REPACKAGING SIGNALS, SYSTEMS AND CIRCUITS IN THE CORE ECE CURRICULUM

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Abstract

For several years, we have been teaching DSP as a first course in Electrical and Computer Engineering at Georgia Tech. Such a dramatic rearrangement of the introductory material requires a new organization of topics and courses when teaching circuits and systems. In addition, the use of computer-enhanced course materials has a profound impact on the systems courses, which are quite mathematical and abstract in nature. This paper addresses some of the issues encountered when adopting a signal processing first approach.

1. Introduction

Computer technology is producing fundamental and widespread changes in the way in which knowledge is created, disseminated, and stored. This transformation in the nature of reading, writing, and calculating is exerting a profound influence on undergraduate and graduate education. Indeed it is not an overstatement to say that we now have a once-in-a-lifetime opportunity to re-invent the way in which higher education in general, and engineering education in particular, is structured and delivered.

In the School of Electrical and Computer Engineering (ECE) at Georgia Tech, we are currently involved in a major program (over twenty faculty members and about thirty students assistants at this time) that is restructuring and repackaging the entire ECE core curriculum. This program is the combination of three previous initiatives: one in computer-enhanced education and distance learning; one in pedagogy; and one in curriculum content. All three of these areas are being driven by the same technological realities, and it is not possible to effectively address them separately.

2. Basis and Scope of the Program

In addition to the obvious technological realities, there are four specific Institute-level elements that are driving the Georgia Tech initiative. These are:

FUTURENET—Georgia Tech's Campus network that supplies high-speed network access to every on-campus students.

STUDENT COMPUTER OWNERSHIP—Since 1997, all incoming students have been required to purchase a computer.

SEMESTER CONVERSION PROCESS—Georgia Tech will switch from a quarter system to a semester system in 1999, which requires that an entirely new curriculum be in place by that time.

DESKTOP DISTANCE LEARNING NETWORK—The State of Georgia has initiated a program to deliver educational services to the desktop throughout Georgia. Georgia Tech will deliver ECE undergraduate courses to other state universities that do not have engineering programs.

Driven by these fundamentals, Georgia Tech has implemented a distributed multidisciplinary effort that involves groups of faculty from all the major colleges. The program vision is based on the technologically enhanced teaching of theory in the context of practice, a principle we call *Technology First*. For us, *Technology First* means that rather than start with theory or fundamentals alone, higher education must begin with the very computer technologies that are reshaping the way in which knowledge is created and disseminated. By making connections between fundamental knowledge and the new computer technologies at every stage of our students' college careers, we seek to provide them with practical expertise in a broad variety of electronic technologies, as well as with the theoretical and analytical skills necessary to employ these technologies effectively in their own individual disciplines. Students so educated will have a better understanding of basic concepts and an enhanced ability to use those concepts immediately and effectively in the technological workplace.

3. Applying the Technology First Principle

The Technology First principle can be applied in almost all engineering, mathematics, science, and even liberal arts disciplines. However, if the principle is very general, the application of the principle is very specific. The redesign of the curriculum in each discipline represents a unique problem. Fundamental educational and technological tradeoffs (e.g., simulation versus animation, linear presentation versus hierarchical presentation, team learning versus individual learning, etc.) must be addressed differently in each discipline, and in different courses and laboratories within the same discipline. Thus, the task of redesigning the entire curriculum is very large and detailed, involving many individual teams of faculty and educational technologists studying, redesigning, and assessing numerous individual yet interdependent courses.

4. *DSP First* in ECE Education

Historically, Electrical Engineering, like many other engineering disciplines, has been heavily based on linear system theory. For at least the past fifty years, most EE programs have used circuit theory as an introduction to both lumped parameter circuit techniques and linear system theory. These two areas, in turn, then lead into electronics, electromagnetics, materials, communications, controls, digital systems, and digital signal processing. One of the reasons for the (relatively recent) emergence of separate Computer Engineering (CmpE) programs within EE has been the fact that the traditional ordering of EE courses does not allow for the early introduction of critical computer engineering concepts in digital systems and computer architecture. Thus, there is a need to re-order and re-prioritize the topics of EE to emphasize the required digital concepts to allow EE and CmpE programs (even in the same department as at Georgia Tech) to become distinct programs.

In our design of a new curriculum based on the Technology First philosophy, digital signal processing (DSP) has assumed a pivotal role in uniting EE and CmpE. The reason is that DSP is basically the computerized version of (discrete) linear system theory, and hence, it lies between Computer Engineering and traditional Electrical Engineering. Therefore, it is both a critical subject area for computer engineers and it also introduces the theory of linear systems. DSP, of course, is also intrinsically computer-intensive and it is now at the forefront of a world-wide technological revolution based on DSP implementations. Nevertheless, at the present time, most undergraduate ECE and EE programs begin with circuit theory and do not introduce DSP concepts until near the end of the undergraduate program.

Our new curriculum turns this around. The core undergraduate program for both EE and CmpE students begins with an introduction to DSP. This new approach traces it roots to 1993 when we first started teaching such a DSP course in our Computer Engineering curriculum. The course used a combination of computer tools and a hands-on laboratory approach to bring DSP theory from the senior level down to an introductory level for sophomores. The rationale was the following: the concepts of DSP provide a valuable basis for later courses; the subject, by its very nature, provides an ideal setting to explore the linkage between computers and theory; and it is relatively easy to link theory and computers to real engineering applications, thereby increasing student motivation. This approach proved very successful, culminating in 1998 in the publication by Prentice-Hall of the book/CD combination called *DSP First* [1]. Based on this success, in 1997 the School of Electrical and Computer Engineering created a common core curriculum for the electrical engineering and the computer engineering programs as part of its semester conversion process. This conversion explicitly mandates the redesign and computer-enhancement of the entire core curriculum to match the *DSP First* model, both in terms of content and in terms of pedagogical techniques.

In this new program, the first ECE course (for EE and CmpE majors alike) is a computer-intensive sophomore-level course that introduces students both to basic DSP concepts and to a sophisticated computer-enhanced learning environment. This course changes the program in many ways. Most importantly, it dramatically changes the way in which subsequent courses in the curriculum can (and should) be taught. Because the students will acquire both new linear systems knowledge and stronger computer experience, it is now *possible and desirable* to teach all the other undergraduate courses differently.

5. Impact of DSP *First*

The purpose of the introductory signal processing course is to teach students the abstract representation of signals and systems as well as the basic concepts of filtering, frequency response, and Fourier transforms for both discrete-time and continuous-time signals. At the end of such a course, students should be able to analyze the behavior of a system by characterizing its frequency response and also solve basic mathematical problems in Fourier analysis and z-transforms. In addition, students should be able to implement working systems by writing MATLAB programs that perform the operations of discrete-time filtering, signal synthesis and frequency analysis with the FFT. Our course at Georgia Tech is a combination of lectures to present the theoretical material and labs to address the MATLAB programming implementations and the processing of real signals. The *DSP First* textbook includes many computerized tools for the labs and for interactive demos. We are looking for ways to develop interactive learning modules that can be integrated into homework and lab assignments. If we could automate parts of the laboratory, TA resources could be focused on coaching students through their lab projects.

5.1 Computer-Based Pedagogy

Our recent experience with using computer-based material as an integral part of this signal processing class has shown us that engaging a student's active involvement is tricky. Computer demos, however flashy, do not necessarily fulfill the slogan "if you build it, they will come." On the other hand, new software tools for course management (such as WebCT) offer a possible solution by tracking student usage of computer demos and interactive resources. A change in pedagogy is needed to make this activity an integral part of the students' coursework, perhaps by assigning homework that involves computer explorations. Another variation on this same theme is to use computer generated and graded quizzes. We are experimenting with short quizzes at the beginning each lab session in order to generate immediate feedback to the professor and the students, as well as to motivate students to keep pace with weekly topics. With computer grading, the overhead of correcting many problems is removed, although the interface to the students is impersonal.

5.2 Impact on Teachers

Changing the first course from circuits to DSP exposes a crucial link—the faculty. As long as the introductory DSP course is taught by a restricted subset of the faculty whose specialty is DSP, the content of the course will be consistent. However, when taught by faculty from related areas such as telecommunications, controls and electronics, the emphasis broadens; and when taught by the faculty at large, the essence of the DSP course might be lost. Since the course has to serve as an introduction for all ECE students, the broader perspective is good. One way to establish this broader perspective is to take an integrated approach to the revision and teaching of both the DSP course and the circuits course. The set of faculty involved in these two courses should be nearly the same, so the viewpoint of faculty for these new courses can be shaped by a team approach. We are using a scheme where faculty being introduced to these modified courses work with others who have previously taught the courses and developed the computer-based material.

In addition, faculty must adopt a pedagogical approach that is dominated by computers. In this arena, the faculty have much to learn from teaching assistants (TAs) who are generally more knowledgeable in computer-based learning. While experienced faculty learn some of these new methods, the GTAs will be a source of continuity in the day-to-day operation of the courses. We also envision that the GTAs will be the primary software developers and maintainers of the computer-based demos, so they can be a resource for presenting those demos in class and interacting with students who are learning the demos.

5.3 Hands-on Learning

DSP has other natural advantages. The revolution sweeping academia at the moment involves computer technology used in the support of learning. Where does DSP fit in? A large part of the revolution involves the use of multimedia presentation methods (over the web), but those multimedia presentations are, in fact, digital audio, digital images or digital video. Students accustomed to seeing web-based presentations are curious to learn about their inner workings, so they are primed to learn about DSP.

To take this one step further, consider how one would teach the concept of lowpass filtering and then filter design. The mathematical approach is known to anyone who practices DSP, even though the work is now carried out by computer programs. But a crucial question in the learning process should be understanding the filter “specs.” In many cases, the specs come from an imprecise process that evaluates the quality of signals processed by the filter. This leads an educator to ask the question: how many of my students have actually “seen” or “heard” the effects of a lowpass filter? In other words, how many have processed sound through a lowpass filter and listened to the result? Nowadays, it is not a difficult task to implement a lowpass filter and process audio, but how many DSP courses expect students to do this experiment?

The facilities to do simple, but meaningful, experiments in digital signal processing are now commonplace. We usually choose software implementations because general-purpose computers are so accessible (with programs like MATLAB), and many books have now included MATLAB exercises. Furthermore, with development kits supplied by TI, Motorola, Analog Devices, or Lucent, it is not out of the question for lower level students to experiment with real-time implementations. This is another area where DSP has a notable advantage over analog circuit theory. It is difficult to construct a useful circuit without lots of lab infrastructure and a fairly long learning curve. DSP lends itself to programmable implementations that quickly become sophisticated systems.

5.4 Motivation

Motivation is a key issue in core courses. Most engineering students would probably testify that their initial courses are endured, not enjoyed. In a marketplace with many students, educators could use the first course as a “gate.” However, many recent curriculum changes at the entry level have turned this attitude around by involving students in projects and activities that convey some interesting aspect of the engineering process. The goal is almost always to motivate further study and questioning, and this is where DSP has some natural advantages. An early course should have interesting projects based on realistic systems that are readily understandable to beginning students. Audio, speech, and music fit that description; so does digital image processing. Programming a simple music synthesis algorithm is a moderately challenging task that gives a sense of accomplishment when the song plays correctly. Furthermore, it should be easy for the instructor to link theory to such projects. In the music synthesis example, the theoretical backbone is the frequency spectrum. Continuing this style in other core courses may be more challenging because the link between theory and common applications is not as tight.

5.5 Impact on Advanced DSP & Communications Courses

One risk with the DSP First approach lies in the theoretical development of methods for signals and systems. Later courses in DSP, controls, and telecommunications tend to be very mathematical, but a sophomore-level course will be limited in its mathematical sophistication. This shifts the burden onto the senior-level courses for the mathematics training of the students. The rationale for this approach is that a broad course that serves all ECE students cannot provide the in-depth theory needed by specialists in that area. In other words, students with interests ranging from computers to microelectronics will benefit from a basic education in DSP, but they would have to study further to acquire a strong working knowledge of the subject. On the other hand, a broad course will benefit those students who take more signals/systems courses because the initial course will focus on concepts with wide applicability.

6. The Impact of Technology First on Teaching Circuits

The fundamental departure from a traditional ordering of courses in the EE curriculum, i.e., the presentation of DSP as the introductory engineering course, has an enormous impact on the circuits course. Students enter the circuits course with an understanding of several fundamental principles, including the concepts of linearity, time-invariance, convolution, and Fourier transforms (both continuous-time and discrete-time). Students are also proficient with manipulating complex exponentials and complex numbers and they are experienced with a number of computer-based tools such as MATLAB.

The circuits course must incorporate and build upon this base of knowledge and skills. Being freed from the necessity of introducing basic concepts, such as frequency response, complex phasors, and solving linear systems, the course can focus on building fundamental engineering concepts within the context of circuits as implementations of linear systems.

Given this change in student background, circuits are presented as examples of linear, time-invariant systems. The course outline can be rearranged so that the behavior of circuits to complex exponential inputs is presented early. This makes it possible to discuss the system function and the frequency response of a circuit in conjunction with its time response. This provides a natural mechanism for discussing the interrelationship between the time-domain and frequency-domain behavior of circuits, such as the role played by the poles of the system function in determining the transient behavior of the system.

Students who have completed the introductory DSP course also have considerable experience in the design of systems as well as in their analysis. To maintain this design momentum, at Georgia Tech the circuits course also introduces operational amplifiers as circuit elements early in the semester. Later the students learn to use these for implementing circuits that have arbitrary transfer functions, so that they can then design and implement circuits with prescribed frequency responses.

Circuit simulations and solutions are performed in MATLAB and PSPICE, but equally important to the new course is the development of a series of computer-based tools that facilitate both the teaching and learning of the course material. Two goals have guided the development of these tools. First, the tools should help students understand and develop intuition about concepts. Second, they should provide a mechanism for immersing the student into the technology. A number of topics in circuits are particularly difficult for students to visualize. These include such concepts as: the relationship between time and frequency; the differences and relationships between transient and steady-state responses; the behavior of active circuits, superposition and linearity; and the process of circuit design. A number of these tools have been developed, but others are still under construction.

7. Related Disciplines

DSP courses, which formerly were taught only at the senior and graduate level, can be made more accessible to a wider set of students. The gap between what is taught at a typical university and what graduating engineers need to bring into the workforce has been widening. Powerful software software packages make it possible to perform sophisticated DSP design without much mathematical training. And yet, in academia, most courses in DSP have historically been restricted to the graduate level and, at that level, the emphasis is often on the mathematics and theoretical issues.

Furthermore, DSP is no longer the sole province of EE. In fact, the student base is swinging toward computer engineering and computer science, and it also encompasses most other engineering and science majors. The typical EE service course for other majors has always been circuits, but other topics deserve consideration. In the future, DSP is much more likely to be useful to most engineers and scientists than circuits. We often get questions from researchers in other fields about frequency spectrum estimation methods for their data, which now comes in digital form from an A-to-D converter. It is quite likely that students in engineering and science will work with experimental data that must be analyzed with the FFT or more sophisticated methods, so a fundamental background in DSP looks more and more like a necessity. A pioneer of this approach is Ken Steiglitz, who first developed this sort of book[2] for CS students with an interest in computer music.

8. Summary

All of this adds up to an interesting challenge to engineering educators. Digital processing is invading every technical curriculum to the point that it is a basic skill that ***all*** engineers and scientists should know. The whole curriculum, not just EE, must respond to the pressures of a computer-dominated profession by educating students within the context of the latest technology and the most powerful software tools. At the same time, most will agree that we must also give our students a firm theoretical base from which to use these powerful tools. In short, our challenge is nothing less than teaching our students how to *think* when they sit down at a computer! DSP provides this unified approach to computers and theory.

9. References

1. J. McClellan, R. Schafer and M. Yoder *DSP First: A Multimedia Approach*. Prentice-Hall, 1998.
2. K. Steiglitz. *A DSP Primer*. Addison-Wesley, 1995.