EXECUTIVE SUMMARY

The Information Revolution is transforming society – creating new careers, new industries, new academic disciplines and the need for new programs of education and research. Being an informed citizen in this Information Age requires knowledge of computing systems, global communications networks, and interactive information resources. The requisite level of knowledge goes beyond being comfortable with computing tools. It requires the ability to apply computational ways of thinking to design, to writing, to experimentation, to artistic expression, and to problem solving. In the Information Age, our ideas are no longer constrained solely by what is physically possible, but by what is computationally realizable.

Major advances in computing and information science have frequently been in partnership with other disciplines, especially mathematics, physical sciences, engineering, and the cognitive sciences. The leading institutions in this field have been those that recognized the identity and significance of computing and information science (CIS) and also created a fertile environment for such interactions. In the future a broader range of fields will participate, including the arts, humanities, and social sciences.

The Computing and Information Science Task Force has been charged with investigating how Cornell should address these fundamental changes in the world. Cornell is in a unique position to create an interdisciplinary group of scholars, from a wide range of departments and fields, devoted to CIS research and teaching. Our initial report from June presented a set of proposed recommendations about how to respond to the rapid pace and broad scope of this change. Subsequent campuswide discussions of the report and its recommendations have revealed strong support for the notion that Cornell must respond quickly and creatively to the need for new programs of education and research in emerging areas of computing and information. Moreover, there is broad support for the notion that Cornell must act to ensure that we continue to nurture our existing strength in areas such as computer science, computational science and engineering, and information technology. At the same time, however, some concerns have been raised about the specific recommendations of the Initial Task Force Report. This final report discusses those concerns and makes a modified set of recommendations intended to address them.

Campus discussions of the Initial Task Force Report have also revealed large differences in the degree of awareness and understanding of the Information Revolution – its breadth and the educational needs of students in this new age. One issue that we feel is particularly important is the distinction between computation and the physical machines that are used to perform that computation. While today's physical machines are based on the flow of electrons, future computers may well be based on biological or quantum effects. The key conceptual basis of the Information Revolution is the fact that these differences in the physical machines are not visible in the solution of computational and information processing problems. Abstractions such as the Turing machine isolate us from how a machine is built and free us to work in a new world defined by computational rather than physical laws. These computational laws, as well as the methods for solving computational and information processing problems, are what make computing so broadly applicable.
Summary of Recommendations

In view of the strong support for the vision described in the *Initial Report* of this Task Force, we reiterate that Cornell University should undertake to become an institution where anyone can bring ideas from computing and information science to bear on any discipline. One of Cornell's great strengths is its breadth. It is imperative that Cornell move quickly to capitalize on its current strength, to attract and retain the best students and faculty, and to provide the best education for students whose interests in this area are rapidly growing. We must also position Cornell to benefit from unprecedented increases in funding for computing and information science and technology, and unprecedented opportunities for enrichment of this discipline by deep interaction with other fields.

Our main recommendation is to create a new academic unit called a Faculty (termed here the Faculty of Computing and Information, although the actual name of the unit may be different). This Faculty is intended to complement the traditional academic structures of the university in order to provide more flexibility to respond to new educational and research needs in the fast-paced Information Age. Administratively, the FCI has some of the attributes of a college, while academically, it consists of its multicollege majors and interdisciplinary programs. The cross-college nature of the academic programs is suggestive of an undergraduate version of the field structure of the Graduate School; however, the addition of faculty resources provides the ability to seed and create new academic programs.

The proposed Faculty should be a focal point for academic activities in computing and information and should have resources to seed and nurture the development of both existing areas and emerging activities. It should serve the broad and strong student interest in computing and information and should incubate new concentrations, programs, majors, and departments as needs emerge. Members of the Faculty will serve to tie their home departments to the FCI and to one another, providing new channels for cross-disciplinary activity related to computing and information. The FCI will be a home that encourages and facilitates exchanges between computing and information science and the broadest possible range of disciplines.

While we realize that the kind of structural change embodied in this proposed Faculty is not easy to undertake in a university, we believe that the speed of change in the world makes it critical to explore new, more flexible and more inherently interdisciplinary structures. The Information Revolution is likely to reorder the reputations of many major research universities. Those with the most effective response will reap enormous benefits as society reacts to this revolution. The goal of our recommendations is to permit Cornell to enhance its excellent reputation in computing and information. Like all distinguished universities, Cornell must continually transform itself to adjust to changing realities.

In order to be successful, the new structure must complement the departments, which we believe should remain the main academic homes of both faculty and students. At any point in time, the FCI will contain departments whose majors are part of the degree programs of more than one college, concentrations that span multiple departments (those departments being both inside and outside the FCI), and new academic programs, some mature and some new, but all excellent.

Specifically, we recommend:
1. A Faculty of Computing and Information (or FCI) should be created, although the actual name may differ from this. The Faculty will have some of the attributes of a college and some of the structure of fields in the Graduate School. Like the fields, it will cut across the traditional college structure. Like a college, it will control university resources and faculty positions. It will be led by an academic dean, a member of the Dean's Council, who will have the usual administrative responsibility for departments, such as managing appointments, promotions, and budgets.

2. The Faculty should be the focus of significantly expanded educational and research activity in computing and information. It will work to develop new programs of education and research. Given the inevitable change that this fast-moving area will provoke, the Faculty should be viewed as a "breeding ground" for new activities on the campus. At the undergraduate level, new programs will initially be minors or concentrations. The precise nature of these programs will depend on the interests of those involved, student needs, and funding opportunities. Over time, we believe that some of these will evolve into new majors and may also require the creation of new departments. We expect that such new departments would be in the FCI with degree programs in the traditional colleges. We do not, however, expect that the FCI will cover all activities in computing and information at Cornell, either at the start or in the future. Rather, the FCI provides a way of focusing a large fraction of these activities in a manner that is accessible and visible to students and funding agencies and that serves as the basis for new academic programs.

3. The FCI affiliated faculty should reflect a balance of faculty on campus with expertise in computing and information areas. Some professorial positions in the Faculty will be shared with other units (primarily departments). Some of these positions will be of indefinite term, and others will be fixed term. The shared appointments will provide funding to other departments, but tenure and promotion decisions will rest with the home departments. Some positions will be partially supported by the FCI, while others will be fully supported by these resources. We expect that professors affiliated with the Faculty will have a home department, although some of these departments will be within the FCI.

4. Certain academic disciplines are critically important to the success of the proposed Faculty, and we recommend that the Computer Science Department (CS) should be administratively in the FCI from the start. We recommend this because computer science is playing a central role in the computing and information revolution nationwide – in academia, in federal funding, and in the software industry. Other programs at Cornell should also have strong ties with the FCI as detailed in this Report. An Advisory Board, described below, will balance the interests of programs and departments and will act to ensure an open and interdisciplinary community.

5. An Advisory Board representative of the computing and information constituencies on campus should be formed to advise the dean on matters related to the Faculty, such as new courses and programs, appointments of affiliated faculty, and other academic and research program matters. We recommend that this board have between eight and twelve members, actively engaged in the areas and mission of the Faculty, drawn from across the campus. Moreover, we recommend that this board have no more than twenty percent of its members from any one department. The dean will retain the usual administrative responsibilities for full-fledged departments that report to the dean. The Board will counterbalance the influence of the departments in the FCI. We recommend that an initial board be appointed by the Provost with input from campus constituencies for a
term of one or two years. This board would further be charged with developing a permanent board structure.

6. The Faculty should develop and oversee a new university-wide Undergraduate Computing Program modeled after the Knight Writing Program. This program would have the mission of aiding in the design and teaching of computing and information courses, in a manner that is most appropriate to the students in each discipline.

REPORT

Intellectual Context

The Information Revolution is transforming society – creating new careers, new industries, new academic disciplines, and the need for new programs of education and research. These changes affect how people work and think, two things that are fundamental to universities. While it is perhaps tempting to dismiss the Information Revolution as hype or as a passing fad, the evidence runs quite to the contrary. For instance, about one-third of the economic growth in the U.S. since 1992 has been in computing and information technology. Not only are the founders of new high technology companies often barely in their 20's, new careers in computing are also appearing in traditional companies. For example, this year's ranking of the 500 best and worst jobs lists Web Site Designer as the top job in terms of pay, flexibility, and satisfaction. This is a position that did not even exist five years ago, and it requires a combination of skills not easily found in today's educational programs. While the Internet and the Web are perhaps the most visible aspects of this change, the revolution is pervasive, touching nearly every field and discipline, from computational techniques in the physical and biological sciences, to new interactive media in the arts. This revolution has already brought fundamental social change. However, we do not yet understand the impact of this change, nor do we know how much more is yet to come.

Being an informed citizen in the Information Age requires knowledge of computing systems, global communications networks, and interactive information resources. The requisite level of knowledge goes beyond simply being comfortable with computing tools. It requires the ability to apply computational ways of thinking to design, to writing, to experimentation, to artistic expression, and to problem solving – to the very core of human intellectual activity. Just as a higher education requires writing skills that go beyond the mechanics of sentence and paragraph structure, it is also beginning to require computational skills that go beyond the mechanics of programming and software packages. In the Information Age, our ideas are no longer constrained solely by what is physically realizable, but by what is computationally realizable. For example, an artist is now able to create an artwork that only exists when someone interacts with it – specifying a framework within which each visitor can create a work of art. A chemist is now able to search more effectively for new compounds by modeling them, not only because of new tools, but also because of new computational ideas and paradigms.

The Information Revolution rests on fundamental advances in the physical sciences, electrical engineering, communications, and information technology. These advances are the product of the Industrial Revolution, which gave rise to colleges of engineering. Core enabling disciplines have emerged in the computing and information sciences (CIS) that are realizing the potential of the technology base. The embodiment of knowledge and techniques in computer software and protocols is now driving the revolution and opening a new "endless frontier" in a virtual place called "cyberspace."
One of the central underlying theoretical concepts is that of the universal computing machine. While this is a theoretical notion, it has had immense practical consequences. Consider the meteoric rise of the World Wide Web, a fundamental change that has happened in just a few years. Such rapid change was only possible because many people already had computers – which are universal computational machines – in their homes and offices. Prior to the Web, people largely used these machines for word processing and calculation. These same computers have now been transformed from typewriters and calculators into global information resources. While we have gotten used to this notion of the universality of computational devices, it is worth noting how different it is from physical devices, which are specialized to a particular function rather than being universal (e.g., physical universality would allow your refrigerator to function as a dishwasher).

Educational Challenge

The great challenge for universities like Cornell is to discover how to teach the new conceptual models of the computational world. More students are seeking to combine computing with a liberal education in the arts and humanities, to prepare themselves for jobs that increasingly require both technical depth and liberal breadth.

We know from our own direct experience, from the campus discussion, and especially from student reaction to the Initial Report, that student needs are not currently being met, even in areas where we have excellent faculty but scattered courses. In fact we view the current situation in computational science at Cornell as somewhat of a missed opportunity, because there is considerable research excellence but virtually no coordinated educational offerings and certainly no educational programs that would guide students to take advantage of the extraordinary richness of the Cornell environment in this area.

During the Senate discussions, we heard eloquent testimony about topics in computing and information where student interest is almost completely unsatisfied. Students and faculty alike are looking to the FCI as a voice for these needs.

Looming National Crisis

The rapid growth of the information economy is in danger of destroying the very educational system that enabled U.S. dominance in this area. The shortage of skilled workers is making it increasingly difficult for universities to attract and retain both faculty and doctoral students in computing related fields. At the same time, demand from undergraduates is soaring, resulting in huge classes and crushing teaching loads. This is affecting a number of departments, but is worse in computer science, as recently reported in an article in the Chronicle of Higher Education (September 24, 1999). We are in danger of “eating the seed corn” needed to sustain this revolution beyond a single generation. While this problem has been recognized in Washington, the main ability of the federal government to respond is to create more funding. This has been done. Universities must strive to create an environment that is at least as intellectually exciting as that found in the new information companies.
These industry jobs often provide the kind of intellectual challenge that attracts people to academic careers. While universities cannot match the financial opportunities in industry, we can and must strive to create an environment that is more intellectually stimulating.

**National Priorities**

The U.S. government has also studied the impact of the Information Revolution on society. In particular, the President's Information Technology Advisory Committee (PITAC) issued a report on February 24, 1999, outlining a federal government response to the revolution. Here is what the report says:

"Information Technology will be one of the key factors driving progress in the 21st Century – it will transform the way we live, learn, work, and play. Advances in computing and communications technology will create a new infrastructure for business, scientific research, and social interaction. This expanding infrastructure will provide us with new tools for communicating throughout the world and for acquiring knowledge and insight from information."

The report recommends a massive increase in federal research funding, specifically in: software research, building a flexible information infrastructure, high-end computing, and the socioeconomic impact of the Information Revolution. It says:

"To address these problems, the Committee estimated in its Interim report in August 1998 that the Federal government should increase its support for information technology research by one billion dollars per year by FY 2004."

The first installment of this investment has been appropriated. The Computing and Information Science Directorate of the NSF has received an unprecedented budget increase of $90 million for basic research in information technology, called the ITR program, plus $36 million for equipment. Additionally the Social, Behavioral, and Economic Sciences directorate allocated $23 million to a new program in information infrastructure.

**Impediments to Change**

Some universities have made major investments in computing and information. MIT, Carnegie Mellon, and Georgia Tech are prime examples. Other peer institutions, such as Harvard, have yet to act vigorously. What are the forces that have moved some universities quickly ahead, and what are the forces restraining others?

There may be a sense among the professorate that they are custodians of a very special institution, and change must be undertaken with great caution. On the other hand, many of our colleagues have praised our Initial Report for proposing something that is an organic part of Cornell and something that the faculty should develop.

One of the impediments to change here and elsewhere is a general lack of understanding of the field. Computing is still a relatively new academic discipline, and the basic discoveries in it are not widely known and appreciated. For example, many leading Cornell professors were graduate students at a time when there were no computer science departments and relatively few computers. Other faculty, unacquainted with computer science, focus entirely on the computer and are impeded in their understanding of the underlying theory. The modern notion of information science is even more novel and less well-defined. We noted confusion over this discipline in our recent campus forum and senate discussions. At the
same time, we were struck by how many faculty expressed a concern that their students were frequently better prepared than they were to cope with the computing revolution already at the doorsteps of their domains.

**Seeds of Action at Cornell**

In 1997 a Cornell faculty committee identified three strategic priorities in the sciences and engineering: (i) **biological sciences**, in particular genomics, (ii) **advanced materials science**, and (iii) **computing and information science**. Initiatives have already been undertaken in the first two of these three strategic areas, and we are now crafting Cornell’s plan of action for the third area.

A prior committee, on Digital Futures, explored this third strategic priority in 1997. Its proposals did not have sufficiently broad scope, and the effect of that work might have been to inform the administration on how to establish this Task Force.

In 1999 the Provost created the Office of Computing and Information Science, which is charged with bringing into being whatever structures and programs seem best in light of the extensive on-going deliberations about computing and information science as a strategic direction for Cornell. This office is exploring the administrative needs to support various structures and is helping with fundraising.

**Vision for Cornell**

_In the tradition of Ezra Cornell, we believe that Cornell University should become an institution where anyone can bring ideas from computing and information science to bear on any discipline._ Cornell has a nearly unrivaled combination of depth and breadth upon which to build – with one of the top computer science departments; outstanding research programs in computational science and engineering, coordinated by the Theory Center; the new computational genomics initiative; and pockets of computational expertise across the campus, in engineering, physical science, mathematics, arts, humanities, and social science. We believe that it is crucial for Cornell to act quickly to capitalize on these strengths, so that we can attract and retain the best students and faculty and provide the best education for students whose interests in computing and electronic information resources are rapidly growing. _We can be the first university to broadly integrate computing and information science into education for all students and into research and scholarship for colleagues across the campus._ While several other institutions have created new schools, colleges and laboratories, these new units do not address the broad-based nature of computing education and research in the Information Age. Moreover, a number of the new programs are focused solely on research and graduate or professional education, as we discuss later.

**Campus Response to our Initial Report**

The _Initial Report_ elicited a great deal of discussion, from department meetings to college committees. The Dean of the Faculty, J. Robert Cooke, organized a Faculty Forum in September and his office maintains a Web site that has collected relevant documents and opinions from the faculty. The Senate Committee on Academic Policies and Programs (CAPP) proposed six motions for Senate debate and informed the debate by a document providing a rationale for the motions.
In addition, the new Dean for Computing and Information Science, Robert Constable, is a member of the Task Force. He spent much of the fall semester listening and talking about the FCI ideas with interested groups and departments, including the engineering chairs and directors, the engineering Advisory Council, the Academic Assembly of the University Library, the Senate’s CAPP Committee, the Arts College Educational Policy Committee, the Arts College senior associate deans, the Cognitive Studies Executive Committee, Johnson School committees, the Genomics Task Force, and various delegations of faculty from around the university. He met with other deans and with several department chairs. His input from these meetings also informed our deliberations.

The Task Force learned a great deal from this diverse activity, and we have modified our recommendations to address those concerns we saw widely shared. The potential for weakening departments by draining expertise in computing and information into the FCI was a paramount concern. Additionally, there was concern that the computer science faculty might dominate the FCI decision-making. While everyone recognized that this department’s expertise is vital to the success of the FCI and that most CS faculty would be members under any reasonable organization, there was also a worry that they might discourage some activity that was vital to broad success of the FCI but not to the core of computer science. The concern seemed to be equally strong whether the department itself was imagined to be a member of the FCI, the CS major was thought to be one of the charter programs, or the individual faculty were all counted as members.

We judged that an Advisory Board to the FCI dean could contribute to representation of the broad campus interests. This is now part of our recommendation. We also anticipate that the FCI will benefit from the normal structures of governance through which representative committees of the colleges recommend policy.

The Senate ratified much of the Task Force vision but cautioned that a large amorphous collection of faculty linked only by an interest in using computers was unlikely to achieve the aims we set for the FCI. The Senate suggested that whatever organization emerges should be driven by faculty interest in particular educational programs, programs that served the students well, and clearly have substantial computing and information science content. The Senate also explicitly recognized the need for leadership at the dean level of an organization that would represent the computing and information faculty at Cornell.

Another concern raised was that an FCI might dilute Cornell’s exceptional strength in computer science and its growing strength in information technology. The lesson here is the one Cornell knows well: we must build excellent programs and attract outstanding students and faculty. That is precisely the goal of an FCI. Combining this concern with the Senate’s caution, we believe all the more fervently that we must build first from our strengths.

The overwhelming response to the Initial Report, even from the most vocal critics, was that the initial draft tapped into the right vision and that Cornell must move forward.

A FACULTY OF COMPUTING AND INFORMATION

We believe that Cornell should create a central home for computing and information research and education, spanning the entire campus. Such a home would serve to bring together experts in computing with researchers and scholars in a variety of disciplines, including but not limited to these interdisciplinary focal areas: Digital Arts and Culture; Human and Social Systems; and Science, Mathematics, and Engineering. Such a home
would provide fertile ground for emerging research and scholarly activities. Such a home would further provide a framework for creating new courses, new concentrations, and eventually new majors to better serve the educational needs of our students who increasingly seek to combine computing with their disciplines of interest.

We have considered a number of ways in which to best create such a home. Based on what other universities are doing in the computing arena, as well as by considering other cross-disciplinary programs at Cornell, we have identified four broad classes of existing structure:

1. A department that has the bulk of the expertise, with additional expertise in a few other departments. Many disciplines at Cornell operate this way, including Computer Science. (A slight modification of this is having a small number of related departments, perhaps in different colleges, such as Physics, Applied & Engineering Physics, Materials Science, and Electrical Engineering).

2. A center or laboratory, with participation from faculty in a number of departments, focused on research rather than education. The Theory Center at Cornell operates this way.

3. A division or other structure that cuts across departments and colleges, focused on research and education. The former Division of Biological Sciences at Cornell operated this way.

4. A college or school, offering undergraduate degrees, focused on both research and education. In the computing area, Carnegie-Mellon, Georgia Tech, and Penn State all operate this way.

The main advantage that we see for the department model (#1) is that it involves little or no change, as this is what we currently have in place. However, we see several significant disadvantages with this model. First, we believe that the scale of interactions that are required would be unwieldy for any single department to manage – both in terms of the sheer number of faculty and the intellectual breadth. We envision research connections and new educational programs integrating computing with the arts, the humanities, the social sciences, engineering, the physical sciences, the life sciences, and the professional schools. The number of faculty involved and their disparate backgrounds call for focal areas, such as the three we identified above, that in and of themselves could be as large as many departments. The combination of these focal areas with core computing and information science could be the size of a small college, and far broader intellectually.

A second critical problem that we see with the department model is the necessity of maintaining the strength, identity, reputation, and visibility of core activities such as the Computer Science Department and the computer engineering area. Adding a broad range of people to the departments that contain these core activities could easily be perceived as diluting their strength with "soft" or "applications" work. Thus we do not see the common home for broader activities fitting inside any single department. We have also seen, during campus discussions, that the model of diluting a department with a large number of joint appointments is damaging to the fundamental nature and purpose of departments.

Finally, we do not believe that having multiple activities in separate departments scattered across the campus works well because of the substantial structural barriers to the development of broad collaborations and cross-disciplinary courses. Also we know that this "scattered expertise" dilutes the impact of our strength when national rankings are tabulated. We return to this issue with model #3 (a division).
The main advantage that we see for the research center model (#2) is that it can support cross-disciplinary research that would otherwise be difficult to undertake. The Theory Center has done quite well recently in building such research partnerships for computation in the sciences and engineering (computational science). The main problem with this model is that it has no educational component and would be quite unlikely to support such a broad educational enterprise as the one we imagine. Moreover, we believe that it cannot play such a role, since departments and colleges rather than centers fill this academic role.

In fact, we are critical of the current situation in computational science at Cornell because there is considerable research excellence, but virtually no broadly coordinated educational offerings and certainly no educational program in this area. In our view, simply building two other research centers, in Digital Arts and Culture and in Human and Social Systems, would yield the same problem. Moreover, we believe that it may be more difficult to start with research efforts in some areas, rather than with scholarship and teaching.

Finally, we note that the very idea of a center is a local Cornell notion with little national standing. If we hope to play a national leadership role in education, we must look for structures that could be a national role model.

We find little to argue for in the division model (#3). A division is a cross-cutting management structure that has little or no resources or authority (e.g., budget, faculty lines, etc.). As such, the director of a division is generally reduced to being a broker between deans and department chairs. This causes difficulties in coordinated hiring, in setting directions, and in building integrated curricula that are co-taught across colleges or other academic boundaries. It is our belief that unless a structure has resources to bring to the table, it can get little accomplished in terms of building ties. Without authority and resources, the transactional costs of such a model are too high. Moreover, a division acts to exclude those not within it, much as a college does, without many of the benefits of a college.

The main advantage that we see for the college model (#4) is that it is the de facto way of creating broad-based academic endeavors that involve both research and teaching. A college or school has financial resources, faculty lines, and a structure for creating programs of education and research within it. The main disadvantage that we see for this model is that it limits interdisciplinary activity. It is doubtful that a college could truly reach across the campus, building joint programs with units from the arts, humanities, engineering, and sciences. In practice, a college creates barriers to cross-disciplinary activities unless they happen to fall entirely within the college.

A second critical drawback that we see with the college model is that it could create additional complications for undergraduates. Moving between colleges is difficult for students to do, and it is hard to imagine that this would change. Adding another college would simply add to this difficulty.

All this being said, many people have argued that a new traditional college is the only option that is viable in the long term. Indeed, if the traditional colleges do not cooperate with the structure we recommend, it might not be viable without degree-granting authority. Bearing this in mind, we believe that, whatever we create, it should be flexible enough to evolve, either expanding or contracting as it adapts to change. If we build it to be flexible, we are in a situation where we cannot lose by trying this change.

We have discussed various pros and cons of each of these models, and believe that none of the models is best for Cornell. In the following section we discuss a different model, called a
that we believe will better achieve the goal of supporting broad-based programs of education and research in the computing and information related areas.

Recommendations and Discussion

Our main recommendation is to create a new academic unit called a Faculty (termed here the Faculty of Computing and Information, although the actual name of the unit may be different). This Faculty is intended to complement the traditional academic structures of the university in order to provide more flexibility to respond to new educational and research needs in the fast-paced information economy. Administratively, the FCI would have the attributes of a college, while academically, it would benefit from a combination of the majors of its multiple college departments and its interdisciplinary programs. The cross-college nature of the academic programs is suggestive of an undergraduate version of the field structure of the Graduate School.

The proposed Faculty should be a focal point for academic activities in computing and information and should have resources to seed and nurture the development of both existing areas and emerging activities. It should serve the broad and strong student interest in computing and information across the university and should incubate new concentrations, programs, majors, and departments as needs emerge.

While we realize that the kind of structural change embodied in this proposed Faculty is not easy to undertake in a university, we believe that the speed of change in the world makes it critical to explore new, more flexible, and more inherently interdisciplinary structures. The Information Revolution is likely to reorder the reputations of many major research universities. Those on the top will reap enormous benefits as society reacts to this revolution. The goal of our recommendations is to position Cornell to expand its excellent reputation in computing and information.

To be successful, the new structure must complement the departments, which we believe should remain the main academic homes of both faculty and students. At any point in time, a snapshot of the academic programs will show majors in departments of the FCI that are part of the degree programs of more than one college, concentrations in various departments across the university and new academic programs, some mature and some new, but all excellent.

Specifically, we recommend:

1. A Faculty of Computing and Information (or FCI) should be created, although the actual name may differ from this. The Faculty will have some of the attributes of a college and some of the structure of fields in the Graduate School. Like the fields, it will cut across the traditional college structure. Like a college, it will control university resources and faculty positions. It will be led by an academic dean, a member of the Dean's Council, who will have the usual administrative responsibility for departments, such as managing appointments, promotions, and budgets.

2. The Faculty should be the focus of significantly expanded educational and research activity in computing and information. It will work to develop new programs of education and research. Given the inevitable change that this fast-moving area will provoke, the Faculty should be viewed as a "breeding ground" for new activities on the campus. At the undergraduate level, new programs will initially be minors or concentrations. The
precise nature of these programs will depend on the interests of those involved, student needs, and funding opportunities. Over time, we believe that some of these will evolve into new majors and may also require the creation of new departments. We expect that such new departments would be in the FCI with degree programs in the traditional colleges. We do not, however, expect that the FCI will cover all activities in computing and information at Cornell, either at the start or in the future. Rather, the FCI provides a way of focusing a large fraction of these activities in a manner that is accessible and visible to students and funding agencies and that serves as the basis for new academic programs.

3. The FCI affiliated faculty should reflect a balance of faculty on campus with expertise in computing and information areas. Some professorial positions in the Faculty will be shared with other units (primarily departments). Some of these positions will be of indefinite term, and others will be fixed term. The shared appointments will provide funding to other departments, but tenure and promotion decisions will rest with the home departments. Some positions will be partially supported by the FCI, while others will be fully supported by these resources. We expect that professors affiliated with the Faculty will have a home department, although some of these departments will be within the FCI.

4. Certain academic disciplines are critically important to the success of the proposed Faculty, and we recommend that the Computer Science Department (CS) should be administratively in the FCI from the start. We recommend this because computer science is playing a central role in the computing and information revolution nationwide – in academia, in federal funding, and in the software industry. Other programs at Cornell should also have strong ties with the FCI as detailed in this Report. An Advisory Board, described below, will balance the interests of programs and departments and will act to ensure an open and interdisciplinary community.

5. An Advisory Board representative of the computing and information constituencies on campus should be formed to advise the dean on matters related to the Faculty, such as new courses and programs, appointments of affiliated faculty, and other academic and research program matters. We recommend that this board have between eight and twelve members, actively engaged in the areas and mission of the Faculty, drawn from across the campus. Moreover, we recommend that this board have no more than twenty percent of its members from any one department. The dean will retain the usual administrative responsibilities for full-fledged departments that report to the dean. The Board will counterbalance the influence of the departments in the FCI. We recommend that an initial board be appointed by the Provost with input from campus constituencies for a term of one or two years. This board would further be charged with developing a permanent board structure.

6. The Faculty should develop and oversee a new university-wide Undergraduate Computing Program modeled after the Knight Writing Program. This program would have the mission of aiding in the design and teaching of computing and information courses, in a manner that is most appropriate to the students in each discipline.

Goals of the FCI Structure

With these recommendations, we aim to achieve the following:
1. Enable Cornell to attract and retain the best faculty and students in the Information Age. The formation of the FCI will accomplish this by creating an exciting, fertile research environment in both current and emerging areas, offering innovative new courses, and reducing the high teaching loads and the resultant lack of faculty-student contact.

2. Increase the diversity of interests and backgrounds of students and faculty involved in research and education in computing and information. The FCI will broaden the reach of and the accessibility to computing-based programs across the campus. Particularly in the humanities and arts, this will greatly broaden the reach of CIS material beyond the traditional science and engineering arena.

3. Create interdisciplinary programs of computing research and scholarship and grow existing ones. Strong programs in these areas might substantially increase Cornell’s research funding in Computing and Information Science, taking full advantage of the projected doubling in federal research funds for CIS. In addition, Cornell’s competitiveness for computing-related research awards in a wide range of science, art, and humanities will be enhanced.

   ♦ In Science, Mathematics, and Engineering, expand on the strong foundation provided by the Theory Center and Computational Genomics, developing and applying computational models and techniques that help reveal properties of the physical and natural world.

   ♦ In Human and Social Systems, help "understand and enhance the effects of information technology on people, our economy, society, culture and political system" (from PITAC report to President Clinton, February 1999) and apply computational models and techniques to the understanding of human cognition, perception, and activity.

   ♦ In Digital Arts and Culture, enhance the practice, performance, and exhibition of digital arts and digital expression, such as visual arts, theatre, film and video, music, architecture, creative writing, and journalism. Develop critical approaches to the Internet, the culture of digitality, and the digital organization and distribution of knowledge; explore the theory of virtuality and the reality of virtual communities.

4. Create new educational programs that bring the ideas of computing and information science to all disciplines. Capitalize on our strengths in research and scholarship to develop new courses, new minors (concentrations), and eventually new majors in emerging CIS areas complementing the research focal areas. Use the broader reach of these programs to increase the diversity of background and of interests among students and faculty in CIS disciplines.

Structure and Mission of the FCI

Some of the possible subunits of the FCI are these: (i) the current Computer Science Department (CS), and the interdisciplinary focal areas of (ii) Digital Arts and Culture, (iii) Human and Social Systems, and (iv) Science, Mathematics, and Engineering, and the emerging subject of Information Organization and Management. Of these focal areas, computational science, mathematics and engineering are already quite strong at Cornell, with active research programs and the Theory Center playing an important interdisciplinary
role. However, there are no broadly coordinated academic programs associated with this research, and we believe that this focal area in the FCI could complement and enhance the Theory Center’s research role. The areas of Digital Arts and Culture and Human and Social Systems reflect emerging areas of research and scholarship. Other institutions are beginning to recognize these new areas. For instance, the Media Lab at MIT fits squarely within Digital Arts and Culture, and the School of Information Management and Systems (SIMS) at Berkeley lies within Human and Social Systems. We expand below on these areas in the section entitled Background of the Recommendations. We believe it is critical that upon conception the FCI have faculty in all of these areas, not just in CS. The focal areas cross every college boundary on campus, and thus we expect that the FCI would have joint appointments with faculty in every college.

As noted above, we believe that the FCI must improve the educational opportunities in computing and information at Cornell. It would offer majors and minors but not admit its own students or set requirements other than those of a major or minor. The FCI would offer an undergraduate major in computer science, as well as minors in new areas that align with the focal areas. Eventually some of these minors might become new majors. The FCI would be responsible for teaching the courses and setting the requirements for each major or minor. The FCI need not have its own undergraduate admissions or undergraduate degree, but rather would offer its programs in many (if not all) colleges. Initially the only major offered by the FCI would be in computer science. This major is already a part of the programs in two colleges (Engineering as well as Arts and Sciences). This would remain exactly as it is now. However, it is anticipated that a CS major in other colleges would also be added. We further expect that the new minors offered by the FCI would also be available to students in any college, with the approval of their college. We believe that the FCI should have membership in the college curriculum committees of each college where its majors or minors are offered.

In order to broaden the educational opportunities for our students, we expect that the FCI would develop and offer new undergraduate minors (or concentrations) building on Cornell’s excellence in research and graduate education. These minors could include areas such as computational science, computational mathematics, information organization and management, visualization and visual expression, cognitive studies, and other programs that fall within the focal areas identified above.

We further believe that the FCI should play a leading role in developing introductory computing courses that serve the needs of students in all areas. To that end, we recommend that the FCI establish and manage an Undergraduate Computing Program, similar in many ways to the Knight Writing Program. This program would have the goal of bringing fundamental ideas from computing and information science to students in all disciplines, while at the same time respecting the different educational contexts of various disciplines. We expand more on this Undergraduate Computing Program in the section entitled Background of the Recommendations.

Flexibility

The FCI structure allows flexibility. If necessary, the unit could be given degree granting authority to move it closer to a college structure in the event that many other universities adopt the college model for computing and information. That is the model adopted by CMU, Georgia Tech, and Penn State. In the unlikely event that student interest wanes and research funds become scarce, new departments would not form and exploratory programs would disappear. The result could be a cross college CS Department with some of the
attributes of a school reporting to the Office of the Provost, the way CS started. In the case of severe contraction in this area, the Faculty structure could be used to combine CS with other fields that cut across traditional colleges.

**POSSIBLE IMPACT**

**External Impact**

We hope that formation of an FCI will have a national impact, continuing Cornell’s leadership role in computing and information science. The Cornell Computer Science Department was one of the first in the nation and has been a model for many others, and the Theory Center established Cornell as a leader in computational science.

To achieve impact, the proposal should have national credibility. We want to examine the national context of our proposal. The campus discussions also raised the point of how Cornell’s peer institutions are reacting to rapid changes in computing and information science.

While there are different interpretations of the data, we want to make widely available some of the raw facts, as there appears to be some confusion regarding the situation at other institutions. We first consider computer science departments, as that topic has been specifically raised in the campus discussions. We note that there are several different structures for CS, none of which is really dominant. For instance, among the top ten CS departments in the current *U.S. News and World Report* rankings, two are joint EE/CS departments in Engineering Colleges (MIT and UC-Berkeley), one is a CS department in an Engineering College (Stanford), one is a separate School of Computer Science (Carnegie-Mellon), and six are departments that offer programs through both the equivalent of the Arts and Sciences College and the Engineering College (Cornell, Illinois, Princeton, Texas-Austin, Washington, and Wisconsin-Madison). Some of these six departments are in one of the two colleges that they serve, and others are joint in two colleges. Overall, the majority of these CS departments are organizationally part of engineering colleges; but at the same time, the majority have programs of teaching and research that fall in Arts and Science.

If we instead consider the CS programs at universities with top ranked engineering colleges, we see a similar diversity. In fact, many of the institutions are the same as above. Again using the *U.S. News* rankings, three schools have joint EE/CS departments (MIT, UC-Berkeley, and Michigan), two have CS departments in an Engineering College (Caltech and Stanford), two have separate colleges of computing (Carnegie-Mellon and Georgia Tech), and four have departments that offer programs through both Arts and Science and Engineering (Cornell, Illinois, Michigan, and Texas-Austin). (Note that Michigan appears twice here because it is both a joint EE/CS department and offers its CS degree through the Literature, Science and Arts College rather than through Engineering).

Thus, seven of these ten top-ranked CS programs lie fully or partly outside of engineering colleges, and only two are joint EE/CS departments.

Going beyond CS departments, there are significant initiatives in computing and information science at several institutions – notably the Media Lab at MIT, SIMS at UC Berkeley, the School of Information at Michigan, the College of Computing at Georgia Tech, and the School of Information Science and Technology at Penn State. The first three of these efforts have largely grown up in competition with, or separate from, activities in computer science.
departments. This is a situation that the Task Force finds particularly worrisome, as it tends to produce duplicate efforts, competing programs, and a lack of cross-unit collaboration. While correlation does not necessarily imply causality, we note that these three institutions are precisely those with joint EE/CS departments.

We wish to stress that the activities at other institutions exhibit a broad range of possible structures, with considerable opportunity for breadth that reaches a substantial number of people outside of departments such as computer science. These activities also illustrate some of the dangers that we can and should avoid at Cornell. Each institution must evaluate its own strengths to determine how best to respond to the challenge of teaching and advancing knowledge in computing and information. One of Cornell’s historical strengths has been its extraordinary breadth, something that we believe will be a real asset in this arena.

**Internal Impact**

While the design of this Faculty is intended to maximize the positive impact, there is the potential for any far-reaching changes to have negative effects as well. Here we consider some of the potential impact on the College of Engineering. To set the stage, let us consider in more detail what would happen to the Computer Science Department with the creation of the FCI.

We have claimed that computing and information extends well beyond engineering in its impact. This is a major premise of our report. We also realize that for a new home for computing and information to be credible, either inside Cornell or outside, essentially all of the thirty or more computer scientists at Cornell should be part of the structure. If all of the faculty are members, the department must report to the dean of the FCI in order for FCI to have the autonomy and authority we deem necessary to distinguish the FCI from a division. Thus, the FCI will have administrative responsibility for at least one department from the start and probably others as the FCI matures. To this extent it shares attributes of a college. On the other hand, CS is one of the largest majors in Engineering and also has substantial research ties with several engineering departments. Any proposed change should not detract from the teaching and research role of CS in the Engineering College. In our proposal, the CS undergraduate program in Engineering would remain exactly as it is today, with CS as one of the central undergraduate majors for engineering students, as well as being a source of both required and elective courses for students in other engineering majors. CS would continue to participate on engineering curriculum committees just as it does today.

This is precisely the manner in which the CS major currently functions in the College of Arts and Sciences. Arts and Sciences has no budgetary or other authority over CS; however, CS operates a fairly large major (around fifty students per year) in that college. CS also participates in curriculum and admissions committees in Arts and Sciences. Moreover, the CS major in Arts and Science is widely perceived as an asset by both the College of Arts and Sciences and by the CS Department. We expect that with the FCI this would remain true for Arts and Sciences and also be true for Engineering.

Another important issue is the impact of any change on the external perception and the rankings of the College of Engineering. We believe that the Faculty structure offers considerable flexibility in this regard. For instance, the faculty in the CS Department could continue to be listed on the Engineering College roster (as is currently done for CS in Arts and Sciences). Moreover, the research support for CS faculty could be included in the external reporting of the Engineering College research expenditures, as is done now. We further expect a substantial number of joint appointments between Engineering and the FCI,
in computational Science and in computer engineering, making the close ties apparent both inside and outside Cornell.

The FCI would need to have faculty lines beyond those currently allocated for CS. This would be both for growth of full-time faculty, and for joint appointments with other units. Currently growth in the CS department has been completely within the confines of Engineering, which has caused considerable tension. Already some of this growth has been for ties with areas such as Cognitive Studies that are not particularly important to engineering. With the FCI, the growth in both CS and particularly in other parts of the FCI will be even less appropriate to engineering. It is arguably better for Engineering not to have to absorb this additional growth, particularly in areas such as the arts, humanities, and social sciences. Another resource related issue is that joint appointments of faculty with the FCI would provide half-lines back to the Engineering College. We expect that there would be a number of such appointments.

To the extent that a strong CS department is important to Engineering, we believe that a structure such as the FCI will benefit Engineering because it will result in a stronger CS department at Cornell. With the current situation, the national problem affecting all computer science departments could strike Cornell as well. The majority of computer science faculty have exciting and lucrative opportunities elsewhere. We believe that by broadening the campuswide expertise in computing and information, the Faculty structure will make Cornell more attractive for core CS as well.

Bold action in the computing and information sciences arena, such as the creation of the FCI, would likely attract substantial new resources to Cornell. Many alumni recognize, perhaps better than we do ourselves, the broad impact of computing and information science on our economy and our culture. They realize the importance of making sure that Cornell is a leader rather than a follower in the Information Age. We believe that these people can help us identify funds that would not otherwise be available.

Moreover, there are substantial new government and foundation programs to support research, education, and scholarship in interdisciplinary areas that involve computing and nearly every subject. The FCI would make it clear to such agencies that Cornell is strongly committed to these areas. Given the substantial partnership between faculty in Engineering and the FCI, we believe that any increased flow of funds in this area would also have a positive impact on the College of Engineering.

**DISCUSSION OF POSSIBLE FOCUS AREAS**

Cornell is in a unique position to create an interdisciplinary group of scholars, from a wide range of departments and fields, devoted to CIS research and teaching. By focusing our efforts and building together, we would be in a stronger position to create the research and educational partnerships for the future. We would be better positioned to leverage funding from federal agencies, private donors, and foundations interested in supporting research in computing and information systems. We would be better able to create the new interdisciplinary programs that "educate for the future". Above we identified focal areas that we believe capture the main interactions between computing and other disciplines – these areas fall along the lines of traditional divisions between fields, the arts and humanities, the sciences, mathematics and engineering, and the social sciences. Our discussions also have emphasized the strong potential for fertile cross-disciplinary exchange between these fields. We believe that the FCI could provide a home to nurture what are now fledgling activities in
many of these areas. We also discuss possible new programs in areas closely related to
computer science and information technology.

We recommend that the FCI have faculty in each of the focal areas in order to build activities
that truly span the campus. Moreover we expect that many of these would be jointly funded
appointments with other academic units, including not only many departments on campus
but also the professional schools. In this section we briefly describe some of the kinds of
emergent or ongoing activities at Cornell that could help define the focal areas. We stress
that these are simply illustrative examples and are not intended to delimit the scope of any of
the areas. We hope that a number of faculty at Cornell will see their intellectual activities as
overlapping with one of these focal areas. At the end of this section we also briefly describe
the background rationale for an Undergraduate Computing Program.

**Digital Arts and Culture**

Visual literacy and the ability to express ideas in new multimedia formats are increasingly
important in the Information Age. Skills in visual and multimedia digital communication
and analysis are now important educational, artistic, and communication tools of equal
social importance to textual literacy and skills in writing.

At Cornell, we perceive interdisciplinary approaches to Digital Arts and Culture to intersect
across three central axes: 1) Digital Arts: Practice, exhibition, and analysis of digital practice
in visual arts, theatre, film and video, music, architecture, creative writing – from the studio
to the web, from the library to the museum. 2) Digital Culture: Critical approaches to the
Internet and the culture of digitality: the organization and distribution of knowledge (from
cultures to sexualities), the Web, games and mass culture, television and film, multimedia,
public spaces (from libraries and museums to performance spaces, sports arenas, and
congressional chambers). 3) Digital Theory: Theory of virtuality and virtual reality (from
philosophy, psychoanalysis, and linguistics to literary and art theory to emergent Internet
communities), theory of digital art and performance.

Pedagogical and research initiatives organized around Digital Arts and Culture would
establish a structure with which to capitalize on preexistent and emergent Cornell strengths
in these areas. Cornell is home to a number of ambitious initiatives in the study and practice
of digital arts and culture. Innovative research projects currently in place include: the
Program of Computer Graphics; the Multimedia Lab in the Art Department; digital
production and performance initiatives in the Department of Theatre, Film, and Dance; the
Digital Music Program; Cornell Digital Library; Cornell Digital Museum; the John S. Knight
Writing Program; The Society for the Humanities; the Africana Studies Center Digital
Catalogue of African Art; The Graduate Field in Film and Video Studies; The Einaudi Center
Predissertation Workshop on Comparative Visualities; Academic Technology Services; the
Herbert F. Johnson Museum of Art. Add to these projects, parallel initiatives in human
social systems: The Program in Science and Technology Studies; the Human Computer
Interaction Lab in the Department of Communication; and the Theory Center Visualization
Group. These initiatives have been recognized for their individual contributions to the
development of research and performance in digital arts, visualization, performance, and the
humanities.

Cornell faculty associated with these innovative research projects have given equal attention
to the initial development of a pedagogy in what could be termed "digital studies." Creative
initiatives in computer instruction in writing, cinema, music, and art have introduced
students and faculty to new trends in scholarly production that promise to revolutionize the
means and nature of academic production in the future. Just as a growing number of courses
are managed through websites, strong efforts have been made by a broad group of humanities, arts, and social science faculty and instructors to introduce students to the latest digital developments in their fields. This includes courses on the impact of computer technology on society, the globalization of communications, the history and theory of electronic art, critical approaches to the Internet, human perception, the theory of virtuality, and digital practice in art, theatre, cinema, dance, music, and architecture.

Other temporary initiatives have contributed immensely to Cornell’s visibility as a leading research center of digital visualization. Cornell has hosted such a significant grouping of conferences and exhibitions this past year alone to position itself at the forefront of this field. Exemplary of the fruits of increased interaction and communication is the forthcoming international tour of the exhibition, Contact Zones: The Art of CD-Rom. Cosponsored by The Society for the Humanities and Cornell Information Technologies (CIT) with the aid of the Cornell University Library and the Johnson Museum, this was the first international exhibition of CD-Rom art in the United States (and the largest such exhibition to date) and is currently on an international tour (Mexico City, Charlottesville, Calgary have been confirmed to date). Translation of the exhibition website in Spanish will permit the Cornell server to offer the first bilingual American art catalogue on the web. In addition, last year’s annual theme of the Society for the Humanities, “The Virtual: Old and New,” brought to Cornell leading theorists and practitioners of digital culture who offered an innovative set of courses on the topic – certainly the most cohesive curriculum of its kind to have been offered by any institution, from courses on the history of the philosophy of the virtual to courses on digital art and virtual reality. Similarly, last spring’s workshop cosponsored by The Society for the Humanities and ATS, "Artistic Discourses of Digitality,” assembled at Cornell an international grouping of theorists and artists. Cornell also has benefited from collaborations between the Graduate Program in Film and Video Studies and the Park School of Communications at Ithaca College in bringing leading digital artists and theorists to both campuses. Another innovative conference this past fall, "French and Francophone Cinematic Futures," cosponsored by French Studies, Cornell Cinema, and The Society for the Humanities, staged at Cornell an exciting gathering of film scholars who considered the move of film into the digital future. On a related front, the Theory Center sponsored a workshop in May on "Virtual Worlds in Formal and Informal Education.” The Departments of Art, Architecture, Music and Theatre, Film, and Dance also have invited exceptionally visible digital artists to campus. Finally, the University Library, in collaboration with the Interactive Multimedia Group in Communications, is planning the development of a series of multimedia ‘creationstations’ that will provide students with an academic space and context for the creation of multimedia essays and art projects.

Given the promising results of these early efforts to teach and research the arts and humanities in "virtual form," Cornell is poised to position itself as a leading East Coast center of such research and pedagogy. What makes Cornell unique in this field is the potential of its collaboration in digital visualization between research projects in computing science, social science, the humanities, and the arts. If such projects were encouraged to collaborate in jointly sponsored research and pedagogy, they could provide the framework for one of the East Coast’s leading centers in digital visualization and performance. Few institutions can boast of these results nor so imagine the expansion of their potential.

Human and Social Systems

1The Art of CD-Rom: http://contactzones.cit.cornell.edu
The Provost's Task Force on the Future of the Social Sciences at Cornell contains examples of 
the computational modeling problems and data management problems that Cornell faculty 
are investigating. The very nature of these problems illustrates the transformation of the 
social sciences made possible by the unprecedented amount of digital data now available 
and the opportunities to computationally mine it for knowledge about social systems. As 
one example, the Cornell Institute for Social and Economic Research (CISER) has launched a 
project to provide formal support for a variety of confidential data access modalities (U.S. 
Census Bureau, U.S. Bureau of Labor Statistics, U.S. Social Security Administration, other 
national statistical agencies, etc.) in order to promote the use of confidential data for 
nonproprietary scientific research. CISER, CIT, and the Theory Center have already begun to 
implement parts of this plan. There are many other large data sets that arise in the social 
sciences, involving such issues as the analysis of temporal processes (such as state 
dependence and duration) and multilevel modeling.

However, the overlap of computing and information science and the social sciences is far 
greater than just the application of computational methods for data mining and analysis. To 
take just one example, consider the study of judgment and decision making at both the 
individual and group levels. The standard "rational-actor" model in decision theory, widely 
used in economics and political science, has assumed that decisions are made by rational 
individuals. Roughly speaking, a rational individual is one who seeks to maximize his 
expected gains. Among other assumptions, it is always implicitly assumed that these 
individuals have unlimited computational resources to allow them to compute which actions 
will indeed maximize their expected gains. Much of the focus at Cornell has been to 
challenge and elaborate this traditional model. This work has shown that, while intuition 
and judgmental rules of thumb function reasonably well in many settings, they also give rise 
to systematic departures from the behaviors predicted by the rational-actor model.

Computer science provides a fruitful viewpoint on issues such as rational decision-making 
and the presence of computational limitations. If we build software agents to help us on the 
Web, they will have to make decisions. But if we are to program them, we must take into 
account the computational problems involved with making such decisions. It may be very 
difficult to compute what the best decision is. There is work actively going on now in 
computer science to design approaches to making sensible decisions in the presence of 
resource limitations. This work may help clarify some of the systematic deviations from the 
standard model that have been observed. At the same time, computer science is being 
influenced by the work in decision theory, and there are current efforts at Cornell to see how 
decision theory can be applied to design better, more adaptive computer algorithms.

Once we move to a multi-agent, dynamic setting, we encounter a host of new issues, ranging 
from problems of game theory to questions of how social systems, institutions, and 
organizations adapt and evolve. Again, there is a surprising commonality of concerns 
between the work going on in the social sciences in these areas and work in distributed 
computing within computer science. Issues such as coordination and stability are as 
important in distributed computing as they are in societies and organizations. There are also 
ties between both these computer science and social science models and the nonlinear and 
dynamical systems models used in mathematics and physics.

Cornell has exceptional strength in the social sciences in the area of Social Adaptation and 
Decision Research, which is currently centered in three existing interdisciplinary programs at 
Cornell: the Center for Behavioral Economics and Decision Research (BEDR), Cognitive 
Studies, and the Multi-Disciplinary Research Program on Organizations and Institutions 
(MRPOI). It is also exceptionally strong in the areas in computer science most naturally 
aligned with these areas – distributed computing and artificial intelligence. Indeed, there is
active work in computer science on decision theory and adaptive systems. Preliminary collaborative efforts have already begun; a structure such as the FCI would certainly encourage more and help Cornell become a leader in this emerging area.

Another area of rapidly increasing importance is that of developing a better understanding of how the Information Revolution is changing society and the economy. For instance, the emergence of new global "citizens of the net", who share common interests but may be of different nationalities, creates the potential for substantial change in the ways that nation states operate. The free flow of information across many borders is already altering how people learn and inform one another. Internationalization and changes in forms of communication raise fundamental questions about copyright and intellectual property. The PITAC report to President Clinton identifies these societal issues as being critical for further study, and recommends that they receive a substantial increase in government funding. Cornell has the opportunity to build on its strength in the social sciences and in computing, including existing programs such as Science and Technology Studies, and building new ties between computing and the Law School and Business School. These programs will be important on their own and as part of an emerging area we are calling Information Organization and Management. Courses on information and society will be essential in a coherent program in this area. We look at it next.

**Information Organization and Management**

During the past few years, the fields loosely known as "information management" or "digital libraries" have emerged as exciting and vigorous areas. The unifying theme is intellectual information, in digital formats, delivered over networks. The challenge of creating such systems is motivating fundamental research in information science, multimedia information retrieval, human computer interaction, distributed computing, economics, law and other disciplines. It is closely related to many developments of the World Wide Web and the internationalization of computing systems. At present Cornell has a number of high-quality research activities. Exciting experiments are being carried out by several academic disciplines, but there is no focus for these activities.

Digital libraries and electronic publishing are of vital importance to Cornell for another reason: libraries and publishing are a central part of every university. There are great opportunities to combine education and research with innovation in the libraries and publishing activities across the campus. Other universities that have developed programs in this area have usually been constrained by the existence of a traditional library school. By starting from scratch, Cornell is able to design a curriculum that will be truly suited to the new world of electronic information.

Cornell is among the world’s top ten centers of research in digital libraries. Individuals from the Computer Science Department, the Department of Communications, and the University Libraries have a number of joint research grants, which currently total about $2 million per year. Several of these research projects are collaborations with other organizations in the USA, Europe, and Australia. Two of the major publications in this field are edited from Cornell (D-Lib Magazine and DigiNews).

A special objective of the program will be to provide a bridge between research and implementation at Cornell. The Cornell University Library is in the midst of a movement to digital information that will shape it for decades. Meanwhile, substantial information services have been developed in other parts of the university. (A notable example is the Legal Information Institute in the Law School.) Scholarly publishing could well be entirely
electronic within a decade, certainly in the sciences. Research prototypes should not be confused with large-scale implementation projects, but they can each learn from the other. Education and research will benefit from direct exposure to actual implementations; the implementation projects will gain from close contact with the research.

Science, Mathematics, and Engineering

The coming decades will be marked by the development of increasingly interdisciplinary approaches to science. However, doing "interdisciplinary science" of the same quality as "disciplinary science" is a challenge. The goals, methods, approaches and standards can differ wildly from one field to another, even between two closely related physical sciences such as geology and meteorology. When one tries to work at the interfaces between, for example, a biological and a physical science, problems multiply.

Computing provides a common thread for collaborative work across disciplines. It is no accident that much of the strongest interdisciplinary science being done today is computer-based modeling. In many branches of science, modeling and simulation have become a "third way", complementing theory and experimentation. Reorganizing the Computing and Information Sciences at Cornell in a way that opens access across disciplines and encourages collaboration will foster exciting and viable research directions. These new directions will be precisely those in which we can expect to see the greatest student interest and research support over coming decades.

Here we briefly provide some examples of how a reorganization and broadening of CIS can inspire such initiative in the sciences, mathematics, and engineering, as well as examples of the continuing and ever-growing requirements within emerging disciplinary lines of inquiry. We stress that these are only illustrative examples. There are many such projects underway at Cornell, some of which benefit from interdisciplinary interaction with computational experts and some of which do not.

Mathematics. One of the origins of modern computer science was logic and mathematics, and of course mathematics to many people is synonymous with computation. Many of the fundamental abstractions on which computing and information science rests came from logicians. One of them is the universal machine (from Turing machines); another is the concept of a formal language and the notion for a high level programming language. All branches of mathematics have provided the models that are the source of many of the important algorithms powering computer systems. The connections between mathematics and computing will remain strong since computing theory is deeply mathematical. The interface between mathematics and computer science is a place where new results can translate quickly into vastly increased capabilities in systems; it is a place where mathematical results get a "price tag," and it is sometimes in the billions of dollars.

Conversely, computer science has contributed new methods to mathematics and has created new subfields. It is now possible to explore mathematical structures computationally, and computation has become part of the notion of proof as exemplified in the solution of the famous four color problem. Several open problems in mathematics have been solved by so called "intelligent computer systems." This is likely to be an area of sustained innovation because computers can now be brought to bear on many of the intellectual processes that are so purely manifest in mathematics, such as deduction and explanation. Mathematics is one of the fields in which one can see so clearly to the heart of computer and information science. What one sees is that computer science is about the automation of intellectual processes. In
the case of mathematics, computer science has shown how to implement it and bring it to life.

At Cornell the ties between CS and mathematics are especially strong since professor of mathematics Anil Nerode was one of the founders of the CS Department. There has been lively research and educational ties between the two departments since CS was formed. This important connection should be sustained for the well being of both of these disciplines and Cornell.

**Engineering and Physical Science.** There are many cross-disciplinary activities in computing coordinated by the Theory Center. These efforts in computational science span a broad range of departments and several colleges at Cornell. For example, the NSF project on "Crack Propagation on Teraflop Computers" is joint between Computer Science and Civil and Environmental Engineering. The goal is to simulate fracture in macroscopic engineering parts like airframes and gears, using parallel adaptive finite-element methods. In order to solve these problems for realistic size problems, new computational techniques are also needed. The project is researching areas such as 3D mesh generation, preconditioners for iterative solvers, compilation methods for sparse matrix computations, and automatic load-balancing on parallel computers. These technologies will permit engineers to simulate crack growth in 3D systems consisting of a million degrees of freedom (including systems with many interacting cracks) in about an hour on a parallel machine with roughly a hundred processors.

**Earth System Science.** A systems approach to better understanding our planet has developed hand-in-hand with advances in computing and information science. From the very beginning of large-scale computation, solutions of the equations that govern atmospheric motion and thermodynamics have been used to push the edges of computing ability. Because the earth system is intractably large, computer modeling provides the only laboratory for experimentation. It also provides challenges in the design of computer algorithms and simulations. Cornell has significant efforts in many areas of earth system science, including climate modeling, satellite observations, ecosystem dynamics, agricultural systems, and biogeochemistry. We have special interests and strong programs in regions all over the world, including the Amazon Basin, northern Africa, Patagonia, and the Himalayas, as well as in Tompkins County watersheds, local ecosystems, and New York State agriculture. One can envision a centralized earth system science modeling effort through which, for example, climate models are made available for "experiments" designed by ecosystem scientists or geologists (or both). Such a facility would foster interactions that would improve existing models and encourage joint efforts to couple models of climate system subcomponents. Coordinated activities at Cornell would complement efforts at national laboratories to develop comprehensive models of the entire earth system, in the best traditions of university science with in-depth collaboration between deep-thinking scientists. Such efforts are increasingly attractive to funding agencies such as NASA, NSF, and NOAA.

**Life Science.** Cornell is undertaking a major effort in computational genomics, with cooperation between several departments and colleges. In addition to this large effort, there are a number of other activities in computational biology. For example, the study of protein shape can be greatly aided by the use of advanced computational techniques. Random mutations of proteins are the elementary steps of evolution. Databases of protein structures and sequences suggest that the shapes of proteins are better conserved than the sequences during the course of evolution. A single three-dimensional shape seems to accommodate an exponentially large number of sequences that share no more than a few percent of identical residues. Widely different sequences can share the same global topology and three-dimensional structure. Answering many of the fundamental questions about protein
function and shape seem best addressed by the use of computational models and techniques, including the development of new computational methods. The biological questions include issues such as whether it is possible to find a single or a few mutations that cause a dramatic change in the stable shape of the protein, or whether it is possible to trace remote evolutionary relationships between species by following structures and not sequences (since structures seem better preserved than sequences). Questions of this form are computationally hard and require the design of new models and new computational algorithms, making them an interesting challenge for computer scientists as well as biologists.

**Information Technology.** Another point of origin of computing and information science is the creation and improvement of digital computers and the creation of a high speed communications infrastructure. This activity has been largely an engineering enterprise conducted in universities and major corporations. Collaborations between computer science and electrical engineering produced the *digital abstraction* that is one of the first steps in a tower of abstractions that define modern computing systems. Also, communications engineers were the first to deal with *information* as a precise scientific concept.

Taken together the concepts and technology in computer architecture, digital and wireless communications, digital signal processing, and information theory have become part of an area that overlaps strongly with information science and is part of information technology. It is important for software systems designers to understand the technology base that will physically realize their designs, and it is important for the hardware architects and network designers to understand the software that will animate their artifacts. Both groups are concerned with system design. At Cornell the subjects of computer architecture, information theory, signal processing, digital electronic systems, and wireless communication are taught in Electrical Engineering. In this report we refer to these as Information Technology and Computer Engineering (IT / CE). It is important that this group be closely aligned with the FCI. It would be natural for it to be one of the programs in the FCI even though it will reside in exactly one college.

In one outstanding example of the connection, groups from CS and EE have worked together to blend wireless communication technology, probabilistic inference, and complexity theory into multi-layer communication networks that are extremely efficient in their support of multimedia communications, while predicting and solving operational problems before they occur. Such activities will directly benefit the future FCI and the university at large through recognition by the telecommunications industry, government funding agencies, and the general public.

As increasingly sophisticated data processing and resource management algorithms are built into the communication networks of the future, the need for embedded, powerful computational engines will become critical. On-going research by EE computer engineering faculty in the areas of computer architecture, asynchronous systems, and hardware-software interaction will play a fundamental role in the development of Information Technology within the FCI. The dividing line between hardware and software has already begun to blur; in the future it may be difficult to find altogether. The FCI will serve as a locus for collaboration between the software scientists of the Computer Science Department and the computer engineers of the School of Electrical Engineering. It is critical that the "higher" and "lower" layers mix, sharing information and synthesizing the computational technology that will support the on-going communication revolution.
Undergraduate Computing Program

To better prepare our students for the Information Age, we propose that Cornell develop an Undergraduate Computing Program. This program would in large part be patterned after the Knight Writing Program. Its goal would be to teach all students the fundamental ideas of computing and information systems, in a context where they can apply these ideas within their own areas of study. While the Computing Program would have the goal of educating all students, we do not envision a computing requirement for all students until there is a campus mandate to do so. We strongly encourage a timely campuswide discussion about what computing curriculum might be required of all students. Just as writing seminars go beyond the mechanics of writing, the computing program must go beyond the mechanics of programming or software packages. Our students must learn how to think computationally, not just how to use computational tools - although the tools will be taught as a necessary prerequisite.

There are many parallels between introductory computing and introductory writing. In computing, there is an inherent tension between the concepts that the computer scientists want to teach and the tools that the other disciplines want their students to learn. A similar tension exists between mechanics and concepts in writing, and the Writing Program has developed a careful balance between these needs. Computing courses such as CS100 teach fundamental principles of object oriented design and iterative versus recursive processes, currently using the Java language. In many areas of science and engineering, however, the faculty want students to learn particular programming languages or software tools such as Fortran or Matlab. There often is a disconnect between the principles that are taught in CS100 and these particular tools, leading to frustration for faculty in other departments.

It would be nearly impossible for a single department to offer versions of CS100 tailored to each discipline. Even with the current situation, where "only" about one-third of Cornell students take CS100, this is not possible. This failure to meet the needs of the disciplines has been a source of frustration for a number of departments, some of which now teach their own introductory computing courses. It is also a source of frustration for the CS department, which finds that those other courses generally teach little in the way of fundamental principles that apply more broadly. Thus we propose to follow a model more like the Writing Program; although we do not envision the computing program necessarily having small classes and sections (however, in some disciplines that could be highly beneficial). We propose that a Computing Program Office be created, overseen by a FCI faculty member (probably at least initially a faculty member in the CS Department). This office would set curricular standards and help in the development of computing courses across the campus, much as the Knight Writing Program does for writing seminars. Initially we do not envision computing being a campus-wide requirement, but we recommend exploring this option over the next few years. The Computing Program Office would not only set standards, but would work closely with departments that wish to offer computing courses, in order to develop curricula that both serve that department's needs and serve the need of providing a broader computing education. We expect that the office would employ some professional staff to both administer the program and to work with departments across campus.

We believe that there could be substantial opportunity in integrating the Computing Program with planning for the new North Campus as a potential location for classrooms, additional labs, and faculty contact. For instance, one problem with many computing courses is the lack of contact between students and faculty or course staff. In part this is because much of the work by the students takes place outside the normal 8:00 a.m. – 4:00 p.m. time period for classes. Increasingly students have the necessary computers in their dorm rooms to do this work, but may still need to return to central campus for access to
teaching staff. It appears that it could be advantageous to hold tutoring sessions in the living
groups and have faculty or course staff available at the "off hours" when students really do
their work.

We further propose that the Computing Program Office be active in "teaching the teachers",
much as the Knight Writing Program does. One of the major educational challenges of the
moment is that entering students often know more about computing tools than the faculty
(and even graduate students) who are teaching them. Thus we must both bring faculty and
teaching assistants up to the level of the students, as well as preparing them to teach the
concepts that incoming students do not generally know. Again, an analogy to the Writing
Program can be useful here. Most incoming students are adequately skilled in the mechanics
of writing but not with how to use writing as a means of clarifying their own thinking.
Similarly, more and more incoming students are skilled in the mechanics of computing but
not in how to use computational ideas in their thinking.

A program for teaching teachers could take several forms. One could envision faculty with
computational expertise co-teaching courses with other faculty. One could also envision
summer programs for faculty and teaching assistants. We expect that in order to be
successful, there must be adequate resources available to create such programs without
placing an added burden on any of the faculty involved (either instructors or participants).
Thus it will be important to be able to buy out faculty teaching responsibilities and to pay
summer salaries for faculty and teaching assistants involved in teaching the teachers
programs. We hope and expect that such a program would be attractive to both foundations
and private donors.
MEMBERSHIP OF THE TASK FORCE

Daniel Huttenlocher, Chair (dph@cs.cornell.edu)
Professor of Computer Science

John Abowd (jma7@cornell.edu)
Professor of Labor Economics and Director, Cornell Institute for Social and Economic Research

Thomas Coleman (coleman@cs.cornell.edu)
Professor of Computer Science and Director, Cornell Theory Center

Robert Constable (cis-dean@cornell.edu)
Professor and Dean for Computing and Information Science

Kerry Cook (khc6@cornell.edu)
Associate Professor of Atmospheric Science

Geraldine Gay (gkg1@cornell.edu)
Associate Professor of Communication

Marcia Lyons (ml113@cornell.edu)
Assistant Professor of Art

Polley McClure (pam28@cornell.edu)
Vice President for Information Technologies

Timothy Murray (tcm1@cornell.edu)
Professor of English

Robert Richardson (rcr2@cornell.edu)
Professor of Physics and Vice Provost for Research

Saul Teukolsky (saul@spacenet.tn.cornell.edu)
Professor of Physics and Astronomy and Director, Center for Radiophysics and Space Research

Sarah Thomas (set9@cornell.edu)
University Librarian

12/8/99