Creating Synergy Between Computer Engineering and Computer Science Programs

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Abstract

Development of academic programs in computer science, computer engineering and electrical engineering that are mutually supportive has been a challenge at many universities. In this paper we examine the dimensions of computers and digital systems. From this perspective we review the creation of the computer engineering program at UCSC and the simultaneous development of computer science. We identify factors that we believe have resulted in the synergy between these programs at UCSC. Some of these are: the hiring and mentoring of junior faculty, the sharing and management of space, facilities and budgets, development of joint research projects that support faculty and students from both departments, employment and supervision of shared staff, and the sharing of courses and teaching assignments.

Introduction

Engineering which creates and designs computers, at the chip level and as systems, and engineering complex computer-based systems, are the domain of computer engineers. These engineers require skills and expertise in a broad range of topics in hardware and software, including design of integrated circuits and subsystems, operating systems, programming languages and software engineering, design and analysis of networks and applications, and knowledge of system modeling and performance prediction and evaluation. From the perspective of the engineering of computers, the fields of electrical engineering, computer engineering and computer science, as generally defined, are a continuum. They are broken apart into departments for academic or management purposes, but are clearly interdependent and not obviously separable. Computer engineering, as characterized by the IEEE Computer Society [1] and ABET [2] is a field combining computer hardware and software, and thereby developing engineers capable in both hardware and software -- engineers who can design digital systems that take maximum advantage of technology by implementing designs in combinations of hardware and software. As such, computer engineering fits "between" computer science and electrical engineering in most traditional engineering schools.

Digital Electronics / Systems, Computer Engineering, Computer Science, etc.

The fields of electrical engineering, computer engineering, and computer science, in their academic instantiation, cover topics related to computing and digital computer systems in a range of subjects:

- Digital Devices and "Hardware": arithmetic and logical digital circuits, microprocessors and other digital subsystems architecture, interconnections and "bus" architectures, imbedded and digital controllers, etc.;
- Computer-Aided Design: tools for the design of digital systems, including layout and routing of ASICS, gate-arrays, FPGA, etc.; and their applications, technology mapping, simulation of digital devices, processors and subsystems;
- Programming and Computer Applications: microcoding and firmware, operating systems, device drivers, database systems, parallel and distributed computing, applications support, "middleware", computer graphics and scientific visualization, user interface and human / computer interaction, applications programming and "software engineering";
- Computer Languages: design / comparison of languages, languages for parallel execution, compilers and optimization, graphics languages, database query languages, and other special-purpose languages;
- Digital Networks: all layers of the OSI model, from the physical media to the applications support, and including switching, scheduling, routing, and management of complex networks;
- Capture and Processing of Digitized Data: analog-to-digital conversion, digital filtering, signal processing, image processing, information theory, coding and error detection / correction, data compression, pattern recognition, computer control of dynamical systems;
- Computer and Computer System Performance: modeling, simulation, measurements, and optimization
- Reliability and Testing: digital circuit, device and subsystem testing, reliability analysis and design for reliability, testability;
- Machine Learning / Artificial Intelligence
- Computational Science: Theory of computing, computational algorithms

UCSC Perspective and Experience

My personal perspective on the topic of computer engineering was shaped by over 30 years of experience in universities and industry. During this time, I have been affiliated successively with Stanford University, IBM Research, and the University of California at Santa Cruz, where (as an electrical engineering graduate) I now chair a Computer Engineering Department. At UCSC, we have created a promising new program in CE, and simultaneously strengthened a Computer Science (CS) program. Computer science at UCSC (under a variety of earlier names) can trace its origins back over three decades. However, in 1984 when I arrived at UCSC to start Computer Engineering, Computer Science was primarily an undergraduate program, with few graduate students and very little supported research.

Today, CE and CS at UCSC share a common research and administrative facility and are both located in the Baskin Center for Computer Engineering and Information sciences. Each department currently has 12 faculty; and of these 24 faculty, 21 have reached tenure, although only four were hired as tenured appointments. Each department offers both undergraduate degrees (combined total of approximately 320 students) and graduate degrees (MS and PhD programs with a combined enrollment of approximately 160 students). For administrative and personnel purposes, faculty "belong" to one academic department as their primary affiliation. Most of the faculty have courtesy appointments in the other department as well, especially those that teach courses in both departments or who have joint research and share students with faculty in the other department. Joint faculty meetings are regularly held, on the average of one per year. Other important committees, such as the one managing the computing and research facilities of the Baskin Center, have membership from both academic departments. The physical layout of the Center is a two-story section of the Applied Science Building, with a central stairs connecting the two floors. The central academic office, which supports students and faculty (and the mail room) for both CS and CE, is on the lower floor, along with the shared computer "machine room" and some faculty offices. Both department chairs, the shared conference rooms, kitchen and coffee area, and most of the research laboratories, are on upper floor. All space is managed together; there is no specific CS or CE space. The assignment of faculty offices is complex, but does not segregate the faculty. CE and CS faculty at UCSC see their primary affiliation with the Baskin Center, and secondarily to their respective department.

Faculty work closely together on curriculum matters, with courses in each department carefully created to complement the offerings of the other department. CS requires several CE courses for its students, and CE requires CS courses in programming, data structures and operating systems. On a regular basis, CE faculty with computer science backgrounds teach CS courses such as data structures or operating systems, while CS faculty may teach the CE courses in applications of probability and statistics, or in discrete math. The numbering of courses are chosen such that no CE and CS courses have the same numbers, and some sequences "split" across departments (e.g. the introductory three-course sequence in programming, data structures and machine organization, the first two are offered by CS, while the third is a CE course, but these three are required of all CS and CE undergraduate majors.

The current research in the Baskin Center can be grouped into four main areas: (1) Computer (VLSI) Design and Testing; (2) Computer Graphics, Image Processing and Multimedia Systems; (3) Computer Systems, Networks, Applications and Performance; and (4) Computer Science. These groupings are not disjoint; rather there is significant overlap. Faculty generally see themselves as belonging to more than one of these clusters. The faculty in the first area are all from Computer Engineering, and in the last, all from Computer Science. The two middle areas involve faculty from both CS and CE. The faculty appointments in computer graphics are in CS, (one occupying a position belonging to CE, and on loan to CS), while CE has responsibility for image processing. Faculty in both CE and CS have interests in parallel and distributed systems architecture, and share students and research. VLSI design and testing, machine architecture, and networks topics (above the physical layer) are in CE. A proposed EE program is expected to bring emphasis to analog electronics and instrumentation, image processing and to digital communications topics such as coding and information theory, and to networks and communications and signal processing as well as control systems.

The combined level of extra-mural research funding is approximately $2,500,000 per year, including a joint NSF Infrastructure grant. A major example of joint research that includes several of faculty from CE and CS representing the areas of parallel and distributed systems and graphics and image processing is The Real-Time Environmental Information Network and Analysis

System (REINAS) project [3] funded by the Office of Naval Research, REINAS is a complex system utilizing a distributed architecture to support a variety of user needs related to the collection, management, analysis and display of environmental information. Another example is a significant new activity, with NSF funding, which involves faculty from CS with expertise in machine learning and CE faculty expertise in computer architecture and VLSI design, joining together for research in biological computation for DNA string matching. This group works closely with biologists from the campus' RNA center and is developing learning algorithms and their hardware implementations.

Of the current CS and CE faculty at UCSC, all except for two in CS have been hired since the initiation of CE, so the joint venture of CS and CE has grown up with the faculty at UCSC. Graduate students in either program may be directed by supervisors in either academic department, and many thesis committees contain faculty from both departments. Admissions to graduate school are the responsibility of separate committees, but these committees share their criteria, and in some cases reassign applicants when better matches of student and faculty interest may be in the other department.

Generalizations

This section attempts to generalize from our UCSC experience and to look more broadly at the creation of coordinated offerings in important areas that have overlaps between the "usual" departments of computer science, computer engineering and electrical engineering.

Graduate Programs

The MS degree is seen by many as the professional degree for engineers focused on careers in industry. The MS degree must provide breadth and depth of both immediate and lasting value to the engineer's career. This requires a combination of basic theory courses as well as in-depth treatment of topics in the area of the student's focus, effectively blended into a coordinated program. In some schools, there are areas of overlapping courses, and sometimes competitive offerings of courses, between computer engineering and electrical engineering. For example, CE may claim the area and offer courses in "microcomputers and embedded systems" while EE has offerings in "digital systems design". These are closely related, and can be mutually supportive, although the EE work may have more hardware (device or circuit) emphasis while CE takes a more systems approach. However, in either digital systems or embedded systems, the "system" is both hardware and software. Clearly, to be effective, programs must be coordinated. The challenge is get faculty to work together and efficiently, smoothly and economically provide students with an integrated perspective of both hardware and software (and thus to become a computer engineer).

The important area of VLSI design, as well as computer system design, is an area where CE, EE and CS have overlapping interests. Ideally a student preparing for a career in the area of VLSI design needs understanding of circuits and devices that is part of an EE curriculum, VLSI design techniques from CE, and basic software and programming courses including programming languages, graphics and operating systems that are usually the domain of CS.

For software engineering, the courses may come from CS or CE or a combination of both. Usually the necessary courses in data structures and algorithms come from CS, as do those in programming languages. The software engineering courses, which require projects, case studies or other real software engineering exposure, may be offered by CS or CE, but are clearly engineering courses.

Parallel and distributed computing, and computer networks, again overlap the interests and courses that may be found in CS and CE, including computer architecture, operating systems, performance modeling and evaluation, and computer networks (which may also be found in EE). In computer networks the appropriate courses in graph theory, plus those in programming and data structures, are usually CS courses, and are needed by students interested in routing algorithms and network management. Probabilistic analysis and modeling (e.g. queuing theory) is needed for performance analysis, and these courses may come from CE. CE also may have the courses in computer networks, covering the layered architecture and protocols, etc. EE courses in communications cover the important topics of signaling, modulation and noise, signal processing, etc. The well-educated network engineer needs an understanding of all of these, and a network curriculum (assumed here at the MS level) must integrate these into a coherent program.

In all of these, development of coherent programs requires leadership and faculty vision and cooperation, and participation and decision-making by all faculty relevant to the program.

Factors in achieving synergy

From our UCSC experience, creation of synergy between or among closely-related departments such as CS, CE and EE, is dependent on many factors. At Santa Cruz, we had the advantage of essentially a fresh start in both CS and CE, and now EE. We could take a "top-down" approach, and focus first on the areas of emphasis for research, hire faculty for those areas, and then let the curriculum develop from those faculty and their interests and expertise. We selected areas of emphasis, as broad and integrating themes. Finding joint research projects and research support integrates faculty into a common purpose. We located all the faculty in the same facility, sharing the same computing equipment, and the same technical and administrative support, coffee and mail rooms, etc. The importance of physical layout, in my opinion, cannot be over-emphasized. Holding joint meetings to develop curricula and degree offerings, to managed space and equipment, etc. is also important.

Leadership is a critical component, as it must provide a broad vision, must take the lead in acquiring the necessary resources, and provide continuity and institutional memory. Separate leadership of the research enterprise, as an organized research unit of the campus or an institute, is one attractive structure (which seems now we should have at UCSC). This person would be responsible for developing the research vision, the creation of research clusters and leading in the development of research support, relationships with industry, etc. There would then be separate chairs to head the academic departments and to administer the curricula and the academic personnel process. In some schools, the center or institute head might be an associate dean or such appropriate level, at least parallel that in stature of a department chair.

I believe a key component in creating synergy among CS, CE and EE, so that students are properly served, requires that all three programs be part of the school of engineering. If CS is elsewhere, experience has shown that synergy is not achieved, and effective programs do not result, especially CE programs.

Faculty hiring is critical to success of new or expanding programs. Someone must create and present a clear vision of the program, and its areas of emphasis. Faculty must "buy in" to the vision of a coordinated multi-disciplinary engineering research environment. At UCSC, in creation of the new CE program, a preliminary plan was developed by a committee that included members from industry to give it some guidance especially relating to areas of emphasis for both research and degree offerings. I inherited this plan, and revised it in consultation with some of the committee and the dean, and began the hiring process. Faculty hired became part of the committee, but had already "bought in" to the plan when they were hired. Beginning with a basic plan which was given to a small hiring committee as a starting point, a vision and direction was created and developed in a focused and consistent manner. Larger hiring committees may be more democratic, but may not be as effective or focused. If an established plan for a program does not exist (or is not accepted by the hiring committee) then new faculty are hired into areas deemed most important to the hiring committee, who may set priorities and candidate qualifications based on their own personal perspective (e.g. for particular set of skills and interests that match or complement their own or their research objectives). Hiring should be based on a broad assessment of the field, the interests and directions of the related industry, potential employment opportunities, the interests of students (and projected interests). This requires a keen vision of the key areas in a discipline, as well as breadth and experience, and this does not always occur naturally with hiring committees.

Summary

I have offered a perspective on the inter-relationships between computer science and computer engineering, and their mutual relationship with electrical engineering. Drawing upon my experiences in developing the research programs in the Baskin Center at UCSC and the academic programs in CS and CE, I have attempted to identify some of the factors that have produced synergy between those programs at UCSC: sharing of facilities, joint (courtesy) appointments, joint research projects, shared supervision of graduate students, sharing of courses, and the offering of a coordinated curriculum providing both breadth and depth to both computer engineering and computer science students at all levels: BA and BS, MS and Ph.D.

References

1. Model Program in Computer Science and Engineering. IEEE Computer Society, 1983
2. Accreditation Board for Engineering and Technology (ABET) Accreditation Yearbook, 1995
3. “REINAS: A Real-time System for Managing Environmental Data,” D. Long, P.E. Mantey, E. Rosen, C. Wittenbrink, B. Gritton. Proceedings of 1996 Conference on Software Engineering & Knowledge Engineering, June 10-12, 1996.