gel plays with short phrases interrupted by silences, so it is up to the tubist to "perform" the silences, adjusting their length in order to sustain a feeling of musical tension. You could hear a pin drop during this performance.

The 2e2m ensemble featured music by composers living in France, starting and ending with the two most well known: Iannis Xenakis and Pierre Boulez. Xenakis's *Morsima - Amorsima* for violin, cello, double bass, and piano was one of the very few pieces in the festival composed with the help of a computer. It belongs to the cycle of works Xenakis composed in the 1960s with his stochastic music program (SMP), using an IBM 7090 computer. Boulez's *Derive I* for flute, clarinet, violin, cello, vibraphone, and piano was definitely another high point in the festival. The piece is composed from small gestures, based on a pattern of pitches derived from the letters of Paul Sacher's last name, interplayed between the musicians.

Of the many performance artists seen during the festival, Henning Christiansen really deserves mention. His *Umwalzung - fluxorum organum*, dedicated to the late Joseph Beuys, is conceived as a contribution to the changes taking place in Europe today. The actions that took place (rolling over of railway ties, a handstand in a tub of water, a gaggle of eight-year-old children distributing apples across an expanse of sheet metal), although sounding trivial on paper, were performed with an unparalleled intensity, and Christiansen's 5-m long fiberglass tubes, played with clarinet mouthpieces, sounded incredible.

In the closing days of the festival, yet another version of the chamber ensemble came to light with a concert and two exhibitions dedicated to the work of the Fluxus artist, Joe Jones. His *Confrontations* (1989) for string quartet and solar orchestra (a battery of instruments played by motors running on solar energy) combined string sounds ranging from lyric to aggressive with the relatively delicate sound of the solar orchestra. The exhibitions, featuring motorized guitars, mandolins, and the like, were equally enjoyable, although an attempt to demonstrate a collection of solar-powered instruments in Berlin at the beginning of February was not a complete success due to overcast skies.

The Inventionen provided a magnificent variety of new music. Nevertheless, there came a point when both of us wondered if it would ever come to an end. The festival organizer's have already announced that they intend to put together a shorter, more tightly focussed program next year. Inventionen '91 is tentatively scheduled for 25 January–5 February 1991.

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Publications

F. Richard Moore: Elements of Computer Music

Prentice Hall, Englewood Cliffs, New Jersey USA, 1990, 560 pages, softcover, $30.80

"The power of computer methods is . . . that they provide a programmable means whereby the musician can design sounds according to the requirements of a particular musical idea. Programs for digital sound synthesis "instruments" allow musical sound to be analyzed, modified, and synthesized in ways that are limited only by the imagination of the creative musician." This quote from *Elements of Computer Music* provides a summary taste of this useful book. Why should you learn signal processing when a variety of electronic music instruments and signal processing boxes are available with prepatched voices and sound effects? Since calculators are cheap, why should kids learn arithmetic?

Some composers design the structure of each timbre to have specific relationships of frequencies of (harmonic or inharmonic) partials to reflect, in various ways, pitch relationships at the score level, or vice versa. The timbre of a voice may mutate dramatically over time. The distinction between a dense voice and the orchestra may blur, as may the distinction between timbre and the entire score. The sound may move through different acoustic environments. To work with these musical concepts, a composer should be able to design or program the timbre, score, and room acoustics. An understanding of sound analysis techniques is useful in developing active scores that "listen" and react to other musicians. Analysis of the sound from traditional instruments, animals, etc. can also aid in the development of interesting new voices. After taking apart (analyzing) an interesting acoustic sound, one can reconstruct it differently, or crossbreed its parameters with parameters from the analysis of the sound of another instrument to create unique sounds.

Many musicians become bored after hearing the same or similar electronically generated or sampled voices in various musical pieces. The default voices provided in commercial synthesizers and samplers (and synth/sampler combinations with additional processing) are the voices

most often heard on pop radio. These new voices may initially sound interesting; however, canned voices have a tendency to become stereotyped or trite. Similarly, sounds processed by popular signal processing boxes can become passé. A limited ability to connect processors and memory will limit the variety of sounds that may be created. However, unlimited programmable signal processing power will produce little interesting music without a knowledgeable composer.

With some imagination, the ability to listen and an understanding of signal processing, one can design unique voices and sound processing by patching together fundamental units of computing (e.g., adders, multipliers, memory, logic, etc.). The *Elements of Computer Music* provides a relatively easy way to develop an understanding of sound analysis, synthesis, and signal processing. Like the ability to compose (program) at the score level, the ability to work with sound in an intelligent, repeatable, and flexible manner is fundamental to computer music. Manufacturers concerned about musicians' ability to work with cryptic internal languages might consider providing access to a graphics screen and pointing device (mouse, track-ball, joystick, etc.) to facilitate the patching of processes and memory.

The field of computer music comprises too many disciplines to be covered in depth by any one book. *Elements of Computer Music* concentrates "on elements that have proved to be useful in the analysis, modification, and synthesis of musical sounds and structures." Included in the introduction to computer music is a concise description of our ability to listen. The useful integration of psychoacoustics where needed in the rest of this book is easy to take for granted, yet is often missing or poorly used in other books and articles. A clearly written introduction to digital audio theory includes: A/D and D/A conversion, sampling, aliasing, quantization, noise, and distortion. Moore's teaching skills are revealed through his numerous analogies and examples throughout the book.

A large portion of the book explains signal processing and instrument design, with a useful level of detail. Instruments are software; the author does not describe hardware design. An appropriately designed multiprocessor system could run most of the software instruments in real-time. However, one could program these software instruments on most computers (including many personal computers), storing computed samples on a large disk drive for subsequent playback in real-time. For example, the CARL software (including cmusic) provides a powerful, general-purpose synthesis, analysis, and processing package, which runs on NeXT, Sun, and other computers that run UNIX. In addition to being useful for composition and signal processing, the CARL software package (available from the Center for Music Experiment, Q-037, University of California, San Diego, La Jolla, California 92093) is a good learning tool for experimentation with ideas and programs described in this book. The excellent chapter on instrument design is followed by an introduction to room acoustics, reverberation, and movement of sound through space. The last chapter provides a brief description of computer techniques in composition. Following this are valuable appendices, including sections on mathematics, tuning, and cmusic.

Compared to most engineering texts, the author guides readers painlessly through the mathematics of signal processing. Fourier transformation, convolution, and windowing are explained with the appropriate extension for time-varying spectra. The Z transform is used to introduce digital filters, poles, and zeros. The design and properties of finite impulse response (FIR) and infinite impulse response (IIR) filters are explained. Table-lookup oscillators and their code, approximation errors and applications are described. These sections provide a foundation to instrument design. FM (with extensions), waveshaping, and other forms of nonlinear synthesis, as well as additive synthesis and the phase vocoder, are explained with block diagrams and cmusic definitions to supplement the text and math. The phase vocoder is a useful tool for analysis and modification of the spectrum of a sound. The pitch of a note may be altered without changing the duration, and vice versa, with the phase vocoder. Use and calculation of phase vocoder parameters is well explained. Band-limited excitation sources, including closed-form summation formula, and the design of time-varying filters is described for use in subtractive synthesis. The author also explains the plucked string algorithm and provides help in using it effectively. The section on formant synthesis describes an example of an instrument for producing the sound of a male singing voice.

Many insightful observations are provided throughout the book, such as: "The major difference between linear prediction and the short-time spectrum measurements discussed previously (e.g., phase vocoder) is that linear prediction ideally measures only the overall shape—or envelope—of the spectrum of the input sound rather than the amounts of energy at a large number of equally spaced frequencies." Linear prediction may be used for restoration of distorted recordings as well as for cross synthesis, in which the spectral envelope (coefficients derived from linear-predictive analysis) of one voice is used to control time-varying digital filtering of another voice, in-

strument, orchestra, etc. After explaining linear prediction, a useful combination of analysis techniques is described. The shift in timbre that results from shifting pitch with the phase vocoder may be corrected by applying the spectral envelope, determined with linear prediction, to the pitch-shifted result.

The chapter on rooms explains reverberation, room acoustics, and hall simulation as well as sound spatialization with Doppler shifting. C programs are included to calculate some of the relevant parameters. Numerous helpful block diagrams, graphs, and figures are also provided. For example, a block diagram for a "space" unit generator is provided. This space unit generator is composed of early echo FIR filters, an IIR comb filter, delays, allpass IIR filters, multipliers, and adders to combine elements. Although this chapter does not cover the most recent developments in the field, it does a good job of teaching the underlying theory.

Throughout this book you will find numerous C-coded examples, many of which are ready to be used. However, the value of this book is in the lucid explanations of the underlying processes, including relevant mathematics. After reading this book, you should be able to program and modify the author's examples and experiment with new processes. Background concepts are well developed and used to introduce more complex ideas. Many good references are provided for further reading. If your math skills have grown rusty from lack of use, you may refer to an appendix containing a concise summary of mathematics used in signal processing. Over a decade ago, the author published a two-part article on math for musicians in the *Computer Music Journal* 2(1), 2(2), entitled "An Introduction to the Mathematics of Digital Signal Processing." Interested readers should be able to find these issues in a university library. [See also the reprint of these articles in J. Strawn, ed. 1985. *Digital Audio Signal Processing: An Anthology.* Madison: A-R Editions.—Eds.]

If you do not know how to program a computer, I would suggest reading *Programming in C with a bit of UNIX* (Prentice Hall), also by Moore. Originally this introductory book was to be a chapter in *Elements of Computer Music,* but it was expanded into a 193 page book instead. This book provides a quick and easy way to learn computer programming. Descriptive explanations are provided with many easy-to-understand examples.

The last chapter of *Elements of Computer Music* is about using the computer in composition, providing an overview along with the basics. Even the author admits that his treatment is incomplete because the field is too broad. Whole books could be written on composition algorithms and languages. There is an explanation of the concepts of random number generation, which is fundamental to most forms of computer composition. There is also a description of linear congruential method, a common form of random number generation. Filters and sieves, Markov processes, and probability are covered in sufficient detail for composers to understand and use existing instruments with these processes, modify them, or write their own processes, learning by experimentation.

The appendix on tuning provides a concise description of the different tuning systems, their derivation, advantages, and problems. Good use of psychoacoustics is made in describing relations between pitches. This appendix mentions a few of the tuning possibilities provided by a computer. Dynamic tuning may be used to keep just-tuned intervals in tune. Some of the results of using equal-tempered tuning with other than 12 steps are described. The use of sounds with stretched partials is also mentioned. It is to be hoped that readers will be stimulated to write more unique pieces of music, instead of using only harmonically tuned partials or the standard twelve-tone, equal-tempered scale. A good description of the cmusic program and its unit generators is included as the last appendix. Besides being a useful reference, this appendix provides a good supplement to the sections on instruments and signal processing.

Most terms and concepts are clearly explained at appropriate points in this book or used minimally until sufficient background has been provided to explain them. Numerous analogies are provided to help the reader gain insights into the workings of complex processes. Unlike terse manuals and dry articles, this book was often a pleasure to read. In the detailed explanations, I would often be reminded of fundamental assumptions in using some mathematical process. Such assumptions often work as a crude approach to solving a problem, but may be an obstacle to refining a process in the long run. In reconsidering fundamental assumptions, I found myself thinking of new ideas. Other books provide greater detail on the mathematics of signal processing, but none are as well tuned for composers as this book. Few books consider the problems and violations of mathematical assumptions in processing musical sound. Other books on signal processing oversimplify assumptions about the nature of musical sound.

Although C is practical for real-time experimentation, the usage of any particular computer language may eventually date a book, although this book would be less practical if coded examples were left out. Despite the fact that this is not a book about MIDI, it will help one understand the processing inside electronic

music instruments and signal processors. It will help the insightful reader to use and intelligently combine various pieces of equipment. Readers will refer to this book long after the current electronic widgets, and books about them, have become obsolete. Although a good appendix on cmusic is included, I would not describe the book as a cmusic manual. Few books, including this one, can describe the most recent advances due to the time it takes to write and publish a book. Rather than attempt to describe every new technique, this book focuses on teaching readers the fundamentals of signal processing and "classical" techniques. Readers will then have the ability to understand technical articles on new forms of processing.

Moore does an excellent job of teaching the theory that underlies computer music. Signal processing is clearly explained for those without an electrical engineering degree by a musician who earned a PhD in EE at Stanford University. Moore earned two bachelor degrees in music composition and performance at Carnegie-Mellon University and did graduate work in composition (with Lejaren Hiller and others) at the University of Illinois. With Max Mathews and others at Bell Labs, Moore collaborated on the development of the Groove system (one of the first real-time computer music systems) and on the Music V program. He designed and built a modular, all digital, real-time sound synthesizer (the FRMBOX), while at Stanford, and later wrote the general music synthesis and processing program, cmusic. Moore left Bell Labs to found the CARL project at the Center for Music Experiment, University of California, San Diego, where he has been Professor of Music since 1979. He was also Director of CME for many years during the last decade.

This book is written especially for composers and musicians. However, programmers and those with scientific backgrounds may find the book helpful if they have focused on one area of computer music (e.g., user interfaces) and want to learn more about another area (e.g., music synthesis). The text is more explanatory than engineering texts or programming manuals. The math, code, and diagrams throughout the book serve as a nice reference in addition to the concise appendices. This book should be one of the primary texts for teaching computer music to graduate composition students, as well as to undergraduates, who tend to be more computer literate. Moore's book will be valuable in creating a generation of composers who use their computers more effectively. Now that a good foundation has been laid, perhaps someone will write an advanced text on signal processing of music. I would highly recommend *Elements of Computer Music* for anyone who is interested in analyzing, manipulating, and creating sound using computer technology.

Reviewed by John Snell
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Max Mathews and John Pierce, Editors: Current Directions in Computer Music Research

MIT Press, Cambridge, Massachusetts, USA, 432 pages, hardcover, $35.00; CD, $18.00; Video Tape, $75.00

The book *Current Directions in Computer Music Research* is a wonderfully crafted collection of 20 chapters by the leading scientific and musical minds of our time. It is a monument to the state of the art in computer music research and to the investment in our field made by the System Development Foundation (which also supported the production of the book). The essays in this volume are as varied in length, approach, intended audience, and tone as are their topics. It is difficult to outline or summarize *Current Directions* other than to say that the topics of music and technology, composition and performance, and software and hardware, are each treated from several perspectives, and that the chapters range from surveys to tutorials to composition and realization descriptions.

The topics of the chapters can be summarized as:

- processing and synthesis of the human voice,
- digital sound synthesis and processing,
- music perception and psychoacoustics,
- real-time performance, and
- composition tools and applications.

The outline of *Current Directions* sorted by topic reads:

- Introduction—John Pierce
- Speech Processing
  - Compositional Applications of Linear Predictive Coding—Paul Lansky
  - On "Speech Songs"—Charles Dodge
  - Synthesis of the Singing Voice—Gerald Bennett and Xavier Rodet
  - Synthesis of Singing by Rule—Johan Sundberg
  - Frequency Modulation Synthesis of the Singing Voice—John Chowning
- Signal Processing and Synthesis Software
  - Spatial Reverberation: Discussion and Demonstration—Gary Kendall, William Martens, and Shawn Decker
  - Spatialization of Sounds over