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Sharing Knowledge and Building Communities in Signal Processing

The textbook has traditionally been the fundamental tool of university teaching. The text both serves as the repository of facts and information and provides the recommended structure and sequence for teaching and learning the material. Today, textbooks can be in traditional paper form or electronically available over the World Wide Web. However, the material in domains like signal processing changes rapidly as new theory, applications, and hardware continually come on the scene. In some ways, having a textbook as a course's main tool actually impedes course and curriculum development. Problems with traditional books include:

- *Sequential and inflexible:* All paper and most Web-based textbooks cover topics sequentially, which both misleads and bores students. Students are following a curriculum and taking several courses at once, but the cross-fertilization of ideas present in their daily collegiate lives is not reflected in their courses either intellectually or pedagogically. The self-contained nature of courses resulting from reliance on an inflexible text inhibits holistic curriculum development by obscuring the connections among the range of courses that make up a discipline. Further-more, existing texts provide inflexible, off-the-rack content that caters to only a single learning style and often falls short of the instructor's needs.
- *Static and inefficient:* Under the current development model, textbooks are developed by a single author or small team and take years to write, reach bookstores, and undergo revision. Only a small proportion of potential authors ever contribute to the body of published materials due to the large time commitment.

There is a great need for information technologies for developing and delivering quality, up-to-date educational materials that convey to all learners that knowledge is a dynamic continuum that stretches across disciplines. Ideally, many authors should contribute to the body of knowledge from which instructors and/or learners select to create a course's text. The resulting "book" should freely reference ideas and applications arising from both related and diverse fields. Moreover, how the material is presented should not greatly influence the way the knowledge is stored; in this way, present and future technologies would be supported.

The Connexions Project (cnx.rice.edu) is an experimental, open-source/open-content initiative that offers an alternative to the way textbooks and other learning materials are created, maintained, and used [1]–[3]. [An open-content license allows anyone to read, copy, modify, and redistribute the work as long as they permit others to do the same (see "Open-Content Licensing").] By design, Connexions greatly impacts current modes of teaching and learning and the development and sharing of knowledge. In combination with powerful software tools, Connexions gives learners free access to educational materials that can be readily manipulated to suit their individual learning styles as they explore links among concepts. The free software tools also foster the development, manipulation, and continuous refinement of educational material by diverse communities of authors and instructors.

Connexions' hallmarks include:

- a content commons (database repository) of diverse educational materials spanning the knowledge continuum, which are modularized for easy reuse and available free to anyone in the world
- free, open-source tools to aid in visualizing and navigating the "connexions" among concepts, courses, and curricula
- high-quality materials, thanks to an iterative development process and an inherent quality assessment mechanism
- rapid, collaborative authoring of the materials by global communities of authors
- flexible, dynamic construction of an infinite variety of customized courses and curricula, enabled by a coherent format (XML) and delivered in a variety of forms, from Web pages to e-books to paper texts.

Conceived and launched in 1999 at Rice University, Connexions has been under intense development and is beginning to attract the attention of a growing number of concerned

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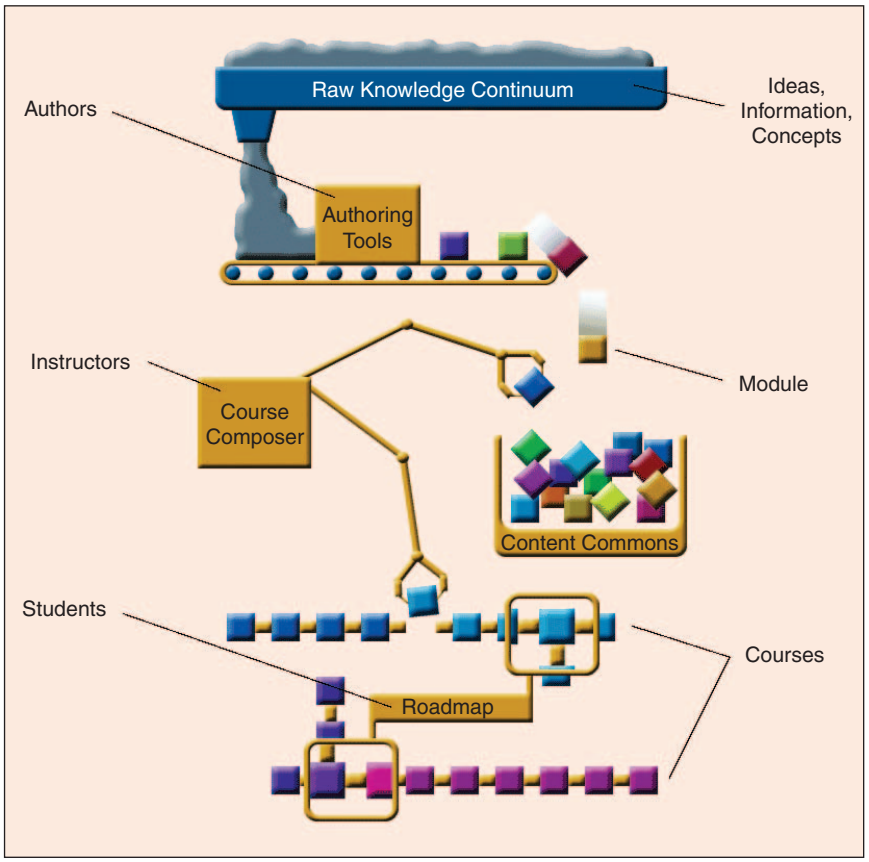
educators worldwide. This article gives an overview of the philosophy and progress of the project, with a particular emphasis on its application to the area of signal processing.

Connexions Tools and Technology

Connexions can be viewed as a kind of "course factory" (see Figure 1). A global community of authors, using special XML-based authoring tools, continually converts "raw knowledge" into small, self-contained modules of information and places them in the content commons repository to be easily used, reused, updated, and adapted. Modules can be thought of as special Web pages that can contain hyperlinks, text, equations, applets, simulations, videos, and other multimedia elements. Instructors use the *Course Composer* software tool to weave modules into customized courses. This process creates the course's text, which can be navigated using the Web or can be printed as a unified book. Students view modules and courses using special visualization and navigation tools designed to highlight the connections among concepts or purchase the hardcopy version from their bookstore as a loose-leaf packet. Students can follow the path and sequence laid out by the instructor or "discover" the ideas along the path of their curiosity.

The Connexions architecture and software toolkit consists of an XML language [4] for content markup (including MathML for mathematics [5], [6], which not only displays equations attractively on the Web and in print but also allows them to be copied into environments like Mathematica [7], which makes every equation a living applet), the Content Commons to store and retrieve the modules, an environment for instructors to construct courses from modules, an annotation capability for instructors to customize modules and for students to personalize them with "margin notes," a browser to navigate courses and modules, and a printing tool that converts a course into a ready-to-print pdf file complete with table of contents and detailed index [8]. An integrated XML/MathML document editor is in the works, as are wizards to help convert from LaTeX, Microsoft Word, and other formats into XML. On the Web, Connexions modules are viewable with a range of browsers. Last but not least, the Connexions author Web site enables groups of authors to form ad hoc workgroups to collaboratively develop new modules and courses. All Connexions software and tools are distributed open source and free; release 1.0 is currently used by faculty around the globe.



▲ *1. Connexions as a dynamic "course factory."*

Community Content Development

Rather than the traditional content development model of one author to one textbook, Connexions invites and links worldwide communities of authors to collaboratively create, expand, revise, and maintain the content commons. All materials are freely available under a Creative Commons open-content license (see "Open-Content Licensing") [9], [10]. The result is a dynamic, up-to-date content base that makes the latest knowledge globally available. Author's professional integrity and an inherent peer review system will ensure high quality (described in more detail below).

Modularity and open-content development substantially lowers the barrier to entry into the author community. Consider this quote

Open-Content Licensing

The open-content development model is the most radical aspect of Connexions, but it holds the key to populating the content commons with a critical mass of high-quality content. Those unfamiliar with open development should read Eric Raymond's classic essay "The Cathedral and the Bazaar" [10] to gain more insight into the benefits of developing software under open licenses. Connexions aims to translate these benefits to content as well, by enabling communities of authors worldwide to continuously collaborate on developing and improving the content commons [12].

In Connexions, authors retain the copyright on their materials but make them freely available under a Creative Commons open-content license [9]. This license shares the spirit of open-source software licenses like the General Public License (GPL) and Berkeley Software Distribution (BSD) license but is expressly designed for content. The license allows anyone to copy, modify, and redistribute Connexions modules and courses as long as they attribute the original author(s). To take the guesswork out of what users can and cannot do with the content, we embed the license information directly into the XML source of each and every module and course.

Creative Commons' overarching aim is to develop a common legal vocabulary for sharing content. This aim evolved because the current legal environment is geared more towards precluding, rather than enabling, sharing of content. Related developments such as MIT's OpenCourseWare initiative [13], the Public Library of Science [14], the Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities [15], and open-source movements in Latin America and Europe indicate that a global open-access movement is gaining momentum.

from an electrical engineering faculty member: "For years I have wanted to write a textbook, because I love to write about fast Fourier transforms (FFTs). However, any complete text in my field also has to cover z-transforms, on which I have no interest in writing." Connexions will allow this faculty member to contribute his excellent FFT material and then weave a custom text for his course using contributions from other authors passionate about z-transforms. Since Connexions authors can contribute a high-quality, high-impact module in a number of hours or days, many more college faculty, industry professionals, K-12 teachers, and even talented students can write about what excites them and contribute modules to the commons.

In May 2004, Connexions hosts over 1,800 modules in the content commons and is used as the primary text for 38 courses [11]. Content in the areas of botany, music appreciation, music theory, nanotechnology, civil engineering, applied mathematics, computer science, and bioinformatics is in active development. Over the next three years, Rice University's Electrical and Computer Engineering department plans to develop a holistic Connexions undergraduate curriculum spanning 15 courses. Signal processing has proved a particularly fertile area for Connexions content development.

DSP Content Development

DSP Theory

Beginning at a Connexions workshop in August 2001, faculty members from the University of Illinois (D. Jones), University of Michigan (A. Hero), Ohio State University (P. Schniter, L. Potter), Georgia Institute of Technology (D. Williams), University of Wisconsin (R. Nowak), Polytechnic University (I. Selesnick), Cambridge University (N. Kingsbury), Norwegian University of Science and Technology (T. Ramstad, A. Gjendemsjo), and Rice University (R. Baraniuk, C. S. Burrus, D. Johnson) formed a cross-institutional "beta community" that plans to develop several hundred modules for teaching DSP. These initial modules will provide both a foundation of material and an organizational framework on which others can build—filling in gaps, drawing new connections, and adding problems, solutions, visualizations, and other teaching materials.

DSP education illustrates the community-building process so important to Connexions. Over the past few years, many graduate DSP textbooks have migrated to the undergraduate level. The breadth of the field complicates graduate textbook development, as each school teaches widely ranging topics; one single text covering most topics would have to contain several thousand pages. All of these diverse topics can be written by authors interested in some particular area and made available in the Connexions content commons. Instructors can then create a customized DSP course appropriate to their school's program.

In a joint venture with Cambridge University Press, Prof. Alfred Hero's new book on statistical signal processing will be simultaneously published as a traditional Cambridge University Press book and made available freely in the Connexions content commons. We expect a vibrant community-of-use to emerge

around this material, helping it evolve and grow with time.

To efficiently share DSP and other mathematical content, users must be able to view modules and courses in a consistent mathematical notation. An instructor or student should be able merge modules contributed by several different authors and view them using the same notation, choosing between imaginary i versus j, signal $x(m)$ versus $x[n]$, and frequency ω versus $2\pi f$, for example. At present, Connexions provides limited MathML notation conversion facilities (i versus j, divergence, curl, vectors represented with boldface, underbar, overbar, and so on). Help is on the way for more complicated conversions (such as ω versus $2\pi f$), but this remains a research topic in the semantic markup community [5].

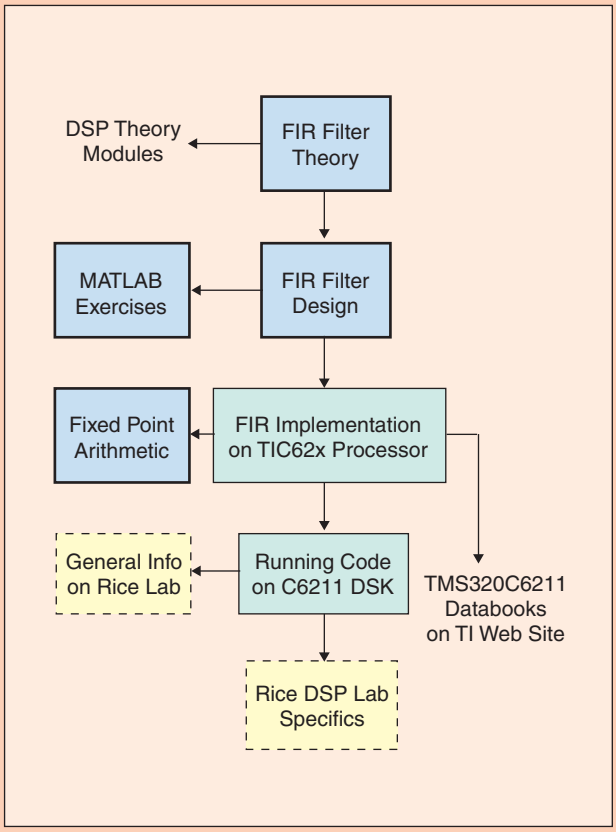
DSP Laboratories

DSP computer laboratories are also being developed [2], since the same theoretical background and many algorithmic details can be shared among laboratories based on different DSP chip architectures. Connexions' modularity and efficient authoring cycle makes it a natural for DSP lab courses, since the rapid evolution of DSP microchips means that lab texts fall out of date almost as soon as they are printed. Moreover, the variety of different processors and lab setups makes it nearly impossible for a single printed text to address the needs of most laboratories, but

DSP Laboratories in Connexions

A DSP laboratory revolving around finite-impulse response (FIR) filtering will typically involve a theory section on the concept, simulation exercises (in an environment such as MATLAB or LabVIEW), discussions of generic hardware theory (fixed-point arithmetic, for example) and specific hardware theory (FIR filter algorithms in Texas Instruments TMS320C6211 assembly language, for example), and a section discussing the implementation and testing that are specific to a particular lab platform (see Figure 2) [2]. The theory modules are readily available in Connexions and have most likely been seen by the students in their other Connexions-based DSP courses. Simulation and hardware modules can be found both in DSP theory courses and other lab courses (even those involving just MATLAB or LabVIEW exercises).

Thus, in a fully developed Connexions environment, an instructor wishing to build a DSP lab class need only choose and assemble a set of preexisting modules to outline her class. The remainder of the class can then be written in module form to cover the actual implementation issues of the local hardware platform. Even at this stage, she can potentially use modules provided by the equipment manufacturer (such as modules covering the assembly language instruction set for the microprocessor being used). A handful of segue modules (either written by the instructor or borrowed from similar DSP labs) tying theory to implementation can round out the course. This approach represents the minimum amount of effort required to craft a quality DSP lab. The instructor is free, under the open-content license, to customize and improve existing modules as she sees fit. These modules, in turn, may gain popularity and become the material most often used in other DSP labs, as commonly occurs in such an open-source development environment.



▲ *2. Connexions FIR filtering lab as used in Rice University ELEC 434—Digital Signal Processing Lab. Each box represents a module, and arrows represent hyperlinks between modules. Boxes with thick boundaries indicate DSP theory and exercise modules that can be used at other institutions with little modification. Boxes with thin boundaries are processor-specific. Boxes with dashed boundaries are specific to a particular equipment setup.*

the natural division of such courses into theory- and application-oriented concepts allows for the reuse of most materials across lab courses, with the exception of only the most platform-specific topics. For an example, see "DSP Laboratories in Connexions."

DSP Lab courses in active development as of February 2004 include University of Illinois' ECE320—DSP Lab (TI TMS320C549 DSP) by Doug Jones; Rice University's ELEC226,Embedded Systems and Microcontroller Lab (TI MSP430 F169) by Patrick Frantz, ELEC 434, Digital Signal Processing Lab (TI TMS320C6211) by Hyeokho Choi, ELEC424/427, High Speed and Embedded Systems Design (TI TMS320C2812) by Patrick Frantz, and Ohio State University's EE609, Signal Processing Lab (Motorola 56002) by Lee Potter. To reach the broadest possible audience, these courses are currently being translated into Mandarin Chinese, Japanese, and Thai.

The Connexions software team has also been working closely with National Instruments to integrate their LabVIEW Player into the environment. The LabVIEW Player is available free of charge and enables users to run interactive signal processing applets and demonstrations. These applets are much easier to design and implement as LabVIEW virtual instruments than in a standalone Java environment.

Distributed Quality Assessment

Over time, a large number of modules and courses will develop around any given topic (wavelets, for example). How will an instructor or student find the right material that suits their needs? And how will Connexions evaluate and direct users to modules deemed of high quality? Unfortunately, standard prepublication peer review is too unwieldy to keep up with the fast pace of Connexions module and course development, where materials may change daily or even hourly.

Instead, Connexions is setting up systems for search and discovery, concept mapping, and distributed, post-publication peer review. In the near future, Connexions will enable users to preferentially locate and view modules and courses rated high quality by choosing from a range of different lenses, each with a different focus. Lenses will be controlled by third parties, who will establish their own review processes. For example, the IEEE Signal Processing Society could set up an editorial board to evaluate and credential DSP content. Lenses based on measures of use (most linked to, most read, collaborative filtering, think google.com and amazon.com) will also be available.

The Road Ahead

Over the next two years, the Connexions team plans to produce a scalable, sustainable content commons covering a wide range of different disciplines and supported by an open-source software architecture. With the lessons learned from this stage, plus careful planning, we plan to launch Connexions as a nonprofit, "dot-org" to emphasize its independence and to best serve its global communities. To learn more about Connexions or to get involved as an author, instructor, student, or software developer, visit the project Web site at cnx.rice.edu or email cnx@rice.edu.

Acknowledgments

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