Report of the

University of Washington
Department of Computer Science and Engineering

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Executive Summary

The University of Washington should take immense pride in this department and its leadership. They have, over the past ten years, risen to become one of the most highly regarded computer science programs in the country, competing for students and faculty in the top 5 to 7 departments nationally. They have developed a "can-do" culture in the department that has led to outstanding undergraduate and graduate programs and a model professional masters program – all of these are consistently producing some of the top students in the country. They have been responsive to change and the demands placed on them by the University and the region.

This department, like no other here, lies at the core of nearly every imaginable future of the University of Washington. This is not just a general reflection of the role of computer science and information technology for any institution of higher learning; rather we see this as particularly germane to the University of Washington because of regional strengths in areas that depend crucially on the success of this Computer Science and Engineering Department. Not only is this an IT centric region, it is one where this department has played and active role – reaching out to the business and the educational community of the state.

The University of Washington is already exceedingly vulnerable to raids on its faculty by those institutions and organizations that provide greater financial rewards.   At the same time, it cannot afford to let the strength and quality of this program slide.   Indeed, merely staying the course, would be fatal to the CSE department and the UW.   The University needs to consider what actions should be taken to elevate the quality of CSE and Information Technology in general (where CSE has formed the core and will likely remain there). Moving the CSE program from the top 5-10 to the top 1-5 is an investment that will pay off at a ratio far greater than any input. Because of these issues,

the committee ended the review with a state of alarm: the faculty, staff and students are working at such full throttle, we cannot imagine their continuing in this manner for very long. Faculty will be drawn away under this "pressure cooker" atmosphere unless immediate action is taken to remedy a crisis that has loomed for nearly a decade at the UW.

The University is aware of the potential crisis and has responded in a number of regards: they have made a correction in salaries to reduce compression, they have made available to the department a modest increase in staff and they have begun to consider immediate space needs.   Despite these moves, there are serious morale problems at the lower ranks (assistant and associate). To address these we propose a number of action items that are outlined below and explained in greater detail further on in the report.

- Provide immediate action on space as a stopgap: solve the immediate space needs with temporary classroom and center space. The committee identified potential teaching space in Odegaard. There may be more in or around Mary Gates Hall.   This is their number one problem and prohibits filling faculty positions and expanding CSE into new areas.

- Place the new CSE Building Number 1 on the Development Campaign. This building was a critical issue at the last ten year review and it has become a crisis now.

- Honor entrepreneurship in a way that reflects science and engineering in the 21st century. The current formulas for redistribution of royalties are antiquated and do not promote the sorts of activities the University should be doing. Much of the dilemma here stems from an administrative response that is so slow and cumbersome that morale in the department is compromised.

- Strengthen and highlight the connections between CSE and the Sciences on campus. Fully half of the undergraduate majors in this most competitive discipline are in the College of Arts and Sciences. The College, however, has a disturbingly poor grasp of the importance of these majors to their mission and that of the UW. We would like to see the divisional dean of sciences in Arts and Sciences encourage research and teaching efforts in ways that foster and *highlight* the strengths of the current and future connections.

- Reward the growing connections to other engineering units on campus with seed money. There are a growing number of research and teaching collaborations within the College of Engineering that mutually benefit CSE and each of the units. Seed money for new classes and seed money for initiatives (UIFs etc) serves the dual role of strengthening appropriate ties and helping CSE deliver some aspects of their teaching.

- Fix the budgetary insanity that currently confounds the department. This includes funding raises out of unfilled positions, recognizing that salary inversions will be a

deadly blow and is just one example of the administrative overhead that compromises effective running of this unit.

- Consider this a department of the University. The allegiances to Engineering are as strong as those to Arts and Sciences and potentially to the School of Medicine, School of Business, School of Art and College of Ocean and Fisheries Sciences. A vision of this department as core to the UW's success appears obvious to this committee. It *should* be obvious to the UW. Given their outstanding record for initiating and following through on valuable services and programs here, the UW would be wise to invest in this department in an unprecedented way. As we all argue that the state should invest in the UW to ensure economic and intellectual success of the region, the UW should invest in this program to accomplish these goals. Do so with a new building, permanent solutions to salary inversions and salary competitiveness, and reward their entrepreneurial activities.

- To further enable the growth of CSE, a Department of the University, the UW must establish a growth model to fund and provide future space beyond the proposed new CSE building. This is an absolutely essential issue if the UW is to meet external market needs and its academic future.

Process

The review committee received its charge letter in February 2000 from John T. Slattery, Associate Dean for Academic Programs in the Graduate School. Following this and the delivery of the department's self study, the review began with an orientation meeting on 8 March. Present were the internal members of the review committee, the Deans of Arts and Sciences, Engineering, Undergraduate Education, and the Graduate School as well as Debra Friedman (Associate Provost for Academic Planning) and John T. Slattery (Associate Dean for Academic Programming). At that meeting, we discussed the review process and a variety of programmatic issues about CSE (Appendix A).

In early April, the internal committee members met with a number of individuals (faculty, staff, graduate students and undergraduates) in the department and several associated with the department to further understand the myriad issues surrounding the self-study of the department and the potential future of the department. We also met with Dean Denice Denton, Associate Dean of Research in Engineering Mary Lidstrom, Divisional Dean for the Sciences Gary Christian, Dean Fred Campbell, as well as Professor Richard Karpen, Director of CARTAH and Professor Christopher Ozubko, Director of the School of Art. In addition, the chair of the committee requested via e-mail commentaries about the research, teaching and service missions of the department. This information was used to structure the agenda for the formal review meeting that convened with the outside members (Ferrante and Wulf) April 18 and 19, 2000.

Throughout the entire process, the committee faced the challenge associated with the centrality of this unit. In short, there are far too many collaborating units on campus to exhaustively assess the impact of the CSE program to the University of Washington. We

chose, instead, to focus on those most strongly linked to CSE and those who have a potential to be profoundly affected by the health of this program. Frankly, if the collective departments and colleges are moving in a rational direction for the future, nearly all would lay some claim to computing. This, then, set the stage for our review.

The members of the committee extend a hearty thanks to all members of the CSE department for their thorough self-study preparation, their open and candid responses to our questions and the inspiring manner in which they conduct their professional lives. Professor Ed Lazowska unfailingly provided *instantaneous* responses to questions raised by the internal members and was exceedingly helpful throughout the entire process.

Department Evaluation

National Stature

The committee feels that this department holds a unique place in the country by managing to maintain an extremely high level of excellence across nearly all aspects of computer science. Thus, while they may not have any single subfield that ranks in the top two in the country, every subfield ranks in the top 10 of published rankings (Appendix 4). Many rank in the top five. The consequence of this is that there is a uniquely rich set of options for potential new faculty and graduate students permitting the department to attract, in the face of low salaries and insufficient space, some of the top new talent in the country.

The outside members of the committee felt that the rankings are actually lower than what the top practitioners in the field might give the department now. Their new hires in databases, networking, graphics and hardware, will likely be manifest as an even higher ranking. Moreover, the uniformly high level of excellence maintained in all crucial aspects of CSE make this department uniquely strong on the national level. Stanford, CMU, Berkeley and MIT are really the only ones maintaining same level of uniform excellence. One committee member (Wulf) maintains that UW has the strongest CSE department for students who are attracted to a wide range of options rather than those that are highly focussed in advance. We all feel that the unique egalitarian culture based on excellence, shared governance, accessibility and interaction with students, has enabled this department to be highly ranked and a highly desirable place to work as a faculty member or a student.

Of particular strength are programs in Animation and Graphics, Databases (two new stellar hires in this area), Hardware, Networking and Systems. New growth planned for embedded systems (a nice overlap with EE faculty) and datamining (a nice overlap with Statistics) with make this program stronger still. These combined with a conscious decision by the department to embrace collaborations with the Arts (via animation and CARTAH), and biological sciences (Computational Biology).

It is important to note that another unique strength of this department derives from its history as a computer *science* program. Thus the traditional models of a computer

program that split off from engineering programs does not reflect a special strength here at the UW. This department has maintained strong ties with specific sciences on campus (statistics, astronomy, and biology) and built new ones (art, library science) while building stronger ties to units in its new college association (e.g. electrical engineering). There are a host (almost too many) of collaborations forming between the faculty at the grass roots level.

Undergraduate Education

There are about 400 majors in CSE.   They are distributed about equally between the College of Engineering and the College of Arts and Sciences and are actively recruited by the department, even at the high school level.   These students are a select group, receiving a blue ribbon education in an environment that encourages independence and collaboration. As a group, they have the highest mean GPA in the College of Engineering and are actively recruited by some of the very best CS graduate programs in the country. Indeed, in our informal meetings with the undergraduates, many were suffering from the problem of deciding whether to go to Berkeley, MIT, Stanford or CMU!

The quality of instruction has risen dramatically over the years, in part as a result of aggressive use of CIDR by the faculty, and in part as a result of departmental culture that fosters respect for undergraduate instruction.   The department has aggressively dealt with the demand for IT education by greatly expanding its offerings for introductory computing courses. As far as we could discern, therefore, there are no problems about quality of instruction and degree structure.

The problem facing the department, however, revolves around the overwhelming undergraduate demand for training in this area. The faculty have gone to great lengths to increase the size of the major and have done so with nearly identical infrastructure support (space) and modest staff increase.   But the demand is beginning to overwhelm the undergraduate advising in the department in an unproductive way. In our view, the advisors should not have a large fraction of their energy devoted to deflecting inappropriate majors. They should, instead, focus on the students that are entering and those in the program. Unfortunately, demand has outstripped supply here. To ameliorate this problem, the advisors offer a weekly information session that is often attended by about 30 people (students and even their family members).   This is a mere stopgap to a bigger problem.

We recommend that the UW hire a IT career counselor whose job is to advise incoming UW students and those considering UW of the wide range of IT options that the UW has to offer. Ideally, this individual would be a staff member in CSE who can, therefore, better coordinate the information sessions about IT versus CSE per se.

It is very important that the divisional dean of science in Arts and Sciences work hard to maintain the option of a BS in Computer Science within the college. This is particularly advantageous to those students seeking double majors between the sciences and CS and

those seeking a broader liberal arts education while still receiving a degree in CS. There seemed to have been some uncertainty in this regard and we recommend that the college of Arts and Sciences make even clearer the exciting options for their undergraduates in this field.

There is a tremendous need for appropriate facilities of undergraduate teaching laboratories.   These fall into three categories: (1) laboratories for reasonable sized classrooms (not giant halls packed with computers), (2) teaching laboratories for hardware aspects of computing (systems, clusters, embedded systems, VLSI design, etc) and (3) an improved graphics and animation facility.

Graduate Program

The graduate program is, by every measure, flourishing. Perhaps the greatest reflections of success in this part of their program is seen in the quality of the graduate students they attract and the satisfaction maintained by the current and recent graduate students (see Appendix **2** for a summary from the poll of graduate students). The CSE full-time graduate program enrolls 150 students, was ranked 6th in the nation for "effectiveness" and regularly produces highly sought after graduates. They have amassed 7 ARCS fellows, 12 NSF predoctoral fellows, making them one of the most "rewarded" departments in the University.

In our meeting with the graduate students, we were overwhelmed with the satisfaction they found in their CSE programs. They were happy, enjoyed the open and collaborative culture of the faculty and their fellow students, and appreciated the high quality of their training and research opportunities. One of the strengths they noted is the commitment of CSE faculty to mentor and develop outstanding graduate students. They also greatly value the departmental colloquia.

Concerns about entrepreneurship and conflict of interest issues between faculty and students (raised with the External Advisory Committee 6/99) have been largely addressed by the recent Commercialization Policy developed and implemented by the CSE Department (http://www.cs.washington.edu/general/misc/principles.html).

Due to the burgeoning demands on CSE faculty for teaching more classes and students, there has been a recent explosion in the number of CSE graduate students teaching CSE courses. The students that teach these courses are overjoyed with this opportunity to teach, have been mentored by the CSE faculty, and received excellent student ratings. As CSE hires more faculty, this will not be the normal mode of operation to have graduate students teaching but it is necessary in this current state of rapid growth.

The CSE Department implemented a response to the External Advisory Committee recommendation to change the emphasis of the Qualifying Exam and the timing of the Generals Exam. They also made the requirements more flexible, to accommodate interactions with other department programs (e.g. MBT). The main goal is to reduce the time to completion for the Ph.D. or the terminal Master's degree. One more change that

may enhance the process and student experience is to make the Generals Exam be, in all cases, a dissertation proposal. The graduate students that we talked with felt that this would make the process worthwhile instead of a mere exercise.

It is the view of both the internal and external committee members that of the students entering the program, a 48% Ph.D. completion rate is comparable to CSE programs in other institutions and is of no concern. Some students do not complete the Ph.D. for a variety of reasons including a wealth of industrial and start-up opportunities.

The strength of the graduate program is evident in its national stature of the faculty, their publications and representation in the field, and the high quality of students that are produced. In order to grow and further strengthen research areas in CSE, this committee recommends that some of the following suggestions be seriously considered by CSE and supported by the UW. It is recognized that nearly every department and college on campus wants some part of CSE. However, if both grass roots efforts and strategic planning efforts are maximized and leveraged, this would help enable CSE to become even stronger than it already is and ensure that it does not miss out on important opportunities. For example, CSE should take advantage of the increasing excellence in other departments in the College of Engineering (and other units on-campus) by effectively partnering with them to develop long term plans for research Centers and/or other joint research programs (like the current ATI/UIF in Animation and the Arts and the CoE funded effort on UW.center.net).   They have been remarkably successful in this regard with partnerships in the Arts, in Biomedical Informatics, and in a growing number of interdisciplinary endeavors. These, along with units in engineering represent the breadth of research and educational activities they have fostered. CSE faculty and graduate students recognize that they currently have gaps in covering the research areas of Human-Computer Interaction (HCI), user interfaces, AI, and computer vision. New faculty hires will likely cover this. The area of mobile wireless embedded systems is growing strong and could be one of the top in the nation with complementary hires in the EE Department and by reducing barriers for CSE and EE faculty to teach joint courses. CSE is currently one of five "Expedition Centers" in the U.S. for DARPA in "embedded systems / invisible computing."

The one huge impediment to elevating the CSE Department in to the top 5 nationally is, again, their meager space. Lack of space ties directly to faculty recruiting and retention and graduate student recruiting. Research laboratories, the glue that hold research groups together, are sorely lacking and impede the positive interactions that should exist among graduate students. Lack of space for TAs to meet with students has forced them to hold TA sessions in the hallways of Sieg Hall. Lack of laboratory space also imposes the CSE survival attitude of "we are heavily balanced towards small projects" and makes it nearly impossible for them to pursue "big" research activities.

UW CSE has a remarkable graduate program. However, if it is to remain in the top 9 overall and advance into the top 5, the UW must act now to remedy the space issues for the present and future of not only CSE but the entire UW community. CSE provides technological competency and information proficiency university-wide and state-wide.

The Professional Master's Program

The Professional Master's Program exemplifies the efforts of CSE to provide continuing education opportunities at the very highest level for working professionals in the computer science field. Established in 1996, this part time state supported program combines intellectual rigor with a flexible schedule of course offerings that is ideally suited to the needs of full time professionals. The program has been successful at attracting high quality students from a wide range of local software companies. The typical entering student has a strong degree in Computer Science or Computer Engineering and five years of work experience at a leading information technology company. The program has been successful at attracting 50 students per year and has a current enrollment of 120 students. CSE faculty have generally been pleasantly surprised at the quality and enthusiasm of PMP students, and it is clear that the PMP has a growing constituency not just among local computer science professionals, but also among CSE faculty who increasingly see this as a desirable program in which to teach.

We believe that CSE should be commended for establishing this program, for the high quality of the student body, and for the rigor of the curriculum. The program has clearly tapped into a previously unmet need among working computer science professionals for continuing education at the graduate level. It is also worth noting that anecdotal evidence suggests that CSE has been more successful than its peer institutions at establishing a professional masters program. This is a testament to the quality of the curriculum, the efficiency of program administration, the dedication of key faculty, and the scale of the need in the local region.

Going forward, a big challenge (and opportunity) for the PMP is to broaden the curriculum so that it incorporates certain business related courses that are essential for full time software professionals. Courses in software project management and the strategic management of technology and innovation can provide material that are key for full time professionals, and could nicely round out their education. On this point, it is worth noting that a new joint hire between CSE and the Business School is intended to begin to address this opportunity.

Entrepreneurship

The faculty of the CSE department has been one of the most prolific in the University when it comes to the creation of new technology with commercial potential. A number of new companies have been created by CSE faculty and a significant amount of technology created by CSE faculty has been licensed or sold for substantial financial gain. There is no question in our mind that the department must be given credit for this. It is the department that creates the environment that attracts high quality faculty capable of creating new technology. Moreover, once faculty are in harness at CSE, the department continues to offer them a supportive environment that enhances their ability to create and commercialize new technology.

However, under the current system at the University of Washington, the majority of the gains from licensing and equity deals flow to central administration and the inventor, leaving little if anything for the sponsoring department. We believe that this approach is incorrect. It does not reward the department for creating an environment within which entrepreneurial activity can flourish. It is also out of step with the practice at most if not all peer institutions. We strongly recommend that the University adopt the practice common at most peer institutions where one third of the equity or royalties from new technology flows to central administration, one third flows to the inventor, and one third flows to the unit within which the inventor is housed.

Financial Support

Central administration has stated that funding of the CSE department should support no fewer than 43 full time faculty, along with the appropriate level of administrative support and lecturers. Currently the department has around 30 full time faculty. Central administration has also committed itself to helping to raise the salaries of CSE faculty. In common with most units at the University of Washington, salaries in the CSE department lag those at peer institutions. Currently, the average salary for full Professors in the department is 7.5% behind those of full professors at peer institutions. This gap is less than that found in most units at the UW and reflects a commitment on the part of central administration to narrow the gap for a strong department whose continued health is central to the mission of the University. We commend central administration for taking action on salaries, and for supporting the expansion of the department.

However, we are concerned by indications that the salary increases, along with funds to support additional staff salaries and other recurring expenses, may have been financed by recapturing funds from unfilled faculty lines in the CSE department. If some of the CSE faculty lines no longer have sufficient funds behind them, we wonder whether the financial resources exist to allow the department to execute on its hiring plans. We believe that it is important for the future health of the CSE department that central administration immediately put real money behind any unfilled faculty lines, and that this money not be used to support the salary enhancements of existing faculty or other recurring expenses.

Leadership

The department has been under the leadership of two chairs since the last ten-year review. Professor Jean-Loup Baer saw the department through its transition from Arts and Sciences into the College of Engineering. Professor Ed Lazowska took on the chair 7 years ago. In that time, the department has flourished with substantive growth in both numbers of faculty and staff and new areas of research strength (computational biology, graphics, databases, embedded systems…).   His leadership and mentoring has been done with a level of commitment rarely, if ever, seen by any member of this review committee. Ed has also established crucial ties in Olympia, he has become one of the University's best spokesmen for technology and education in the region, and he has garnered a

national reputation for a skilled bridge between academics and industry. These factors, along with a tenacious attitude, have made Ed the ideal chair for the department.

The department has flourished under this leadership and under an egalitarian structure. Every member of the faculty carries nearly the same load for teaching, service and advising. Staff, students and faculty work as a team with mutual respect a key factor in their success. The assistant professors feel well mentored and are generally protected from the day-to-day administration of the department. Though they are operating at a very high level of stress because of the many things the department does and because of the large number of vacant positions that demand attention by all the faculty as they attempt to fill these.

The future leadership is of some concern to both the committee and the department. While the views are divided about how best to proceed for the next chair, few doubt that (1) Ed has set a standard that many would find difficult to match and (2) the growth in commitments the department has made impose a tremendous strain on the current leadership.

Professor Lazowska's term expires by the end of the next year. While there are a number of well qualified candidates within the department that could rise to the task, most staff and faculty feel that the intensity by which Lazowska works can not be easily matched. Our committee feels that the faculty would be wise to look at outstanding outside candidates if, for no other reason, to gain perspective on what they have in-house for leadership.

Service to the Community

This department has been utterly amazing in its ability to do everything asked of them (and more) for resources that are far lower than those of peer institutions. It is a familiar refrain here at the University of Washington. But in this case, we cannot emphasize too much how crucial these activities have been.

- They have established, even by UW standards, great collaborations (MBT, Library School, Math Sciences and the ACMS program, Business School, Medical School with the new UIF under Ira Kalet, Art, Law and many in the sciences and other engineering departments).

- They have pioneered distance learning and undergraduate programs and relationships.

- They have established, far beyond any single unit, significant roles in state, local, and federal government with testimony and advising on future roles of computing in education and technology (Lazowska's service on the State Information Services Board).

- They have worked with regional industry and business interests to strengthen the presence of the UW in this sector (with the Technology Alliance, the Washington

Software Alliance, Microsoft). The Professional Masters Program for practicing professionals, the H1-B grants with Seattle-King County , and working with Qwest.

- They have been a model department for coordinating undergraduate recruitment to the UW, for K-12 outreach (the K-20 network design), the UW TAP (Technology Access Program – students working in all Seattle Public Schools as net engineers etc), Pilot Technology Schools such as the John Stanford International School, and FITness courses for high school students.   This is simply beyond the pale for what any other department on campus has done.

- They have become the most effective department bridging interests in research and teaching with other local institutions: UW Bothell and UW Tacoma have had their programs structured in coordination with our CSE program, they coordinate annual meetings with local community colleges and host instructors for one quarter UW residencies, they have developed tutored video instruction to improve the quantity and quality of introductory programming courses (now available to community colleges such as North Seattle, Highline, Centralia, Green River, Shoreline and Heritage).

All of these activities are done by initiative from every member of this department. They are asked to do a small fraction of these and they go well beyond this to have a significant impact on multiple endeavors in the Sciences, the UW, as well as regional and industrial components here.

Principal Recommendations

Because the future of the UW is inexorably linked to the future of this department and because merely staying the course is fatal in this field, we urgently recommend that you follow the recommendations below.

(1) **Interim Space: Fix it now and do so quickly**.   Hiring of new faculty is absolutely linked to this limit.   Realize that the old configuration of space saw Computer Science as a desk sport.   This is now increasingly an experimental science where laboratories are de-rigueur – chip design, graphics labs, building and designing clusters, training on embedded systems are all examples where each faculty member should command as much space as those in EE or Physics or Chemistry. We discussed suggestions for interim space that included some in Mary Gates Hall, some in Odegaard Library, and even some temporary structures.   While details about exactly where to put each bit are beyond the scope of this committee, we would ask that you move undergraduate teaching labs into Mary Gates Hall on a temporary basis.   This means that beyond the current allocation of teaching in MGH, there would be additional labs for Graphics and Animation, Hardware and Design. This would be a temporary solution until a new CSE building is created. It frees up additional space in Sieg Hall for new faculty hires (they really require lab space).

(2) **Permanent Space: Make the CSE Building the highest priority for Development.** Ten years ago, the review committee urged the Administration to solve this problem. The external advisory committee (Wulf as a member of that) were told by President McCormick that this is the highest priority for capital development at the UW.   The only sure way to make this happen is to charge development with the task of completing the fundraising for this project by the end of the year.   This could be rolled into the new capital campaign as an early (the first) major project.

(3) **Develop growth model to fund and provide future space beyond the new CSE building.** To meet internal and external market, intellectual and strategic requirements of the UW, this is absolutely essential.

(4) **Hire an IT counselor (for UW, housed in CSE).** This is a need that supercedes merely the stress on the advisors in CSE. It is a crucial service required of undergraduates in this new world. Many want to pursue IT, not all should be CSE majors.   Options, and coordination of programs could be made far clearer with a person in this role.

(5) **Continue to aggressively address salary issues to retain and recruit the best talent to the UW**.

(6) **Fix the outdated allocation of royalties from entrepreneurial activities**.   Dean Denton has already suggested a wise plan that the Provost should adopt now. The history of this problem dates back 5 years (Appendix 3) and is simply out of step with nearly every other major research University. Reward the key activity the UW wants most: entrepreneurship.

Current National Ranking

US News Computer Science (1999)
 Overall: 7th:

 Subfields:
         AI: 9th
          Databases: not in top 10 but no faculty until '98; have hired two now
         Graphics/UI: 9th
         Hardware: 7th
         Software: 5th
         Theory: 8th
US News Computer Engineering (2000)
 Overall: 9th

National Research Council (1993)
http://www.cra.org/statistics/nrcstudy2/rankcs.html
 Quality: 9th
 Effectiveness: 6th
 5-year Improvement: 5th (only top-10 program in the top 10 for this)

The Role of Computer Science in the Modern World and in the Modern University
(Ed Lazowska)

Computer science is a field whose fundamental advances drive forward many other fields. The impact of computer science has been so great on the science and engineering disciplines, in fact, that it is common to misconstrue computer scientists as principally "enablers of computational science through the creation of ever-faster high-end systems." This view is fallacious in a number of ways. First, even high-end computing is far more than just "cycles" – it is algorithms, programming and operating systems, visualization, computer architecture, and more. Second, high-end computing is only one of many contributions of computer science to transforming all of science and engineering; other examples include datamining, the web, sophisticated algorithms, telecollaboration tools, and the deep intellectual partnerships that characterize the confluence of biology and computation. Third, the impact of computer science on science and engineering – as broad-based and significant as it has been – is rapidly being eclipsed by the revolutionary and transformational changes that computer science is bringing about across the full spectrum of human endeavor. For the true power of computer science is as a *human enabler*, transforming all aspects of our lives: commerce, education, employment, health care, manufacturing, government, national security, communication, and entertainment, in addition to science and engineering.

Properly understood and properly executed, these roles are entirely complementary. Computer science exemplifies "Pasteur's Quadrant" – a field in which research can at once be both fundamental, and driven by concerns of use. On one hand, the extraordinary impact of computer science arises from breakthroughs at the core of the field. Those who use today's computing – even in very advanced ways – are the beneficiaries of *yesterday's* computer science research. The role of computer scientists is to *invent the future* – a future that in many aspects we cannot even envision today. On the other hand, interdisciplinary interactions are critical, both to driving computer science forward, and to driving other fields forward. A university – inherently the home to many disciplines – thus has a significant competitive advantage. Deep intellectual partnerships – rather than "user/supplier" relationships – are the key.