Computer Engineering Plan for 2010

1/17/06

Computer Engineering focuses on the design, analysis and application of computers and on their applications as components of systems. The UCSC Department of Computer Engineering sustains and strengthens its teaching and research program to provide students with inspiration and quality education in the theory and practice of computer engineering.

Departmental Mission Statement

Maintaining and Building Excellence

The Department of Computer Engineering will maintain and build excellence in research, undergraduate and graduate teaching, and service during the next five years.

In research, we target five specific areas of research excellence:

- computer system design
- design technologies
- digital media and sensor technology
- computer networks
- embedded and autonomous systems.

In the coming 5 years, we plan to maintain excellence in these focused areas and build excellence in a cross-cutting interdisciplinary emphasis in assistive technology as we seek to train undergraduate and graduate engineers for the future.

Recent examples of research excellence include leading a $5.2M multi-university consortium to develop the new science of ad hoc networks; creating and receiving national publicity on the development of a virtual white cane for the blind; writing one of the 13 top conference papers in the broad area of Computer Architecture and receiving an NSF CAREER grant on first application; receiving a highly competitive NSF Major Research Instrumentation (MRI) grant to launch our autonomous systems program; working with biology faculty and undergraduates to create a sensor network for coral reef monitoring, creating collars and a sensor network for monitoring of the activites and behavior of coyotes, and receiving continuing funding (with Environmental Toxicology) for research on real-time control of ground-water clean-up.

In teaching, we strive for innovation and excellence in the classroom and in academic programs. We have led efforts to integrate modern technology in teaching, and are constantly working to improve our undergraduate and graduate curricula.

Recent examples of teaching excellence include innovation with tablet PCs and web archiving (supported by COT), offering a new first-year Hands-On Computer Engineering course every quarter to increase excitement and improve retention in

engineering students, creating a Minor in Computer Technology targeting for non-engineering students interested in K-12 teaching, and placement of our PhD and Postdoctoral graduates at leading industrial research laboratories and in faculty positions at UM Amherst (now tenured), UCI, Santa Clara, Georgetown (now tenured), Cal Poly San Luis Obispo, Bahcesehir University, U Naples, U Twente, and the Federal University of Campina Grande (Brazil, now tenured).

In service, we dedicate ourselves to serving the Baskin School, UCSC, and our professional disciplines. Computer Engineering faculty frequently dedicate themselves to leading many efforts, both on campus and off.

Recent examples of service excellence include heading Crown College; chairing the Committee on Educational Policy; leading UCSC's CITRIS branch; directing the Korea Telecom executive program; being Associate Dean for Undergraduate Affairs; leading SOE Outreach; and chairing CONCUR 2005, the lead international conference and concurrency theory. Computer Engineering has also taken significant part in UARC development.

As the Department of Computer Engineering begins its third decade, we look forward to continuing our emphasis on excellence in computer engineering education, research, and teaching, combined with a constant focus on the innovation and incubation of new programs.

1984-1989

- Pat Mantey launches UCSC Engineering
- ABET Accreditation
- Graduate Program

1990-1994

- BS/MS program
- First PhD graduate (1992)
- ISM major launched (Mantey, CS, Econ)

1995-2000

- EE launched
- School of Engineering
- Professional MS program
- CITRIS/ITI Created

2000-2005

- BS Bioinformatics (1st in CA) launched
- Computer Technology Minor
- SURF-IT REU Site

2006-2010

- Autonomous Systems/Control
- Assistive Technologies

Computer Engineering's 20-year history as innovator and incubator of programs

Excellence with diversity

The Department of Computer Engineering seeks to sustain and build excellence with diversity. This is a particularly difficult goal within the discipline of engineering, generally the least diversified area of academic endeavor throughout the nation. Because of this problem, the Department has placed a strong emphasis on diversity within engineering, with the following continuing approaches:

- Professors Hughey, Cox, Manduchi, and Obraczka lead an NSF Research Experiences for Undergraduates Site, SURF-IT (surf-it.soe.ucsc.edu), a summer research program with a focus on increasing the number of women and underrepresented minorities in engineering. In its first three years, the program provided research opportunities to 33 students, 60% of whom were female and 25% of whom came from underrepresented ethnic or racial groups. Students are placed throughout the School of Engineering.
- Professor Ferguson has leadership roles in the Multicultural Engineering Participation (MEP) program and the NSF Developing Effective Engineering Pathways (DEEP) program with De Anza and Foothill Colleges.
- Professor Hughey is faculty advisor by our Society of Women Engineers chapter, and in 2004 helped graduate students organize our newest diversity-oriented group, eWomen, with the assistance of a campus diversity grant.
- Professor Manduchi is advisor to our Society of Hispanic Professional Engineers chapter.

In the coming year, at the undergraduate level we see CE1 as being a continuing instrument for retention and diversity. At all levels (student and faculty) the growing focus on assistive technology within CE and bioengineering within the SOE is likely to significantly promote diversity (in addition to excellence) within the School.

Sustainability within Available Resources

Computer Engineering has had no net growth since 2001-2. In spite of the lack of growth, we have been able to meet or exceed most 10-year plan measures, when adjusted for the number of faculty. The numbers show a high level of effectiveness for allocated resources, lending strong support to the idea of moderate growth within the Department Computer Engineering and its broad interdisciplinary research programs.

For 2004-5, the target was 21 LR faculty and 1 open position; we instead have 16 LR faculty and 2 open positions. Thus, we are 24% below plan in LR faculty. As we had no recruitment authorizations in 2004-5, this deficit is 27% in 2005-6. With current recruitments underway, we expect to have 18 LR faculty in 2006-7, 22% below plan.

Computer Engineering achieved plan or close to plan in 2004-5 in most categories of the 10-year plan, when adjusted for the lower number of LR faculty (16 + 2 slots, rather than 21 + 1 slot). This across-the-board achievement of the 10-year plan goals may be unique within the School. At the undergraduate level, adjustments are made according to LR faculty slots (18) because empty slots enable the hiring of non-senate faculty to cover curriculum. At the graduate level, adjustments are made according to LR faculty positions (16) since only positions we have been authorized to fill can advise graduate students. These numbers include:

- Undergraduate Enrollments: 9% above plan per LR faculty slot
    - 268 FTE enrollments, planned 300, but 18% below LR faculty slots
    - Similarly for overall enrollments
- Undergraduate majors: 25% above plan

    - 57 premajors and 100 majors, plan 125
- Graduate Enrollments: 20% below plan per LR faculty member
    - 57 FTE enrollments
- Graduate students: On plan per LR faculty member
    - Includes 15 part-time MS students
- Research funding: 9% above plan per LR faculty member
    - $3M, not including $444k in cash and equipment gifts.
    - Achieving plan with respect to graduate funding will enable us to support a larger graduate program in the coming years, thus closing the shortfall in graduate enrollments and students.
- Research expenditures: 25% below plan per LR faculty member
    - As research funding is now on plan, research expenditures will follow.

In spite of our success with within the constraints of available faculty resources, recent experiences have been showing in a lack of sustainability within available space resources. Due to the currently reduced number of permanent faculty, the Department does have sufficient computational laboratory research space. However, the Department does not have sufficient space for its autonomous systems research program, and the School of Engineering teaching laboratories are presently insufficient for the growing number of CE and EE majors, undergraduate laboratory courses, and graduate laboratory courses.

The Autonomous Systems group designs, builds, and studies full-size autonomous systems. It requires space that can accommodate parts fabrication, prototyping and testing of large systems, including, for example, an autonomous catamaran outfitted with an 18' hard wing, and a fully autonomous off-road vehicle. The main campus lacks high ceiling labs to accommodate large systems, while suitable dry lab space is in short supply. The amount of equipment used by this productive research group is growing, especially with their recent receipt of a Major Research Instrumentation award. Our current estimate is that the group has the following needs:

- 2,500 asf of fabrication space for fabrication and prototyping
- 1,000 asf of fabrication space for multi-vehicle testing,
- 1,000 asf of 18-20' high ceiling space for prototyping and assembly of large scale devices,

Ideally, because these projects fully integrate undergraduate and graduate students, we would like to have space for this research on the main campus, perhaps in a small structure next to the E2 building.

Computer Engineering has a growing number of graduate lab courses (2-4 per year) that compete on an unequal footing with undergraduate instructional labs. Additionally, recent growth in electrical engineering and computer engineering students completing the two-quarter senior capstone design course has placed considerable strain on instructional laboratory usage. After the sophomore year, most engineering laboratories are a mixture

of scheduled lab section time (typically four or more hours per week) and additional independent work time (typically another four to forty hours per week per student). The extremely high use of our senior design project laboratories, in which the students to the dedicate the vast majority of their waking time to their capstone design project, mean 24-7 use of the labs not adequately accounted for in classroom statistics. During the coming five years, it is clear that additional laboratory space, for both undergraduate and graduate courses, will be critical to maintaining educational excellence.

Future Opportunities for Investment in New Endeavors

The Department has identified five exciting opportunities for the near future. Investment in these areas will enable (in part) the development of a program in bioengineering, the development of a world-class program in autonomous systems and control, and solidification of our international prominence in computer networks.

- Assistive technologies and bioengineering. This area is of extreme importance to the aging population. A group of 3-6 faculty and the creation of a research center could propel us to excellence. The group would have strong collaborations with faculty in digital media and sensor technology, embedded and autonomous systems, Biomolecular Engineering, and Electrical Engineering. This could form a nucleus, with other SOE programs, for launching academic and research programs in bioengineering. Between 1999 and 2002, the number of Bioengineering BS degrees granted increased by 50%, MS by 78%, and PhD by 30%. In the System, bioengineering programs have been or are being created at every campus, and UCSC hosted the 2005 Systemwide Symposium on Bioengineering. Professor Hughey is leading an effort within the SOE and in collaboration with the sciences to develop a bioengineering B.S. program for Fall 2006.
- Program in Autonomous Systems. William Dunbar, Gabriel Elkaim, and Jorge Cortes (AMS) have developed a graduate course sequence in control. Computer Engineering has proposed as part of the five-year perspective, the development of a graduate program in autonomous systems. This cross-cutting area would be expected to include faculty in CE, EE, AMS, ISM, Economics, and potentially other areas. We are poised to launch exceptional robotics research and degree programs with 3 hires in autonomous systems during the next 5 years. The Computer Engineering hires will focus on design and construction of autonomous systems and software (as, for example, Professor Elkaim). When combined with faculty specializing in algorithms and control theory for autonomous systems (Professors Dunbar and Cortes, as well as a planned new AMS hire) and in sensor technology for autonomous systems (Professors Tao and Manuduchi), we will be able to launch a world-class graduate program autonomous systems. This group may form the kernel of a program in mechanical engineering. All such positions may be part of the assistive technology emphasis.
- Networks Pinnacle of Excellence. Computer Engineering's most productive research group is in Computer Networks. Indeed, within the School of Engineering, this group has produced more Ph.D. graduates than any other group, and has placed students at many academic institutions. We presently have a

strong focus on wireless networks (JJ Garcia-Luna and Katia Obrazcka) and on high-speed network architectures (Anujan Varma). This group is poised to expand to internetworking and applied network security. Network and internet security has become a key area of applied research within the computer networks field, thanks to the popularity of wireless networks which are more difficult to secure than wireline networks. The demand for graduates with specialization in network security is currently far higher than the supply, and this is likely to persist for some time.

- Invigoration of core areas of computer system design and design technologies. Because of the loss of Professors Karplus, Dai, and Madhyastha, and the exceptional service loads of Professors Ferguson, Larrabee, and Hughey, we have had to turn away many highly qualified applications in these areas. The successful hire of Jose Renau and the 2005-6 recruitment in this area is the start of rebuilding our core strength, but we will need one or two more faculty in this area within the next 5 years to ensure and enable undergraduate and graduate education, training, and research of the highest quality.
- Sustained excellence in Digital Media and Sensor Technology. Our dynamic and collaborative group working in digital media and sensor technology interfaces collaborates extensively in CE, the SOE, and on campus. We have a particular interest in "rich media" technology for education, both in the classroom and on the web. Collaborative problem solving and decision support will exploit the same technological developments, and this is a joint area of interest with colleagues in TIM (and CS) Another hire in this area in the next 5 years will leverage and multiply our research activity in this growing area.

Synergistic Graduate Programs

Computer Engineering is itself an immensely interdisciplinary program. We study computers and computer-based systems over a broad range of application areas. Our research spans the range from imbedded systems and the basic computers for these, to complex systems, and "systems of systems" where computers and networks provide the essential control and management. We have extensive collaborations with faculty in other departments within the School of Engineering, and we have also developed joint research with many campus departments and organizations including the Psychology; Chemistry; Molecular, Cellular, and Developmental Biology; Ecology and Evolutionary Biology; Earth Sciences; Ocean Sciences; Environmental Toxicology, SCIPP, CFaO, Long Marine Lab, STEPS, UARC, CITRIS, CBSE, and the Educational Partnership Center.

Computer Engineering developed UCSC's first academic degree program in Silicon Valley. Our part-time MS in Computer Engineering with an emphasis in Network Engineering provides working professionals with easy access to a University of California graduate education. We are particularly excited about the development of additional academic programs targeted for delivery in Silicon Valley, such as the proposal for a program in Technology and Information Management (TIM). The growth

in programs in Silicon Valley will enable a much broader level of educational choices for professional graduate students. As CE's part-time students often have a strong interest in the management of technology, and we expect that many TIM students will have a strong interest in network technology, this will be a particularly synergistic combination. We are moving our Silicon Valley site for this program from UNEX Cupertino to the Silicon Valley Center at the NASA Research Park, to improve the quality of our delivery and to develop the synergy with other SOE programs such as TIM.

The development of bioengineering graduate and undergraduate programs, with Computer Engineering taking part in the assistive technology aspects of bioengineering, will be an important landmark for the School of Engineering. This will enable a much broader palette of graduate programs with strong collaborations within the School of Engineering and with the Division of Physical and Biological Sciences, and the Division of Social Sciences.

Our recent development of a graduate sequence in control is a start of an effort to develop a graduate research and training program in this area. The expertise presently in place, when combined was to teach at hires in the coming years, will enable an active group working on the application of the principles of control to a wide range of applications in the physical and biological sciences, business, and other areas.

One means of developing administrative synergy between programs, which then can lead to additional research synergy between programs, is by regular involvement of individual faculty in multiple programs, for example by taking part in departmental meetings of multiple programs. Computer Engineering faculty have frequently been involved in such setups for the years, always with particularly worthwhile results. It is our view that increasing the use of fixed-duration joint appointments at levels corresponding to no teaching responsibilities and one course of teaching responsibility will greatly increase the synergy between our as SOE programs, and if appropriately extended, throughout the campus. One possibility for fostering such interior disciplinary connections would be for the Division to partially fund such appointments within a School, and the Campus to partially fund such appointments across the divisions. Such a reallocation of FTE resources would clearly indicate the importance of interdisciplinary research to the School and the Campus. The Department hopes to look forward to further discussions on these matters as it also pursues potential appointments with several School of Engineering programs.

Plan for Additional Faculty FTE

The Department of Computer Engineering has been exceedingly successful in its recruitment of outstanding faculty. We follow an approach of moderately focused searches, enabling sufficient flexibility to hire the smartest person and ensure the most diverse pool of applicants. Every year CE has had a position, we have successfully recruited our top choice or choices.

Presently, the Department has three senior assistant professors (IV +, members of the faculty for 4 years). Two (De Alfaro and Tao) have received prestigious NSF CAREER grants, while Manduchi has received a major NSF grant in Assistive Technology.

The Department has three more recent assistant professors (II or III, members of the faculty for 1 or 2 years). Elkaim and Dunbar have received an NSF Major Research Instrumentation grant for our growing autonomous systems program. Renau has received a prestigous NSF CAREER grant on his first application.

As a department, we propose to continue our individual and collective excellence with the following hiring plan.

Current staffing includes:

- computer system design (Brandwajn, Hughey, Renau)
- design technologies (Chan, Ferguson, Schlag, Larrabee)
- digital media and sensor technology (Manduchi, Mantey, Tao)
- computer networks (Garcia-Luna, Obraczka, Varma)
- embedded and autonomous systems (De Alfaro, Elkaim, Dunbar)

The following hiring plan will maintain and build our excellence in the core areas of computer engineering while enabling the development of new programs in autonomous systems, and assistive technology, as discussed above.

- 2005-6 (2 replacements)
    - VLSI/FPGA system design
        - Restoring an area with 2 faculty losses (Dai, Karplus).
        - Tenured leader to strengthen area & lead large projects
        - Assistant II – Assoc II approved.
        - 82,900 salary, 200,000 startup.
    - Assistive Technologies (potential embedded/autonomous systems)
        - Addressing the needs of society and the engineer of 2020
        - Assistant professor (requested tenured leader)
        - 75,000 salary, 185,000 startup
        - *This is a non-competitive initial salary, and will need to be upgraded*. Mean starting salary in 2003-4 among PhD-granting CE and CS programs was 77,333. (cra.org)
- 2007-8
    - Autonomous Systems (potential AT)
        - Creating a new program in autonomous systems and control
        - Tenured leader to head graduate group in control
        - Assistant-Professor VI
        - 120,000 salary, 300,000 startup
- 2008-9
    - Networks
        - Strengthening and growing a pinnacle of excellence
        - Assistant-Associate Professor, a rising star

        - 95,000 salary, 200,000 startup.
- 2009-10
    - Autonomous Systems/Embedded systems (potential AT)
        - Creation of integrated systems hardware/software, with a possible Assistive Technologies focus.
        - Assistant II-IV
        - 85,000 salary, 250,000 startup
- 2010-11
    - Autonomous systems (potential AT)
        - Completing a leading group in Autonomous Systems.
        - Assistant II-IV
        - 90,000 salary, 250,000 startup

If additional positions become available, either due to the filling of vacant positions or the availability of more campus resources, we have as additional priorities:

    - Computer system design
        - Rebuilding a core CE area with one faculty loss (Madhyastha)
        - Assistant II-IV
        - 85,000 salary, 225,000 startup
    - Digital media and sensor technology
        - May include biological monitoring, educational / collaborative technologies, rich media, and sensor integration.
        - Assistant II-IV
        - 88,000 salary, 250,000 startup

Plan for Enrollment FTE

The Department has several strategies for enrollment FTE at undergraduate and graduate levels. The Departments current Student-to-Faculty FTE ratio (based on 18 slots) is 18:1. The SOE average is 15:1.

At the undergraduate level, the department has had a focus on excellence and innovation to ensure the highest quality of undergraduate education. Recent changes have included the establishment of the two-quarter senior design course (with electrical engineering), significant revision of our networks concentration, the introduction of mechatronics and other robotics-related courses, and creating a new sequence in computer board design. In the near future, we will be introducing an undergraduate track in robotics. We believe that the responsiveness of our curriculum to rapid technological change has been a key factor in maintaining our major and enrollment numbers near the 10-year plan level in spite of the downturn in the Silicon Valley economy.

One of the most important issues for undergraduate majors is student retention. The Department has recently worked to increase lower-division retention of engineering students (all disciplines, though especially computer engineering) by creating a low-unit

Hands-On Computer Engineering course. Because of the importance of providing exciting introductions to computer technology early in students' careers, we offer this course every quarter and staff it with two faculty and many readers and tutors. During the course, students hooked together digital logic circuits, play with robots, and use our microcontroller microchips. We have additional foci on joining the engineering community by taking part in student organizations, finding out about available resources, and looking toward the future by interviewing senior design project groups. We are beginning to investigate modifying the COSMOS summer course in control and robotics created by Professors Dunbar (CE) and Cortes (AMS) into a similar structure.

Also related to retention, the department emphasizes the development of community among our students. Thus, recently we have encouraged the development of a new Engineering Honor Society (forming a community of our very stop students, many of whom previously did not participate in student organizations) and a graduate student eWomen organization. We continue our Computer Engineering Faculty Undergraduate Lunches, 3-4 times a quarter, and are pleased that this innovation has now been instantiated throughout the School.

At the graduate level, we have engaged in significant recruitment efforts to both US and international schools, created a new brochure and poster for the department, and collaborated with other programs to ensure admission and support of the students within our targeted areas of excellence. In collaboration with AMS, we have introduced a three-quarter graduate sequencing Control, and hope that this will form the basis of a graduate program in this area.

We also see the need for engineering education for non-engineering majors. With a particular focus on students interested in becoming mathematics or science teachers, we have recently launched a new minor in Computer Technology. This minor introduces students to the most fun material within computer engineering combined with a study of the context of computing within society (CE80E, Engineering Ethics), technology (CE80H, History of Modern Computer Technology, or EE80T Modern Technology and How it Works), industry (ISM101, Management of Technology Seminar), and a student's major (elective). As a capstone project, students complete an essay on the impact of computer technology within their major discipline.

In courses, due to exceptional interest we have increased the number of offerings of our topical Introduction to Networking course, and have introduced a new topical courses in the History of Modern Computing.

Plan for Extramural Research Support

The 2001 Computer Engineering Departmental Plan for growth in Extramural Research Support stated:

> *We had a research funding decline in 1998-2001 (graph below, with estimates beginning AY01) due to several faculty taking full or partial leaves to work in industry. These faculty will be returning to full-time appointments in Fall 2001 and Fall 2002. Our overall target is to have a faculty member average of $200,000-250,000 of external funding (including grants, gifts, and other forms of income), much*

higher than our current $80,000. We expect to achieve $100,000 by AY2001 (for a total of around $2M), $200,000 by 2005 (for a total of $4.4M among 22 faculty), and $250,000 shortly thereafter. This will result in about $6.5M in funding by 2010 among 26 faculty, higher if we are successful in recruiting additional fee-funded faculty positions.

We have exceeded our goal for 2005, with an extramural award level of $210k per faculty among 16 (rather than 22) faculty. That is, **in the past five years, Computer Engineering has nearly tripled its level of research funding per faculty member**. In 2004-5, we saw a total of $3.4M in gifts and awards, a 65% growth over the prior year. During the coming 5 years, we plan to similarly extend both our per-capita contribution to the research mission of the Department and Campus, and our overall contribution. We believe that our past performance in meeting our published goals is a strong endorsement of our multidisciplinary, systems approach to computer engineering.

We find that our high-level achievement is particularly meritorious on consideration that nearly one third of the permanent Computer Engineering faculty are engaged in unusually high levels of School and Campus service, approaching full time in three cases (Ferguson, Hughey, and Mantey).

Although our original goal of $250,000 per faculty member is still appropriate for 2010, and expect to exceed this goal by 2010 by reaching $275,000, provided adequate faculty resources are provided to the Department.

Our hiring plan emphasizes broad interdisciplinary research, bringing to the Department of Computer Engineering more researchers tuned to word "hot" yet enduring areas and broad interdisciplinary grant proposals. Thus, our recruitment plans in embedded and autonomous systems, assistive technology, networks, computer system design and design technologies, and computer vision and sensor technology will not just increase our overall level of research funding, but provided sustained growth in per capita research funding, continuing the trend of the previous five years.

A key component to our drive to increase the reach of our research program and the level of extramural funding has been our high level of collaboration within the School and campus, as well as with other Universities and companies. Present external collaborations include

- UCB/LA/SD/D/R/I, UMD, MIT, UIUC, Stanford, UDel
- Cisco, Sun, Intel, Microsoft, IBM, HP, Agilent, Honda, BBN, Raytheon, Aerospace, Honeywell, SRI International, Nokia, NEC, Orion Microelectronics, Smith-Kettlewell Eye Research Institute, Doran Center for the Blind and Visually Impaired, Meru Networks, Xylim

Additional Measures of Success

As an interdisciplinary School of Engineering, at the graduate level we believe that an important measure of success is the graduation rate of PhD students under the advisement of Computer Engineering faculty (regardless of enrolled program), and success in their placement.

Appendix: Bioengineering

The following white paper on bioengineering across the School of Engineering was developed by Computer Engineering Professor Roberto Manduchi and Computer and Biomolecular Engineering Professor Hughey in collaboration with many individuals and departments. The Department of Computer Engineering sees Macro-level bioengineering, in particular Assistive Technologies, as a major research emphasis for the future within Computer Engineering. Also, we see undergraduate and graduate bioengineering to be one of the most important steps for engineering in its path to become a full-fledged and full-service School of Engineering.

UCSC presently has 20-30 faculty members working in bioengineering and affiliated areas. Members of this group are working to create a unified vision of research, graduate training, and undergraduate education in the broad area of bioengineering. This paper presents an initial gathering of ideas of some of these members, and is an evolving draft.

In the first half of the 20th century, the advent of high-speed communication and electrification enabled high-technology engineering. In the second half of the 20th century, the transistor and integrated circuits were the drivers of high-technology . Now, in the first half of the 21st century, it is expected by many that advances in biosystem understanding, measurement, and manipulation will be the foundation of 21st-century engineering and technology.

At UCSC, the late advent of engineering has allowed us to be on the forefront of developing trends. In 1984, we were able to focus our growth into a new, interdisciplinary area of engineering strongly coupled with the neighboring Santa Clara region: Computer Engineering. Now, with our focus on Biotechnology, Information Technology, and Nanotechnology, we are maintaining a commitment to looking forward to the advent of new hybrid, cross-disciplinary technologies. This places us at a tremendous advantage in comparison to other schools with strongly established programs in the older branches and subdisciplines of engineering. We were able to leap ahead of such programs with the creation of cross disciplinary engineering programs emphasizing the cutting edge of technology and its impact on society, as in our electrical engineering program focused on nanotechnology and biomolecular engineering program with worldwide recognition for its contributions to bioinformatics.

The next natural step for UCSC is bioengineering. Within the 21st-century, the rapid advances in the biological sciences, here and elsewhere, provide the underlying framework for a broad bioengineering program at UCSC that focuses on macro, micro, molecular, and societal bioengineering. Engineering is not just the discipline of technology, but one of technology in the service of society. According to the recent report of the National Academy of Engineering (NAE), *The Engineer of 2020: Visions of Engineering in the New Century*,

> It is our aspiration that engineering educators and practicing engineers together undertake a proactive effort to prepare engineering education to address the technology and societal challenges and opportunities of the future.

At UCSC, with a strong emphasis on liberal, scientific, and engineering education, as well as existing research and education in bioethics and the human sciences, we are ready to combine technology, science, and society not just at the research level, but also in the development of undergraduate and graduate academic programs.

The Whitaker Foundation provides one definition of biomedical engineering.

> Biomedical engineering is a discipline that advances knowledge in engineering, biology and medicine, and improves human health through cross-disciplinary activities that integrate the engineering sciences with the biomedical sciences and clinical practice. It includes:
>
> 1. The acquisition of new knowledge and understanding of living systems through the innovative and substantive application of experimental and analytical techniques based on the engineering sciences.
> 2. The development of new devices, algorithms, processes and systems that advance biology and medicine and improve medical practice and health care delivery.
>
> As used by the foundation, the term "biomedical engineering research" is thus defined in a broad sense: It includes not only the relevant applications of engineering to medicine but also to the basic life sciences. (www.whitaker.org)

In this draft discussion of bioengineering, we are focused on the applications of engineering to medicine and the biological sciences in collaboration with the exceptional strong existing programs in the biological sciences, physical sciences, and biomedical research at UCSC.

Our campus presently engages in bioengineering research within the biomolecular engineering, computer engineering, and electrical engineering programs in collaboration with the biological sciences, computer sciences, mathematics, philosophy, physical sciences, and psychology. With existing faculty, it may be possible to create modest graduate minors in areas of bioengineering, such as biomedical imaging, bioinformatics, and assistive technologies. A moderate investment may enable the creation of more general graduate and undergraduate minors in bioengineering. A larger investment will be required to create graduate and undergraduate programs in bioengineering to serve the needs of our students, California, and society.

At all levels, students have realized the importance of the joining of biology and engineering into a discipline focused on using technology to better society, both collectively and individually. Indeed, according to the NAE report, creating and designing “technology for an aging population" is one of the four broad technological challenges that the engineer of 2020 will face. It is only by providing a unified program that we can effectively train our engineering graduates to solve these problems.

Growth in bioengineering has been spectacular, as technology advances enable discovery and design of the highest impact to our aging population. Over 1999-2002, the number

of Bioengineering BS degrees granted increased by 50%, MS by 78%, and PhD by 30%. The formation of a new NIH Institute, the National Institute for Biomedical Imaging and Bioengineering is another indicator of the growth and permanence of this discipline. In the University, bioengineering programs and departments exist at 9 of the 10 campuses; ours is the only campus without a bioengineering program.

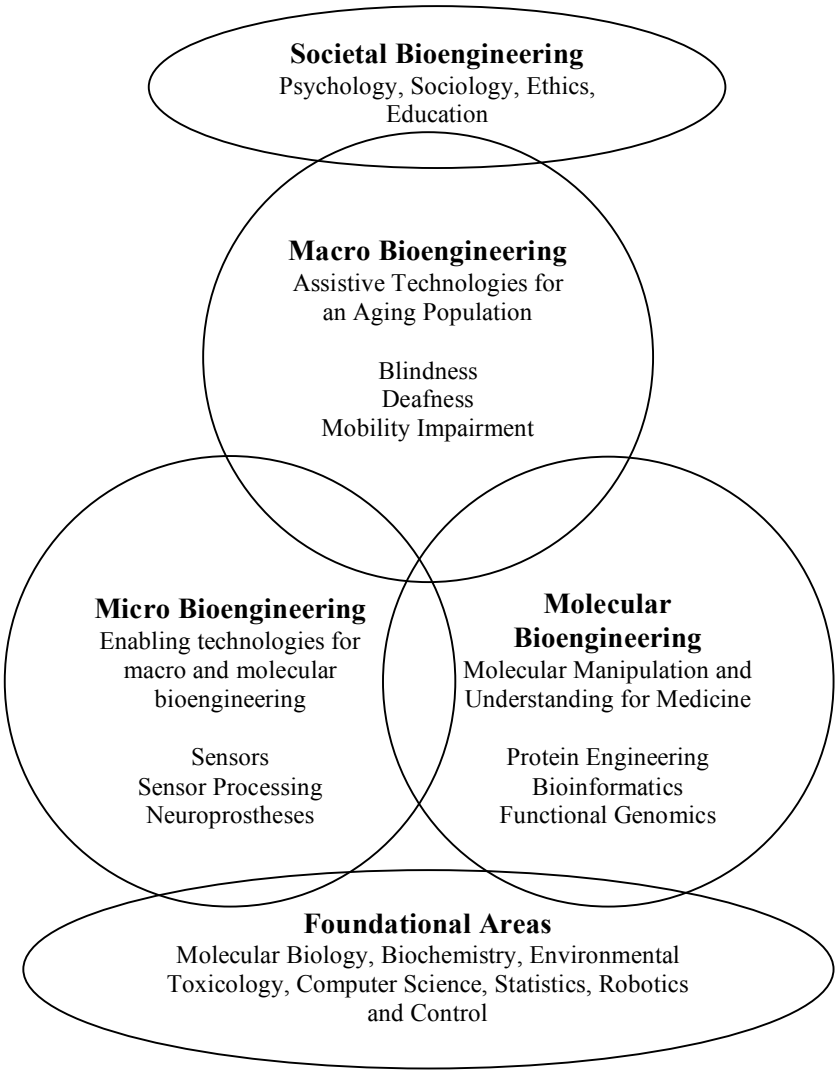
For undergraduates, "bioengineering is one of the fastest-growing majors at many universities" (ASEE PRISM, November 2004). At UCSC, the strong interdisciplinary focus of much of our research can immediately enable undergraduate minors in areas related to bioengineering, and with a few targeted faculty hires, enable a complete degree program.

At the graduate level, there is similar growth, spurred on in part by the influx of Whitaker Foundation funding. The University of California has recently formed a Multi-Campus Research Unit (MRU), the Bioengineering Institute of California. Founded as a collaboration of all of our campuses, the MRU focuses on using distance and Web technologies to enable a broad coverage of bioengineering academics at all campuses, and an annual UC Bioengineering Symposium. In summer 2004, the UCSC School of Engineering and Center for Biomolecular Science and Engineering hostedhthis systemwide event.

Undergraduate and graduate bioengineering is also an exceptional opportunity for diversity within engineering. At the undergraduate level in 2003, 40% of biomedical engineering degree recipients were women. Presently, the School of Engineering has fewer than 20% female students. Bioengineering also provides an opportunity for gender diversity within our faculty; although in 2003 our School of Engineering was eighth nationwide in percentage woman faculty, 13.6% woman faculty is not an accomplishment that indicates that the work is complete. UCSC also has a low population of disabled students, who are, because of the potential direct impact, often interested in bioengineering and assistive technologies. This confluence of research directions, societal needs, and opportunities for diversity makes the development of a bioengineering program particularly timely.

Current and Future Bioengineering Research at UCSC

The goal of all bioengineering is societal—assisting people and society to better the quality of living. In the "primarily macro" area, we propose continuing to develop our current excellence in assistive technologies for the aging population. In the “primarily micro" area, we propose a strong emphasis on bio sensors, sensor processing including biomedical imaging, and the creation of micro prostheses, leapfrogging existing programs with macroscopic prostheses programs. In the "primarily molecular" area, we will continue to develop our excellence in biomolecular engineering and informatics. And societal bioengineering, we will use our understanding of individuals and societies to develop new technologies and seek to understand the impacts of these technologies on individuals and societies.



Macro Bioengineering

We envision a new generation of researchers, educators, and entrepreneurs committed to shaping the future of human–centered assistive technology. Mainstream approaches to engineering education may not adequately take into account human factors that directly affect the usability of new technology. The gap between engineering creativity and final user considerations is particularly serious in the case of technology designed to aid the disabled or the elderly. All too often, engineers are tempted to build tools and devices "just because computers can do it", without enough awareness of the reality and actual needs of disabled individuals. The net result is a very limited adoption of advanced technology by such communities.

We propose a multidisciplinary, "participatory" approach to the development of tools and practices for assistive technology, which relies on close collaboration between technology designers, cognitive scientists, and end–users. This approach offers great potential for cooperation between the UCSC School of Engineering and the Psychology Department. In addition, the establishment of UARC opens new opportunities for research and graduate student training at the NASA Ames Research Center (ARC). In the past, interaction between mathematical science and engineering on one end, and

psychophysics and cognitive science on the other hand, has proven very successful, for example in the development of theories of human vision and in the implementation of biologically inspired algorithms and systems. The proposed cooperation also draws from a large body of knowledge in human–centered design, pioneered by NASA ARC in the context of engineering systems for aeronautical and space systems.

Developing technology to assist an aging population encompasses a number of research fields, straddling across Engineering (sensor processing, human–machine interface, robotics, hardware integration) and Psychology (psychophysical models of sensory loss, predictive cognitive models). Specific areas of research that will be emphasized by the Macro Bioengineering program include:

Mobility, wayfinding and accessibility for the visually impaired and mobility impaired:
Integrated and wearable mobility tools to aid safe and comfortable deambulation; indoor/outdoor wayfinding technology; control of autonomous or semi–autonomous wheelchairs; increased independence in assisted living environment for blind and mobility impaired individuals. (Professors Manduchi, Tao, Elkaim, Dunbar, Nourbakhsh)

Human–machine and human–environment interfaces:
Tactile/acoustic virtual map exploration for the blind; speech recognition for deaf or hard–of–hearing individuals; eye tracking, along with the translation of eye motion patterns into desired actions, for human/machine interface for the mobility impaired. (Professors Manduchi, Pang, Tao)

Cognitive models for predicting and assessing user performance:
Analysis of the influence of cognitive aging and task–coordination strategies for dual–task performances; computational models to simulate aging effects; emotional bias in elderly and disabled individuals and its influence on memory and attention. (Professors Massarro, Travis, Mather)

Assistive technology for the blind at the Macro Bioengineering level ties in with research in Neural Prosthetics, which is part of the Micro Bioengineering area. The prosthetic retina project conducted by Prof. Liu offers opportunity for innovative sensor processing technology and raises fascinating new questions about the psychological and psychophysical aspects of sensorial augmentations.

Additional potential benefits of the proposed Macro Bioengineering program include the establishment of long–term relationships with external research institutions in different areas of assistive technology, fostering continuing exchange of experience, user studies, and technological solutions, and providing insight into psychological, social, and day-to-day practical aspects of living with a disability. Even more important is the potential for creating an open and attractive environment at UCSC for disabled students, who may provide a unique perspective on the future of assistive technology.

Beyond the specific focus on assistive technology, we believe that students formed under this program will represent valuable assets in many other fields of today's professional

world. Participatory and human–centered design are important paradigms for the creation of really usable hi–tech products. We have received very encouraging feedback from several companies, not necessarily directly related to Bioengineering, about job placement prospects for students equipped with the skills developed under the proposed program.

Micro Bioengineering

Micro bioengineering includes the development of sensors for biomedical applications, the computational and algorithms for understanding sensors, and the creation of micro-scale prostheses and other devices for medical use. Presently, all three of these areas are represented by faculty research programs, and there is some likelihood that new research programs will involve in micro bioengineering and nanobiotechnology.

Sensor development, at the boundaries of micro and molecular bioengineering, include "lab-on-a-chip" technology, such as that integrated optical waveguides with liquid cores, enabling light propagation and measurement through small volumes of liquids on a chip (Schmidt), microscopy (Isaacson), and nanopore technology (Deamer, Akeson).

Once sensed, data must be understood using statistical and algorithmic techniques. Examples include cell tracking (Tao, Hughey, Di Blas, in collaboration with Ottemann), signal and image understanding, and related areas.

The use of micro and nano devices to directly solve medical problems is best illustrated in the artificial retina project (Liu) and biomimetic technology development (Liu and Isaacson).

The continued development of robotic and high-throughput technologies for the biomedical science and engineering, a focus of the draft document on biomedical research at UCSC is also an area of micro-scale bioengineering.

Molecular Bioengineering

Molecular-level bioengineering includes the analysis, manipulation, and detection of biomolecules. While the central core for molecular bioengineering at UCSC will be the Department of Biomolecular Engineering, the area also involves many researchers within the biological sciences, computer science, physical sciences, and electrical engineering.

Molecular bioengineering concerns three overlapping fields:

- *Engineering of biomolecules,* including protein engineering and synthetic biology;
- *Engineering with biomolecules,* including biosensors, synthetic biology, biomolecule-assisted nanotechnology; and
- *Engineering for biomolecules,* including bioinformatics, laboratory automation, especially for high-throughput experimental techniques.

The Department of Biomolecular Engineering, founded upon the international prominence of our research in bioinformatics, is one of the Schools most strongly targeted growth area. In addition to expanding the graduate program in bioinformatics to better meet demand (faculty advising capacity limits admission to 20% of Ph.D. candidates), the program will continue to expand into protein engineering, synthetic biology, nanotechnology applications in biomolecular engineering, and high throughput experimentation and analysis.

The natural allies of these technological disciplines include molecular biology, biochemistry, micro fluidics and all areas of micro bioengineering, computer science, and statistics. This fundamental work at the molecular level of bioengineering will provide the basis upon which new medicines, technologies, and procedures will be developed within the domains of macro bioengineering and micro bioengineering.

From its start, the academic programs in bioinformatics have also cultivated relationships with philosophy, co-creating a general education course (required for the undergraduate mathematics degree) in bioethics, and also providing a ready stream of students to upper-division in graduate courses in bioethics as required by the MS and Ph.D. programs. We would like to further strengthen this relationship, in particular with collaborative research associated with the modern ethical quandaries created by the biotechnology revolution.

Societal Bioengineering

We have begun discussions with psychologist and collaborator Dom Massarro about the societal level of bioengineering. Although we have not fully defined this area (this would be a topic of the bioengineering planning retreat discussed below), this area is expected to examine the human factors, human impacts, ethics, and quandaries that our next generation of technologies will bring to bear upon individuals and societies.

We will seek to collaborate with researchers in psychology, sociology, education, and philosophy to develop research in this area and, most importantly, continue our commitment to this most important aspect of bioengineering, as bioinformatics has emphasized and required academic courses in bioethics for all undergraduate and graduate degrees.