cost point) began doubling every 1-2 years. As thresholds in cost/performance of technology were crossed, it became economically feasible to adopt digital technology to more and more activities in society, including communication and large-scale information storage. At present, for example, it has been calculated that the world's total yearly production of print, film, optical, and magnetic content requires roughly 1.5 billion gigabytes of storage. (Ref: http://www.sims.berkeley.edu/how-much-info/) A very major impact occurred in the early 1990s when the Internet, previously an R&D network, was opened and made relevant to the world overnight with the release of Mosaic as the first easy-to-use web browser for the "World Wide Web," which was originally developed to facilitate collaboration in the high-energy physics community.

We are now in an era of ubiquitous and high-performance computing, ubiquitous and high-performance communication networks, and distributed operating systems that enable them to work together. Universities have invested billions of dollars in networks, computers, and staff and are constantly under pressure to upgrade and expand. We are in general agreement that we are in an "information revolution," but what does this mean in fundamental terms for the University in research and related scholarly communication?

To help answer this question, we take the distributed computing environments in which universities are investing billions of dollars as the substrate, not the end-product, of what this technology really can mean. The Internet is increasingly such a platform. It provides the underpinnings for new ways to link—on a global scale—people, vast collections of multimedia information, tools for analysis and synthesis, and collections of facilities and instruments (including super computers and immersive visualization facilities) that augment both individual and team-based creativity and discovery. These linkages, mediated through information-communication technologies and appropriately woven into social fabric, can dramatically relax barriers of time and distance—both geographic and organizational—and support broader participation in research and inquiry-based learning.

Such environments are about a lot more than "computing" or "communication," and in fact their nomenclature is much in evolution. We are at the "horseless carriage" stage in knowing what to call them. Terms like *co-laboratory, collaboratory, virtual co-location, distributed knowledge environments, knowledge works*, and *knowledge networks* are some of the candidates. "Collaboratory" is actually now the most widely used term but has come primarily from work in supporting scientific research. In this report we are using the more discipline-neutral term *knowledge network* to denote a comprehensive, integrated ICT-mediated environment that becomes hugely valuable if not absolutely necessary for

competitive participation and success in a specialized research community. In this sense then, the University community must position itself for creating, managing, participating in, and benefiting from (ICT-mediated) *knowledge networks*. Furthermore, the concept of creating and using knowledge networks can serve as a framework for investing in and coordinating research about ICT, research using ICT, and synergy between the two. We must not only create and use knowledge networks, but explore and exploit possible tools for creating, linking, and reshaping knowledge networks so that, like the Internet itself, the field of knowledge networks can grow and reshape in complex ways responsive to the needs and imaginations of the University and larger communities.

The University has traditionally been place-based as both a physical and an intellectual community, and much of its activity is based on people being in the same place, at the same time. Physical proximity and bricks and mortar will continue to matter—we are not advocating a pure cyberspace, "clicks only" university—but as we now already see in our daily lives, ICT provides access to people, digital libraries, data archives, and online instruments around the world in both synchronous and asynchronous ways. Although the long-term implications for the future of the research university are far from understood, there is a growing consensus that they will be profound, and likely alter the organizational forms in which new knowledge is created and accessed. They will not just make faster, better, and cheaper what we have done for many years—they will also offer opportunities for doing new things in new ways. ICT also enables new organizations and new forms of organizations (including many for-profits) to compete directly with traditional higher education. A university that does not exploit the full set of new ICT-based options for conducting its operations, including new forms of partnering with other organizations, is likely forfeiting competitive advantage. Some are saying that the university of the future will be characterized by *bricks, clicks, and global partnerships*.

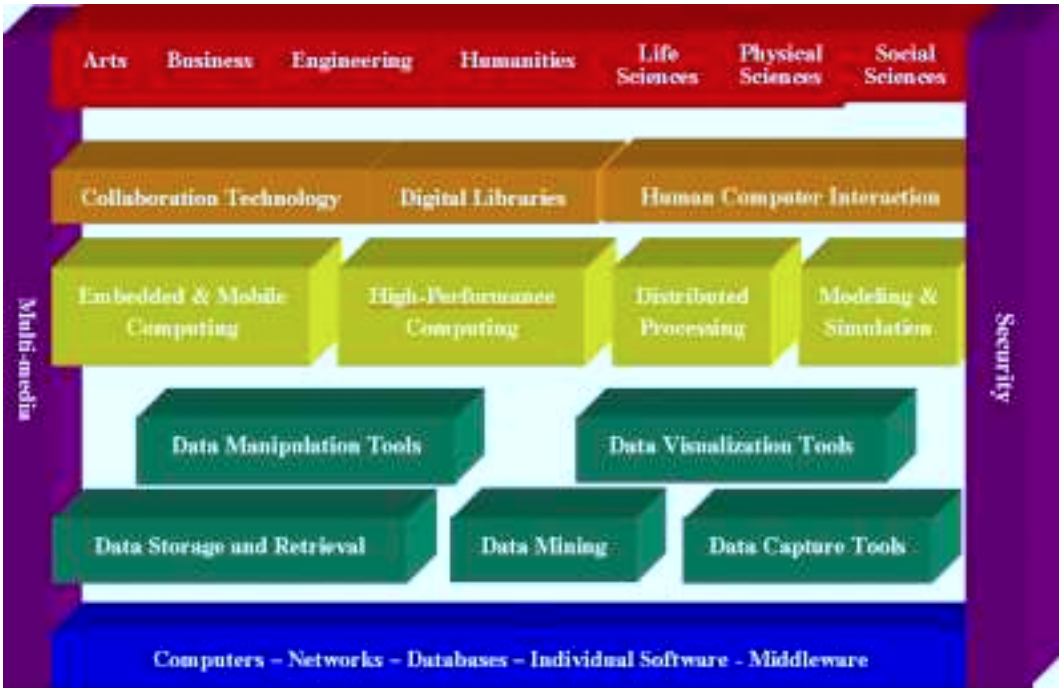
Research Thrusts

As argued and exemplified in J. S. Brown's new book, *The Social Life of Information*, realizing anywhere near the potential of this technology to serve deeply the activities of a knowledge creating community requires a highly integrated approach to both technical and social/behavioral factors. Ultimate progress is best made in an environment of experimentation and collateral learning between technologists, disciplinary (domain) specialists, and social scientists trained to access the fit and impact of the technology on practice.

The list of research sub-areas was derived from extensive input from faculty and staff, which was then culled into a key set of interrelated recommendations (a list of those consulted is included at the end of this document). Each recommended area: a) reflects important national trends in ICT, b) is important as a research field in its own right, and c) also represents part of a powerful, potentially coordinated set of activities linked under the theme of knowledge networking.

The figure below depicts the research areas that support knowledge networking. At the bottom in the physical substrate that all of these research enterprises are based on: computers, networks, databases, basic personal software, and the emerging middleware. Above this level are the fundamental research

areas of ICT most relevant to research using ICT here at Michigan. Above these are crucial ICT application areas that are at the nexus of research about and research using ICT. These in turn (along with the fundamental research areas) directly and indirectly support research across all disciplines. Along the sides, multimedia is included to signify that all of these research projects take place not in just a single modality such as text, but apply to images, movies, sound, music, and sometimes complete virtual environments. Along the other side is security, which is representative of issues that transcend all aspects of ICT.



Research About ICT

A Taxonomy of Fundamental Research Areas

Although knowledge networks are much more than just data, computation, and communication, these are useful categories for roughly organizing research about ICT. There is an additional category that includes security and reliability that transcends data, computation, and communication. Within these categories, each of the technical areas we list represents a national trend, an area of research in its own right, a potentially key contributor to the development of knowledge networking, and thus an area in which the University must be active.

DATA

There is an explosion in data for many research areas—in volume, in data forms, and in access means. Databases on the scale of many gigabytes are common in the humanities, as well as the social, life, and medical sciences. In some areas of physical science, experimental data accumulate at a daily rate measured in terabytes leading to petabyte-scale databases. The University must be prepared to handle this expansion and to help support the capture, analysis, delivery, and access of data-rich research.

Data Capture: ICT together with advances in many engineering fields is greatly expanding the volume and types of data that researchers have available for generating new knowledge. The increasingly experimental nature of many fields demands that if we are to be leaders in those fields we must be at the cutting edge of the technologies that let us sense the world in an ever wider range of modalities and capture the underlying data.

Data Visualization: ICT has brought with it the availability of huge bodies of data, which in turn must be analyzed by humans. Data visualization attempts to find ways of presenting and manipulating data so that we can take advantage of our inherent ability to process visual data. There are currently no easy ways for faculty at large to get involved in data visualization. This work is critical to creating customized and discipline-specific interfaces to the research ICT environments we are advocating.

Data Mining and Manipulation: Visualization is but one technique for analyzing data and although powerful, it depends on the researcher to detect patterns through inspection. With massive databases, automated techniques are required that "mine" the data, looking for hidden quantitative and qualitative regularities and patterns. Advances in data mining and data manipulation promote discovery of unexpected regularities and thereby the development of new theories in many fields, including the physical sciences, the life sciences, the social sciences, and the humanities.

Data Storage and Retrieval: Massive databases must be stored, maintained, and accessed. Developing and maintaining the underlying infrastructure—disk space and networks—itself presents many challenges. However, there are also fundamental research issues in storage, access, reliability, and security that must be addressed before we can build networks of knowledge at global scales. Some of these issues, such as security and reliability, are inherent to data, computation, and communication. Security issues loom ever larger in all sectors of the economy. U-M already has 4 or 5 large projects underway in the security area; these could potentially be built into an effort of national prominence.

COMPUTATION AND COMMUNICATION

The continued exponential growth of computation has brought massive computation to the desktop and made it possible to use simulation and modeling as critical tools for most scientific and engineering disciplines. The latest phase of the information revolution has been driven most visibly by the revolution in the economics of digital communication; the Internet has made it essentially free to distribute and quickly access bodies of information from across the globe. For some researchers, it has changed the way research results are gathered—for instance, instead of having to visit an installation in Greenland, they can directly access the data from their desktops. For others it has changed the way they collaborate with colleagues or publish their results—paperless journals are springing up in most disciplines, with ubiquitous access and extremely fast publishing times. Possibly even more striking is how the combination of computation and communication is leading to new styles of both computation (distributed, mobile, and embedded computation) and communication.

Modeling and Simulation: In many fields, modeling and simulation has made it possible to run orders of magnitude more empirical tests in a fraction of the time and cost possible using physical experiments. Furthermore, it allows scientists to run experiments that are not possible no matter what

the cost, such as when studying the Earth's atmosphere and biosphere. The University of Michigan has an international leadership role in the modeling and simulation of complex adaptive systems from research on campus and through its relationship with the Santa Fe Institute.

High-Performance Computing: Research at the frontiers of many scientific and engineering problems requires extreme amounts of computational resources either locally or through knowledge networks. Just as astronomers with access to the best telescopes have an inherent advantage, so do researchers with access to the fastest computers. Although some researchers at the University have access to high-performance computing, many more need it. And U-M-faculty access can often be gained only through association with other institutions, which impedes U-M faculty in taking leadership roles.

Embedded and Mobile Systems: As computers continue to shrink in size and increase in computation power, they will become ubiquitous; already they are embedded in our cars, appliances, and phones. Besides changing our daily lives, embedded computers that move with us or on their own have changed the data we can gather and use about our world. They have obvious application in fields ranging from medical monitoring and drug release to ecology and manufacturing.

Distributed Processing: The availability of high-speed communication has made it possible to distribute both data and computation across many low-cost machines, possibly sharing costs at many sites across the country. However, with distribution have come many challenges for research, such as maintaining consistency of data across multiple sites, achieving high reliability and performance in the face of failures and varying loads on the individual components.

SECURITY

There is a collection of research areas that span all levels of ICT, such as reliability, affordability, and security. We highlight security because it is still a research area that has not been subsumed by progress in the commercial sector and it is an area of excellence at Michigan. Security issues are ubiquitous but not homogenous. The hospital must protect the privacy of its patients and the integrity of its data from external tampering, for lives are at stake. Astronomers must ensure the integrity of their data, although personal privacy is less of an issue.

Examples of Crucial ICT Application Areas

One of the University's potential strengths is its ability to support interdisciplinary research that brings together many ICT research areas that require a tight coupling between technical and social/behavioral experimental research. These areas build on the fundamental areas mentioned above and take the next step toward integrated knowledge networks. They illustrate the potential we have for success, and they are areas we must continue to vigorously support.

COLLABORATION TECHNOLOGY

ICT has made possible the use of digital video, virtual meetings, and virtual environments and workspaces, all in support of multiple people working together more productively. The University of Michigan has been a leader in fundamental research on collaboration technology and computer-supported work; however, we need to take the next step, in which we develop collaboration technology

in the context of the broader notion of knowledge networks from campus to global scale. A decade of experimental research, much of it at U-M, shows possibilities for greatly enhancing multi-investigator and multi-discipline research across all disciplines and for more fully integrating the activities of faculty and students of all levels in the research enterprise.

DIGITAL LIBRARIES

The University has an excellent reputation in applied research and development in the area of digital libraries and application of this work in providing first-rate digital library services for the academic community. In an operational sense, at present the University is at the top of the digital library world, in terms of size, staffing, tools, services. The Digital Library has been able to achieve tremendous economies of scale and is a great national service provider.

The Digital Library represents a tremendous asset for a large and growing number of research activities on campus that should be strongly supported. It also is an important testbed for new scholarly communication environment and an essential component of collaboratories and knowledge networks.

Despite our great success there are still significant issues to be addressed to assure long-term viability and success of the Digital Library. These include the need for stronger authentication and authorization services to control access and distribution of digital resources; more resources to explore virtual aggregation of distributed collections and services; recruitment and retention of qualified staff; and adequate technical support infrastructure. The subcommission also picked up from many of its visitors the need for a clear understanding within the University of how to handle large-scale public or shared goods. There is an ongoing tension between public resources and what a unit or individual might need to do for himself or herself, but in general the basic level of infrastructure available to all should be much higher.

HUMAN/COMPUTER INTERACTION

Some of the most important questions we now face have to do with examining the interactions between humans and computers. How do new technologies change the ways we function, the ways we view ourselves, the ways we use our machines? As digital technology develops, new ways of interacting with technology are evolving. If we are to be a leader in ICT, we must be a leader in understanding how to design and evaluate it from a human-centered perspective both for individuals and organizations. We currently have a strong reputation in this area, but there is abundant opportunity for more participation.

Research Using ICT

As we have asserted numerous times in this report, ICT is influencing both how research is conducted and even what problems are deemed feasible to explore in a broader and broader array of inter- and intra-disciplinary research areas. Although all the recommendations above for research about ICT have implications for research using ICT, the following recommendations are for research outside ICT that could not be done at all without ICT. The following list hardly exhausts the areas of research in which this is true, but it does set forth some special opportunities at Michigan, with examples from across the

University. All of these projects are inherently multidisciplinary, with teams of researchers that span multiple departments, schools, and colleges.

ARTS

ICT has not only created new tools and methods for generating and experiencing the arts and entertainment; it has also led to the creation of new forms of art and entertainment. These have obvious, significant impact on our culture, but also growing impact on education and research because of the novel and creative uses of ICT they involve. The University has several research projects uncoordinated in this area and further development could establish us as a leader in this inherently multi-disciplinary field.

BUSINESS

The synergy between ICT and business is especially strong in e-commerce, where the University is particularly well-positioned for academic leadership in commerce technology research. The field naturally plays to the University's culture of interdisciplinary collaborative projects and its particular strengths in information technology, information economics, and commerce operations.

ENGINEERING

Computing is already endemic to all branches of engineering and its impact at Michigan was evident this year from the fact that all three of the winners of College of Engineering awards for excellence had computation as a key component of their research, in robotics, modeling and simulation, or visualization of complex data. High-performance computing plays a more and more central role in many projects, and collaboration technology is becoming critical as researchers must get access to unique instruments that are distributed across the globe.

HUMANITIES

There are many examples in the humanities, such as cliometrics, stylistics, image recognition, and indexing. The study of human language existed long before the current information revolution, but the availability of large machine-readable corpora has led to a dramatic shift from studying a few carefully selected phenomena in depth to being able to perform analyses of millions of instances of language as it is used day to day. Moreover, even as the principles, theory, and methods that have been built up over the years are undergoing rapid evolution, they are being applied to many practical problems in analyzing the volumes of text that are now online, be it via search engines, automated summarization, or document clustering. The University is well positioned, with strength in Linguistics, Psychology, Philosophy, the School of Information, and Computer Science, to be a leader in computational linguistics.

LIFE SCIENCES

The life sciences have already been designated a thrust area for the University. Critical to success in this area is a strong program in bioinformatics—indeed in knowledge networking—to support this initiative. Life sciences are already a prime testbed for collaboratory/knowledge net research, and they could be more so. More specifically, advances in technology will soon enable the study of time series of

MRI data, giving biological researchers a powerful new tool for studying the dynamics of the brain, of blood flow, and indeed, of the function of many organs. The images from each patient consist of gigabytes of data, resulting in databases of many petabytes that must be mined for medical and biological discoveries. Teams of researchers from biology, physiology, medicine, and psychology will have to create and access and study such databases. The meaningful interaction of the researcher with the database, through effective visualization of data in three dimensions plus time, will be critical to progress in these areas.

PHYSICAL SCIENCES

Researchers at Michigan are using sophisticated computational models to understand the geology of the earth's mantle, and indeed, the entire planet. Also, researchers in astrophysics are using high-performance computers to model the formation of galaxies, stars, and planets and their individual and aggregate evolution. In fact, such simulations are ubiquitous in almost all areas of science. Access to high-performance computing is essential for the support of this work.

SOCIAL SCIENCES

Advances in ICT create new opportunities for collecting and integrating data of new types and in new combinations. Urban geographers and ethnographers create digitized video and audio streams of activity at street corners and on city block faces over weeks and months and amalgamate such points in space and time with satellite downfeeds of geophysical and environmental information. Survey researchers and epidemiologists, armed with wireless computers, conduct interviews and collect biological specimens in remote regions of Africa, transmitting data in real time to central high-speed processors which signal back to the interviewer to ask additional questions as a result of the analyzed data and assays. Michigan's unique strengths in the social sciences offer extraordinary opportunities for exploiting advances of ICT in defining new research frontiers.

Integrated, Cross-Cutting Initiatives Towards Knowledge Networking

As mentioned earlier, if it acts quickly, the University of Michigan has a unique opportunity to assume leadership in an integrated set of activities to explore the creation and application of the comprehensive ICT environments we are calling knowledge nets. These same environments would also support highly interactive, location-independent learning. Such environments and the principles for designing them have been evolving over the past decade. The University of Michigan has been a leader in much of this work through funded research to explore scientific collaboratories, distributed systems, intelligent systems, digital libraries, and networking. The Space Physics and Aeronomy Research Collaboratory (SPARC) project, for example, is the flagship NSF project in the area of collaboratories and has recently led to an invitation to submit a full proposal for a major NSF National Science and Technology Center in Collaboratory Science and Engineering. Work in networking includes leadership

in creating NSFnet and now Internet2. Michigan has also played pioneering roles in creating the underlying high-performance, electro-optic hardware and novel systems built from them.

The University can and should again visibly pioneer ICT and the next generation of its use and meaning by supporting a few carefully selected experiments that will likely have high impact across all research fields. MTS, NSFnet, and the early inauguration of ubiquitous web page creation for all members of our community made U-M a leader in diverse disciplines and among universities. We recommend initiatives that capture far-ranging aspects of the University and that seek to capitalize on U-M's special resources and intellectual assets—e.g., strength in the social sciences, engineering, humanities; status as an institution equally well respected by publics and privates. Since extramural developments in ICT both force and allow collaboration and multi-disciplinarity, we should exploit our often separate but excellent strengths to pursue one or more comprehensive experiments aimed at radically advancing the fundamental capabilities for collaboration.

The overarching theme of this initiative should be principled research, design, and understanding of knowledge nets and their application in broad areas of research. This should be pursued in a highly interdisciplinary way, involving significant collateral learning among technologists, research users of the knowledge networks, and specialized social scientists to assess fit and impact of the technology as well as find principles of design from a human-centered perspective. Besides building on the numerous collaboratory projects we already have in place, we would also suggest the following related medium-term activities as candidates for fundamentally changing the way we work at the University:

Ubiquitous Data-Rich Portals, Interactive Websites and Delivery Systems

The early provision of the capability for every member of the U-M community to publish a web page at will had profound, pioneering, nationally emulated effects on the nature of research, teaching, public relations, and every other aspect of University life. In today's environment, the most useful websites are often data-rich portals that deliver customized materials on demand. At the moment, creating such portals requires specialized skills and servers, but we imagine another profound sea change if U-M were the first to provide the capability for every member of the U-M community to build such sites. This could be accomplished through creation of a database farm and development of tools for web interface to the database, to make it easy for any member of the University to construct websites with high functionality and intelligent, constructive information retrieval. The tools for doing this exist, but they are not all simple, and they are not readily available; what could set the University apart would be the commitment to implementing a data-rich environment on a massive scale, making ubiquitous rich page construction of websites a possibility. Joining this to an initiative for pervasive computing, be it wireless or jacked, and embedded smart systems would allow the creation of interactions and information-rich activities of sorts yet to be imagined. This would open the way toward flexible, widespread collaboration in all disciplines and at all levels.

Understanding New Models for Extramural Collaboration

U-M's prevailing model of extramural collaboration requires that faculty essentially do contract work for extramural entities, with those entities owning the result of the faculty labor and the faculty owning the right to publish the results, often after a waiting period. Faculty who want to work in extramural research environments typically need to take leaves of absence; extramural experts typically cannot collaborate with U-M faculty without special arrangements. The examples of the Stanford Research Institute, the M.I.T. Media Lab, and, in some ways, our own Institute for Social Research, suggest that structured sharing of research resources and rewards may enrich the University in many ways. As we begin to reach out in other ways (e.g., through Fathom.com), it will become crucial to regularize these collaborative arrangements and, ultimately, provide new forms of support for them.

Later in this report we highlight the need for a central leadership position or positions dedicated to fostering IT innovation and use and marshalling extramural and intramural resources toward those ends. Facilitation of extramural collaboration should be a prime responsibility of such a leader or leaders.

Increase Interdisciplinarity

The University should develop its human capital by facilitating contacts between faculty and students whose research requires new ICT methods and those from units who have such expertise. While knowledge networks will enable contacts across the campus, effective cross-disciplinary communication—for example between mathematical/computer scientists and experimental scientists or humanists or social scientists—can require a significant amount of time to develop, as each collaborator learns the language of the other disciplines. In some cases units have provided support for semester-long interactions between two researchers that have paid off in the development of long-term collaborative research projects (e.g., in bioinformatics). Consideration should be given to establishing a small number of such opportunities on a regular basis. Indeed, it should be a goal of the Office of the Vice President for Research to find mechanisms that facilitate contacts between scientists and scholars with research questions needing ICT support and those with expertise in the area.

Improved Infrastructure, Specialized Resources, and Support Organizations

Information and Communication Technology (ICT) infrastructure is essential to a healthy academic environment. ICT infrastructure is difficult to understand in that it is largely invisible when it is working, it has high degree of complexity that lies below the surface, and it is always changing. The ubiquity of ICT in all aspects of research demands increased and sustained support for the development, deployment, and advancement of ICT across all levels of the University. The University research ICT infrastructure must rapidly and continually evolve and adapt to changing user requirements, the

emergence of new applications and research areas, and the breathtaking advances in computation, communication, and storage technologies. Investments in physical infrastructure, core and discipline-specific services, and professional staff support are all equally crucial to the pursuit of research about ICT and research using ICT.

ICT research-support needs raise questions about the role of the faculty within the University in the emerging digital age. What ICT activities—e.g., word-processing, data analysis, software maintenance, systems administration—are faculty responsibilities, and what are part of the basic level of support provided by the institution? What are the sorts of things that we actually want our faculty to be doing, and receiving credit for doing? Because these issues go to the academic core of the institution, strong executive leadership in articulating the role of the faculty and ensuring that ICT support enables them to fulfill that role is critical. The next section of this report discusses this issue of leadership.

Distributed but Coordinated Infrastructure to Support ICT for Research

Research universities are facing unprecedented challenges in providing effective ICT support to their growing community of users. As the most successful public research university in the United States, the University of Michigan must systematically and deliberately support the computing needs of its researchers in a comprehensive way. The subcommission recognizes that it is a great challenge to address the ICT infrastructure and support needs of researchers, since that support must be focused on all levels of the University's hierarchical structure. In this context, a useful idea is to separate the growing number of research infrastructure needs, which can be considered to be campus-wide (such as campus backbone networks, large-scale databases, advanced visualization systems, and high performance computing resources) from those that are discipline-specific in nature and that should be addressed within the context of individual units. The campus-wide and unit-specific approaches should be complementary and enhance one another. This distributed but coordinated approach would allow ICT organizations to be much closer to their respective user communities, permitting them be more responsive to specific needs. Success will be achieved by an inspired and well-informed central ICT leadership team that makes research-computing support a top priority. This approach would provide the flexibility to address ICT research infrastructure and service needs at the appropriate level, as it also would permit a more effective exploitation of economies of scale for campus-wide needs such as high-bandwidth Internet access.

One danger of any distributed system is underutilization of specific resources. While the administrative coordination of efforts is obviously designed in part to overcome this, administrative coordination alone may be insufficient for individuals who are either external to the system or isolated in one part of the system. How is a musicologist on North Campus to know that help with statistics is available through CSCAR on Central Campus? How is an anthropologist in LS&A to know that the current resource for GIS, such as it is, is in SNRE? How is a faculty member used to charging software to research grants to know that the University, or another college than his own within the University, holds a site license to specific needed software?

The University needs a single point of contact for those seeking ICT resources, be they machine time, software, hardware, technical support, or consulting. This point of contact—available by phone, email, and online—would not directly solve any problem but rather would serve to direct individuals to solutions and simultaneously, by logging requests, help monitor the demand on our existing resources. One crucial project of an office offering this single point of contact would be building and maintaining a database of U-M resources that faculty could query by their needs, affiliations, and locations. Given the expense and indispensability of ICT, it is imperative that we make full use of what we have. A single point of contact would be a major facilitator of research both about and using ICT.

One way to move toward a coordinated infrastructure would be to create single points of contact at several levels within the institution. The subcommission recognizes the needs of the research community for individual points of contact at various organizational layers, again promoting cooperation in a coordinated fashion. A prime example is the need for a software licensing and distribution capability for researchers that leverages across units and is easily accessible. Software licensing should be centralized, negotiated, and maintained by experts, and greatly simplified. A campus-wide research software clearinghouse, maintained by central IT administration, would give researchers access to the growing diversity of specialized software products and services available in the marketplace, as well as access to training related to its use. This theme can be extended to computing or database resource allocation and availability issues as well.

Improve and Extend Physical Infrastructure and Specialized Resources

With the growing dependency on ICT in research projects across all disciplines, demand has grown beyond the capabilities of the current infrastructure to deliver service. Furthermore, the need for infrastructure improvements has created enormous challenges for providing effective quality of service to the entire University community. As recommended by the subcommission on IT Infrastructure, there is a great need to expand and upgrade the campus backbone networks, in-building network infrastructure, and high-bandwidth Internet connectivity to keep pace with this growing demand. The Research subcommission extends this recommendation to include support for selected specialized computing resources such as University-wide data centers, large-scale information repositories, and digital libraries (for several larger scale projects such as geophysical modeling, astronomical sky surveys, high energy physics, and life sciences research). In addition, the entire University research community should have access to high-performance computing resources, both local and national. As ICT continues to play an increasing central role in research projects across all disciplines, the need for high-end technology application services is also anticipated to expand in the immediate future. These needs include, for example, programming for high-performance and parallel computing, complex computer modeling and simulation, Internet 2 networking, advanced visualization and virtual reality, and a broad range of discipline-specific research capabilities. Additional support to develop and deploy collaboration software tools and capabilities is also recommended.

Increase ICT Professional Support for Research

The effective deployment of support staff is required to ensure that personnel are close to where they are needed, and that smaller departments are not penalized by lack of resources for support. There should be some basic level of research ICT support across the University, with more specialized support built on top of that at the college, department, and individual PI levels. For example, funded researchers who require UNIX system administration or applications software support should have access to these specialized personnel and services. Research productivity should not be limited by lack of expert professional ICT support.

In recent years, ICT units at the University have experienced greater difficulty in recruiting and retaining professional staff. As the demand for ICT professionals continues to exceed the supply, the University must develop a multi-faceted approach to handle the ICT support needs for research. The subcommission strongly recommends that the University make a long-term commitment, starting immediately, to hire needed ICT professional staff with research computing expertise, and to further develop and maintain critically needed skill sets through ongoing and specialized training and retraining of ICT personnel. Furthermore, the University should offer market-competitive salaries and innovative compensation packages to attract and retain highly talented ICT staff.

Improved Training and Credentialing: An ICT Training Institute

Currently, no U-M unit has full responsibility or adequate resources to address the overwhelming need in our University, or in the State of Michigan, for training diverse people to be technically proficient in ICT. We recommend the creation of an ICT Training Institute. This Institute would serve a mixed constituency and be staffed according to a mixed model. The aim of this Institute would be to give people both general and specific ICT skills. For example, a student in English, Nursing, Law, or Psychology might choose from a curriculum of workshops that would build toward an appropriate general certification (for example in IT and pedagogy, qualitative analysis software, and database design and applications). Specific ICT certification could upgrade the skills of existing technical staff and train new staff for such important roles as network administrator, webmaster, database administrator, and so on. Such specific, skill-based programs could be offered not only to U-M students at all levels, thus allowing us to develop our own response to the current staffing shortage and increasing the market skills of our students, but could be offered to NCFD (Non-Candidate for Degree) students as well. In this regard, we would do well to coordinate our efforts with such organizations as Focus:Hope in order to reach out to the Michigan community in directly useful ways. This would be of economic benefit to the region and recruiting benefit to U-M. The certification curricula for such NCFD students could be designed in collaboration with individuals who are neither U-M faculty nor U-M staff. Trainers in the Institute could be drawn from U-M faculty and staff and also from local industry, government, and NGOs. Market analysis to keep the Institute offerings current and placement of NCFD certificate holders could be greatly aided through such extramural ties.

IT Leadership and Decision-Making

There must be sufficient coherence in the U-M ICT environment to realize the collaborative vision that is set forth in the other recommendations. This requires a particular kind of central leadership with two crucial components:

1) Leading and nurturing an effective, interoperative ICT environment, one in which units may go their own way within the constraint of campus-wide interoperability and in which, given that authority, units have appropriate levels of control and responsibility. There must be consent of the whole, but consent within which incentives are created to bring units together where possible. And, those given responsibility must also given be authority. In the process of nurturing this environment, it will be important for central leadership to engage in continuous and forthright evaluation of existing cross-cutting or central resources—many of which our discussions have shown to be seriously underutilized or insufficiently integrated into the life of the institution.

2) Leading in coordinating innovation and marshalling resources to support it, be those resources intramural or extramural.

That individual, or those individuals, charged with this centralized and centralizing function, must be responsive to the entire University community, collaborate in decision-making at the highest levels of the University, and deserve the right to speak for the University in matters of ICT as they bear on research, teaching, and administration. Collegial guidance is crucial if we are to coordinate our resources, empower our individuals, and develop most powerfully the collaborative strength potential in the diverse excellences of the University of Michigan.

Recognition and Encouragement of Unconventional Contributions

We take note of recommendations to the Provost that would revise promotion guidelines in order to more effectively and fairly evaluate cross-unit, interdisciplinary, and other unconventional portfolios of intellectual, scholarly production. While not endorsing these specific recommendations necessarily, we nevertheless emphasize the need to rethink how scholarly, scientific, and technological production at the leading edge of ICT itself—and the leading edge of ICT integration into the various disciplines—should be nurtured and evaluated among departmental and collegiate faculties at Michigan. Faculty working at the leading edge of ICT application or "tool" development, for example outside of engineering and other traditional ICT disciplines, can be especially vulnerable. Their work tends to appear more like "application" than new intellectual contribution. Some have noted that leading edge contributions in ICT can often seem, to some faculty peers working outside this arena, more like "artistic performance" or "prototype development" than research. Faculty peer review procedures, organized

around more conventional research production in these disciplinary and professional arenas, may fail to value, to evaluate fairly, and ultimately to nurture such needed cross-boundary, innovative developmental work. These failures in faculty tenure-review and promotion procedures are especially harmful to the efforts of Michigan to retain the most creative ICT faculty and ICT-involved faculty in all disciplines, and to solidify Michigan's international leadership in the future. Uncorrected, these failures could drive more faculty with such unconventional interests and talents into non-academic careers in ICT industries, or, to constrain and refocus their academic work into less risky, more conventional pursuits.

We therefore recommend that in the course of reexamining the promotion and tenure-granting guidelines used across the campus that the Provost pay special heed to the production portfolios of ICT faculty and faculty involved in ICT in both conventional and especially unconventional (where work in ICT is less typical) disciplinary units. Our current academic review procedures (what "counts" toward tenure and promotion and how it is evaluated) may not be sufficiently congruent with the pace and the diverse manifestations of producing (research) and disseminating (teaching/outreach) new knowledge in the current ICT era. Our procedures for mentoring such career aspirations, especially among more junior, pre-tenure faculty, should be reexamined in light of campus-wide priorities for Michigan to retain a national and international leadership position in emerging ICT fields and fields not obviously central to ICT development, for which conventional standards of scholarly productivity must necessarily be in flux.

List of Visitors

Harold Borkin, Professor, A. Alfred Taubman College of Architecture and Urban Planning
Bill Connett, Director of Information Systems and Technology, ISR
James J. Duderstadt, President emeritus and University Professor of Science and Engineering
Gus Evrard, Associate Professor, Physics, LS&A
Tom Finholt, Assistant Research Scientist, School of Information
Michael Gordon, Professor, School of Business Administration
Phil Hanlon, Professor, Mathematics, LS&A; Associate Dean, LS&A
Phil Hughes, Associate Research Scientist, Astronomy, LS&A
Wendy Lougee, Associate Director, Digital Library Initiatives
Tim McKay, Assistant Professor, Physics, LS&A
Robert Merion, Associate Professor, Surgery, Medical School
George Michailidis, Visiting Assistant Professor, Statistics, LS&A
Gary Olson, Professor, Psychology, LS&A; School of Information
Denise Park, Professor, Psychology, LS&A
John Price-Wilkin, Head, Digital Library Production Services
Mary Simoni, Associate Professor, School of Music

Brad Smith, Associate Professor, School of Art and Design; Senior Associate Science, Radiology, Medical School
Nancy Songer, Associate Professor, School of Education
Quentin Stout, Director, Center for Parallel Computing; Professor, Electrical Engineering and Computer Science, College of Engineering
Peter van Keken, Assistant Professor, Geological Sciences, LS&A

In addition to meeting with the above individuals, the subcommission canvassed the University faculty via e-mail and received numerous responses regarding ICT usage, research, frustrations, and concerns.