Electrical and Computer Engineering for a New Generation

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Abstract

Electrical and Computer Engineering and similarly named departments that developed out of Electrical Engineering share an important characteristic, namely, the ability to evolve in response to changing trends in science and technology and to redefine what comprises this discipline. At the same time Electrical and Computer Engineering as a discipline has had and continues to offer students the opportunity to be trained for success in a broad spectrum of career options. In this respect Electrical and Computer Engineering is a new "liberal arts" degree serving as a spring board for traditional and non-traditional career choices. By making clear to prospective students that Electrical and Computer Engineering offers this opportunity and by offering a unified and flexible curriculum, Electrical and Computer Engineering offers the most compelling option for a new generation of students choosing an educational and career path.

Introduction

At Carnegie Mellon University we believe that Electrical and Computer Engineering (ECE) is a single field and that any distinction between "EE" and "CE" is artificial and not useful in undergraduate education. The evolution of the field of electrical and computer engineering demands a new breed of ECE graduates with a broad set of competencies that cannot be classified into "EE" and "CE" or that are constrained by traditional boundaries. Thus, students who will practice this profession need to see the breadth as well as depth of Electrical and Computer Engineering. They must be prepared to understand that application domains do not easily fit into narrowly defined subfields such as "Electrical Engineering" or "Computer Engineering". At the same time for students who ultimately will NOT practice this profession, Electrical and Computer Engineering may be viewed as the new "liberal arts". Many fields of endeavor today have aspects of Electrical and Computer Engineering as their underpinning. It is important that practitioners of these fields understand how technology enables and defines their profession and will also benefit from the intellectual discipline and problem solving skills acquired within ECE

A curriculum that reflects these realities and prepares students for a wide variety of career choices should include a set of core requirements that assure they have a foundation in a set of essential concepts and skills. The breadth, coverage, depth and capstone design requirements should assure students have a sufficiently rich ECE education. Most importantly the number of free electives should be sufficient to encourage students to specialize deeply in a particular area of ECE; or become broadly educated in a number of areas of ECE; or complement their ECE experience with education in another field (e.g., biomedical engineering, public policy, computer science, business, life sciences, humanities, music, etc.).

In the following we offer an ECE curriculum that eliminates the outdated EE/CE distinction and describe how this better prepares ECE students to pursue advanced courses and careers in all subdisciplines of ECE as well as careers outside of ECE.

The Undergraduate Curriculum

By an undergraduate discipline, we mean a domain with a common intellectual core that prepares undergraduates for productive and satisfying careers. Students need the background to adapt to *and lead* change. The curriculum should provide a solid foundation for the duration of a student's professional life, which will span several decades. With this in mind, there are several reasons we believe that ECE should be defined and widely recognized as a unified and flexible undergraduate discipline.

It is still true today that most universities continue to offer separate BS degree programs in Electrical Engineering and Computer Engineering or Computer Systems Engineering.[1] Perhaps there was a time when maintaining ECE as simply an umbrella for two distinct undergraduate disciplines was reasonable, when the concepts, abstractions, and tools used on the EE side of the discipline could be easily distinguished from the concepts, abstractions, and tools used on the CE side of the discipline, but we believe times have changed. Our university introduced the BS in ECE as a single degree over 15 years ago.[2] This curriculum, which we essentially follow today, offers students enough flexibility to choose among many options, either specializing in a particular subdiscipline or taking a broad range of courses from across the wide spectrum of topics. We believe that for several important reasons making this explicit distinction between EE and CE is not useful at the undergraduate level, and that we better serve our students by presenting our field in a more unified and flexible manner.

Breadth of ECE Technologies

It would be difficult today to describe any of the most interesting or important problems, challenges, or technologies that practitioners of ECE address as falling cleanly into either EE or CE. For example, engineers involved in today's energy systems must of course understand the most traditional concepts associated with power systems (generation, transmission, distribution, etc.), but must equally importantly understand a broad range of enabling technologies, including sensor networks, communications, distributed real-time systems, and security, and how all of these technologies come together in a modern power system. It would be difficult to claim that all of these technologies fall into either EE or CE, or that a well-educated engineer who intends to make the greatest impact in this area should be knowledgeable in only the subset of ideas that neatly fit into either the EE or CE category. Said another way, neither the area of power systems nor the people that must be experts in power systems fit into either EE or CE.

As another example, current designers of digital systems may be comfortable with the label of "computer engineers" and may work at a level of abstraction that does not require a deep understanding of the underlying physics of the logical devices comprising the systems they design. The advance of digital technology in both speed and size has however stretched digital systems to operate where idealizations relied on in the past no longer hold and concepts and ideas that were once viewed as the domain of "applied physicists" must be recognized and understood by the designers of emerging digital circuits.

Similarly, the technologies designed by engineers traditionally considered "electrical" are increasingly depending on computing technology in nontrivial ways. For example, the design of read/write heads in magnetic data storage systems relies heavily on computer simulation. Knowledge of advanced parallel computer architectures, in terms of both hardware and software, is needed to perform the amount of heavy computation required for these sophisticated systems.

The Breadth of an ECE Career

In addition to the fact that the technologies associated with the ECE discipline no longer neatly fit into EE or CE, the range of concepts required to address technological challenges is more dynamic today than it has ever been in the past. Engineers in ECE technologies cannot expect to maintain a successful career that focuses on just a narrow aspect of ECE, and those with a narrow background will have limited prospects for the future. They will either be relegated to working on an ever shrinking range of legacy systems, or they themselves will become obsolete.

Given the breadth of the ECE discipline we feel that students require a number of structural characteristics in an ECE curriculum, including: 1) a strong core that introduces them early to the breadth of concepts within ECE; 2) the opportunity to pursue depth in areas of interest within ECE, but which may be different for different students; and 3) the opportunity to bring into their studies educational pursuits that extend beyond engineering.

Students need a rigorous core that introduces in depth the broad spectrum of ECE concepts from devices and fabrication, circuits, information processing, hardware design, and computer systems. Having been offered this solid core and associated foundational courses in science, mathematics, and computer science, students must then be given the flexibility to pursue more advance courses that provide breadth and depth in areas of greatest interest to the individual. This structure gives students the ability to pursue particular sub disciplines in ECE and does not limit them so that they are unable to move and grow into new areas over time as their careers demand. In addition the flexibility of the curriculum along with the required courses in the humanities and social sciences required of all ECE students offers the opportunity to create a curriculum that prepares students for many non-traditional career choices.

An Undergraduate ECE Curriculum

Our ECE curriculum at Carnegie Mellon has four distinct elements beyond the general engineering and university requirements and is illustrated in Figure 1: *core, breadth, depth/coverage*, and *capstone design*. The core is the small set of courses that *all* ECE students take. Beyond that, students make choices: two breadth courses from five areas, 2 depth/coverage electives, and a capstone design course. The large number of free electives makes it possible for students to pursue a wide range of alternatives ranging from deep specialization in a particular technical area to complementing their ECE education with a broad education in another field,

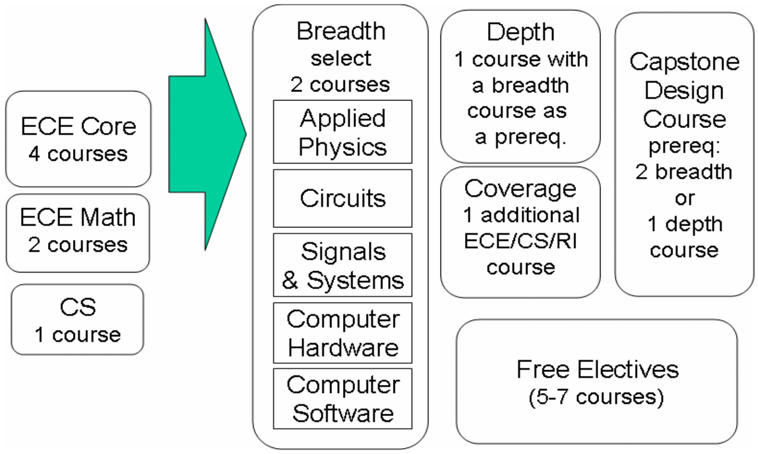

Figure 1. Structure of the ECE curriculum beyond the engineering core and general education requirements.

including preparation for professional careers in areas such as law, medicine, business, public policy, banking, management, and so on.

The Breadth areas shown in Figure 1 cover traditional domains in ECE, but students are required to take courses in only two of theses areas, reflecting our belief that the field of ECE is far too large to expect all students to follow exactly the same paths through the curriculum. Additional ECE courses that can be taken for Depth, Coverage, and as free electives, cover the many exciting domains of contemporary ECE, including, nanotechnology, sensors, digital communications, control systems, multimedia, advanced signal processing, advanced computer architecture, networks, computer security, embedded systems, computer systems, data storage systems, electronic computer aided design, rf circuits, VLSI fabrication processes, etc.

The ECE experience culminates in a Capstone Design Course, where each student applies knowledge from the core, breadth and depth courses to develop and implement a complete system in an area of his or her choice. Figure 1 lists our current set of Capstone Design Courses. We have found that students often organize their course choices around the goal of enrolling in a particular Capstone Design Course.

The ECE Core

The crucial question is; what constitutes the core? Although we don't believe there is a single correct answer to this question, and the answer must evolve as the field evolves. We offer a brief overview of our core below.

Introduction to ECE (freshman course):
Provides an overview of the field of ECE and introduces some of the fundamental tools needed to solve problems in this field.

Fundamentals of ECE:

A. Electronic Devices & Circuits: Provides an introduction to semiconductor devices and circuit analysis with links to digital electronics and signal processing.

B. Signal & Information Processing: Provides mathematical and computational tools for processing signals and information, including sampling, impulse response, convolution, frequency response, and filtering, in terms of both time-domain and frequency-domain analysis.

C. Structure and Design of Digital Systems: Provides a foundation and working knowledge in the application, operation and implementation of digital systems.

D. Introduction to Computer Systems: Provides concepts underlying how programs are executed on computer systems, exposing to students what goes on beneath the abstractions they are taught in programming classes and how those underlying realities affect the correctness and performance of programs.

Giving Students Guidance

Over the years we learned from our students and alumni that students need guidance to take full advantage of an ECE curriculum. In contrast to a more tightly prescribed curriculum in a narrow domain, such as a traditional CE or EE curriculum, students in our ECE curriculum are faced with a number of choices as early as the spring semester of their sophomore year. We have instituted several things to help them identify their specific interests and select courses that will prepare them for their futures. All ECE sophomores register for a 1-unit seminar course, Emerging Trends in ECE, which provides general advice about the options available in ECE. Sophomores are also assigned a faculty advisor who helps them identify the direction they want to take in their curriculum. At the end of their sophomore year, they are assigned a faculty mentor in their field of interest to give them more specific guidance about course selection and career planning. In addition a number of Web-based resources are available to students that provide formal (course descriptions) and informal (student wiki) information about courses. Finally, a staff member working under the supervision of the Associate Department Head has full time responsibility for guiding students through the undergraduate curriculum.

Conclusions and Recommendations

ECE has always evolved and changed with changes in science and technology. This is perhaps the key characteristic of ECE compared to other disciplines. We believe the need for a unification of the ECE discipline and the provision of flexibility and choice are even more pressing today than when the proposal was first made over fifteen years ago. ECE can offer, and we believe that we do offer, students an opportunity to define a customized course of study within a rigorous framework that prepares students for careers in ECE, advanced degrees in ECE or related fields, or for careers outside of ECE. Providing students with the structure and guidance they need to acquire fundamentals, and then giving them the freedom to make informed curricular choices across the breadth of possibilities later in their academic program is a compelling opportunity that attracts many students to ECE as the “new liberal arts” for a new generation.

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