CENTER FOR COMPUTER RESEARCH IN MUSIC AND ACOUSTICS MARCH 1988

Department of Music
Report No. STAN-M-44

OVERVIEW
Center for Computer Research in Music and Acoustics (Recent Work)

edited by

Xavier Serra and **Patte Wood**

Research and composition sponsored by

The System Development Foundation
The National Endowment for the Arts
The National Science Foundation
The Rockefeller Foundation

CCRMA
DEPARTMENT OF MUSIC
Stanford University
Stanford, California 94305

INTRODUCTION

The Stanford Center for Computer Research in Music and Acoustics (CCRMA) is an interdisciplinary facility where composers and researchers work together using the computer-based technology as a new musical and artistic medium, and as a research tool.

Areas of ongoing interest at CCRMA include: Applications Hardware, Applications Software, Synthesis Techniques and Algorithms, Signal Processing, Digital Recording and Editing, Psychoacoustics and Musical Acoustics, Applied Pattern Recognition and Artificial Intelligence, Music Manuscript by Computer, Composition and Real-Time Applications with Small Systems.

The CCRMA community consists of administrative and technical staff, faculty, research associates, graduate research assistants, graduate and undergraduate students, visiting scholars and composers, and industrial associates. Major departments actively represented at CCRMA include music, electrical engineering, computer science, and psychology.

Center activities include academic courses, seminars, small interest group meetings, summer workshops and presentations. Concerts of computer music are presented each quarter with an annual outdoor computer music festival in July. In-house technical reports and recordings are available and public demonstrations of ongoing work at CCRMA are held monthly during the academic year.

Research results are published and presented at professional meetings, international conferences and in established journals including the Computer Music Journal, Journal of the Audio Engineering Society, and the Journal of the Acoustical Society of America. Compositions are presented in new music festivals and radio broadcasts throughout the world and have been recorded on cassette, LP, and compact disk.

Support for CCRMA has been received from the California Arts Council, the National Endowment for the Arts, the National Science Foundation, the Rockefeller Foundation (for artists-in-residence), the System Development Foundation, Doreen B. Townsend, Apple Computer, Dynacord, Sequential Circuits, Symbolics, Xerox Palo Alto Research, Yamaha, and private gifts.

Brief History of CCRMA

In 1964, while pursuing graduate studies with Professor Leland Smith, John Chowning began the work in computer music at Stanford using Music IV with help from Max Mathews of Bell Telephone Laboratories. Initial experiments were carried out with the help of the Computer Science Department on their time-sharing computer system (an IBM 1790 and a DEC PDP-1). Together, Chowning and computer science student David Poole put together the first on-line computer composition and synthesis system, with technical help from Computer Science and Electrical Engineering. As a result, John Chowning wrote the first programs for moving sound sources through a four-speaker space. As part of this project, a 12-bit DAC with a multiplex of four outputs was built. The program had both angular and distance cues, reverberation and Doppler shift.

In 1966, the Stanford Artificial Intelligence Laboratory moved to the D.C. Power Laboratory Building on Arastradero Road and acquired a DEC PDP-6 computer. Music 10, a music compiler for the PDP-6, was written by David Poole. It was at this same time that Chowning joined the music faculty teaching music theory and computer music, and the first course in computer–generated music was offered.

Exploratory work on musical timbres began in 1967 and led to the discovery of the use of frequency modulation (FM) for sound synthesis by John Chowning with the help of David Poole and engineering graduate student George Gucker .

In the summer of 1969 the first summer workshop in computer-generated music was taught by John Chowning, Leland Smith, Max Mathews and George Gucker.

The work in FM synthesis resulted in the composition "Sabelithe," written in the spring of 1971, and the publication of Chowning's paper on FM synthesis, which appeared in the Journal of the Audio Engineering Society in September 1973. The FM synthesis technique was licensed to Nippon Gakki, Inc. (Yamaha) in 1974, and the development of electronic music instruments based on FM synthesis was begun in Japan with consultation from Stanford. A patent for FM was granted in 1977. Other basic work by Leland Smith included the development of SCORE, a computer program written in FORTRAN which enabled composers to synthesize and compose pieces using the DEC PDP-6 and later the PDP-10; and MS, a music manuscripting program which has been highly developed over the years and is now available for use on personal computers.

Working on dissertations in the area of computer music, James A. Moorer, Loren Rush, John Grey, and F. Richard Moore made important contributions to the field in analysis-synthesis, digital editing, and synthesis hardware. In 1972, John Grey and Andy Moorer began working on the analysis and resynthesis of real instrument tones by computer. This work led to important discoveries about the psychoacoustics and perception of sound. In 1968 Loren Rush began working in the area of digital recording using programs written for speech research. Working with Andy Moorer and Ken Shoemake, in 1974 he completed EDSND, a program for computer editing of recorded sound, and in 1976 the first high quality digital recordings were made.

Early compositions from CCRMA included: "Sabelith I" for sound and 3 performers by John Chowning in 1966 (never completed due to the Artificial Intelligence Laboratories move to the DC Power Laboratory Building); "Adoşaman" for tape, by Irmfried Radauer in 1967; "Rondino" for stereo tape, by Leland Smith in 1968; "Pour" for sound and recorded voice, by Martin Bresnick in 1969; "Fragment" for stereo tape, by Martin Bresnick in 1970; "Sabelithe II" for quad tape, by John Chowning; "Machines of Loving Grace" for bassoon and narrator with stereo tape and "Rhapsody for Flute and Computer" for flute and stereo tape, by Leland Smith in 1971; "Turenas" for quad tape, by John Chowning in 1972; "A Little Traveling Music" for amplified piano and quad tape, by Loren Rush in 1974; a realization of John Erickson's "Loops," by John Grey in 1974; and "Song and Dance" for orchestra and quad tape, by Loren Rush and commissioned by the San Francisco Symphony in 1975.

Because of their growing reputation, members of the computer music group at Stanford were asked by Pierre Boulez in 1973 to participate in the planning stages of his music research institute being formed as part of the Centre Pompidou in Paris. In August 1975, the IRCAM group came to Stanford to participate in a special workshop on computer music. The research relationship and exchange between the two centers has continued over the years.

In June of 1975, CCRMA was formed with funding provided jointly by Stanford University, by a gift from Mrs. Doreen B. Townsend, by a grant from the National Science Foundation for research, and by a grant from the National Endowment for the Arts for computing equipment for musical purposes. As a result, CCRMA was able to commission the design and fabrication of the Systems Concepts Digital Synthesizer (designed by Pete Samson and called the Samson Box) which was installed at CCRMA in 1977. Although a part of the music department at Stanford, CCRMA continued to share facilities and computing equipment with the Stanford Artificial Intelligence Laboratory (SAIL) of the Computer Science Department at the D.C. Power Laboratory Building on Arastradero Road. The founding co-directors of CCRMA were faculty members John Chowning and Leland Smith and research associates John Grey, James A. Moorer and Loren Rush.

Funded research at CCRMA at this time included work on "Timbre Perception for Complex, Time-Variant Tones" and the "Computer Simulation of Music Instrument Tones in Reverberant Space."

The first computer music concert ("An Evening of Computer Music and Film") was held August 10, 1976 at Dinkelspiel Auditorium and in 1978 CCRMA presented a concert of computer music at the Stanford Museum of Art.

Additional work accomplished at this time included the development of software for the Samson Box. The initial program was MBOX written by graduate student Gareth Loy in 1977-78 and resulting in his piece "Nekyia" in 1979. Subsequently graduate students, David Jaffe, Michael McNabb and Bill Schottstaedt revised and extended this software into a program called SAMBOX as a result of their own compositional work. In 1977 Marc LeBrun began work on waveshaping synthesis techniques. In 1978 Bill Schottstaedt began work on Pla, an interactive interpreter program which includes a graphics-oriented note-list editor. This program, written in SAIL, was first used in the composition of Schottstaedt's "Daily Life Among the Phrygians" and has become the main program used by composers at CCRMA for compositions that use the Samson Box digital synthesizer.

Another major accomplishment in 1977 occurred when graduate student Michael McNabb, using available software for the PDP-10 computer and additive synthesis, digitally applied the timbres of vocal sounds to instrumental sounds to achieve a smooth transition in timbre between the two. This work resulted in the composition of "Dreamsong" in 1979. This work also led to experiments by John Chowning applying this technique to FM synthesis (in Paris in 1979), which resulted in the composition of "Phone" in 1981, which in turn led to Stephen McAdams dissertation work on spectral fusion.

This was a compositionally active period of time. Works written at this time include: "Dirge" and "Sinfonia for Computer" by Bill Schottstaedt and "Stria" by John Chowning in 1977; "Sandcastle," "Mars Music," "New Music Liberation Army," "The Gong Tormented Sea" and "You're So Far Away" by Bill Schottstaedt, "Mars in 3D" by Michael McNabb and Bill Schottstaedt, "Oracle - 4am" by Paul Wieneke and "Standing Waves" by Stuart Dempster in 1978; and "Nekyia" by Gareth Loy, "Dreamsong" by Michael McNabb, "the servent snapping eye..." by Roger Reynolds, and "Daily Life Among the Phrygians" by Bill Schottstaedt in 1979.

In November 1979, the Artificial Intelligence Laboratory moved to the Stanford campus to new facilities with the Computer Science Department. CCRMA remained at the D.C. Power Building and, with the help of Stanford University and Yamaha, obtained its own time-sharing computer system: A Foonly F2 (later upgraded to a Foonly F4) central processor with 256K of memory emulating a DEC PDP-10 and designed by David Poole, various computer peripherals, and several digital/audio workspaces. Extensive work was accomplished by Andy Moorer and Tovar in writing software for the new system. This included a comprehensive signal processing library for computer music applications by Andy Moorer. No longer having to share computers and work space with the Computer Science Department enabled CCRMA to become an independent and fully functioning center.

In 1980, CCRMA received a grant from the National Science Foundation (NSF) to begin work in the "Intelligent Analysis of Acoustic Signals." Initial work was begun by Loren Rush and Chris Chafe at CCRMA in conjunction with Joseph Rockmore and Bernard Mont-Reynaud at Systems Control Technology in Palo Alto. This work has continued at Stanford under the direction of Bernard Mont-Reynaud and with support from NSF.

In 1982, CCRMA received a major five year grant from the System Development Foundation for operating support and research. This grant enabled the center to obtain needed equipment and support staff. The Center was able to accommodate a larger number of composers, researchers, and students and computer music at Stanford began to flourish.

Important work at this time included dissertations by Stephen McAdams, John Strawn, Jeff Borish, Christopher Sheeline, John Gordon, and Andy Schloss in areas of psychoacoustics, and Julius Smith on digital filters and physical modeling.

Work in the area of digital recording continued under the direction of Loren Rush. Software and hardware interfaces were extended to enable the direct digital transfer of sound between the Foonly and Sony PCM-F1 and PCM-1610 digital recorders. This work resulted in the mastering of "The Digital Domain", a compact disk demonstrating the capabilities of digital audio and released by Electra for Warner Special Products in January 1984. Other recording projects completed included "Michael McNabb: Computer Music", a digitially mastered phonograph disc reseased in 1984 and "Computer Music from CCRMA" produced by Janis Mattox.

In 1982 Julius Smith and David Jaffe began work on the synthesis of plucked strings using the Karpus-Strong plucked-string algorithm. This resulted in the composition of "Silicon Valley Breakdown" by David

Jaffe in 1983 and has led to the exploration of other synthesis techniques based on physical modeling by Chris Chafe, David Jaffe, and Julius Smith.

Other compositions during this period included: "Towers of Hanoi" by Andrew Schloss and "Garden for Orpheus" by Paul Wieneke in 1980; "Phone" by John Chowning, "Attend" by Paul Wieneke, and "Voicespace IV" by Roger Reynolds in 1981; "Colony" by Bill Schottstaedt from 1981-1983 and "Book of the Burning Mirror" and "Dinosaur Music" by Bill Schottstaedt in 1983; "Diptych"for stereo tape, mezzo-soprarno and string quartet by Jonathan Berger, "gamelan R gong gong" by JoAnne Carey, "Mr. Normal and the Details" and "Red Cup and Rat (What's Wrong With This Picture?)" by Doug Fulton, "Bristlecone Concerto No. 2" for solo violin, solo mandolin, instruments and tape, and "Bristlecone Concerto No. 3" for mandolin, percussion and stereo tape, by David Jaffe, "Music for S" by Stanislaw Krupowicz, "Dialogos" by Servio Marin, "Shaman" for percussionist, dancer, bassist, vocalist, and tape by Janis Mattox, "Getz Variations" for tenor sax and tape by Dexter Morrill, "Anira" by Adolfo Nuñez, "Daybreak" by Bill Schottstaedt, "Pentateuch" for soprano, three choral groups, large orchestra and tape by William Sussman, "Areyto" for chamber orchestra and sound by Raymond Torres-Santos, and "Etude (Hommage a Bartok No. 2)" by Amnon Wolman in 1984.

In 1983, the university began to make plans to move CCRMA to the Stanford campus. With the completion of the Music Department's Braun Music Center, the former home of the Music Department, the Knoll, became available for CCRMA's use. (Built in 1916, the Knoll was originally the home of Ray Lyman Wilbur, president of the University. The Wilbur family lived in the building until the early 1940's when the building began to be used by the University for academic purposes.)

Renovation of the Knoll to provide CCRMA with facilities for interdisciplinary digital acoustic research and composition began in April of 1985. CCRMA moved to the Doreen B. Townsend Center for Computer Research in Music and Acoustics in the reburbished Knoll building at the end of March 1986.

References

Borish, Jeffrey. "Electronic Simulation of Auditorium Acoustics," Ph.D. Dissertation, Department of Electrical Engineering, Stanford University, Department of Music Technical Report STAN–M–18, 1984.

Chafe, Chris, Bernard Mont-Reynaud, and Loren Rush. "Toward an Intelligent Editor of Digital Audio: Recognition of Musical Constructs." *Computer Music Journal,* 6(1):30–41, 1982.

Chowning, John M. "The Synthesis of Complex Audio Spectra by Means of Frequency Modulation." *Journal of the Audio Engineering Society,* 21(7):526–534, 1973. Reprinted in Curtis Roads and John Strawn, eds. *Foundations of Computer Music,* Cambridge, Massachusetts: MIT Press, 1985.

Chowning, John M. "Computer synthesis of the singing voice." In Johan Sundberg, ed. *Sound Generation in Winds, Strings, Computers,* Stockholm: Royal Swedish Academy of Music, 1980, pp. 4–13. Chowning, John M., John M. Grey, Loren Rush, James A. Moorer, and Leland Smith.

"Simulation of Music Instrument Tones in Reverberant Environments, Final Report." Stanford, California: Stanford University Department of Music Technical Report STAN–M–8, 1978

Chowning, John M., John M. Grey, Loren Rush, and James A. Moorer. "Computer Simulation of Music Instrument Tones in Reverberant Environments." Stanford, California: Stanford University Department of Music Technical Report STAN–M–1, 1974.

Chowning, John M., John M. Grey, James A. Moorer, and Loren Rush. "Instrumental Timbre and Related Acoustical Phenomena in the Perception of Music, Final Report." Stanford, California: Stanford University Department of Music Technical Report STAN–M–11, 1982.

Chowning, John M., Loren Rush, Bernard Mont-Reynaud, Chris Chafe, Andy Schloss, and Julius Smith. "Intelligent Systems for the Analysis of Digitized Acoustic Signals, Final Report," Stanford, California: Stanford University Department of Music Technical Report, STAN–M–15, 1984.

Gordon, John W. "Perception of Attack Transients in Musical Tones," Ph.D. Dissertation, Department of Music, Stanford University, Department of Music Technical Report STAN–M–17, 1984.

Grey, John M. "An Exploration of Musical Timbre." Ph. D. Dissertation, Department of Psychology, Stanford University. Department of Music Report STAN–M–2, 1975.

Grey, John M., and James A. Moorer. "Perceptual Evaluation of Synthetic Music Instrument Tones." *Journal of the Acoustical Society of America,* 62:454–462, 1977.

Jaffe, David A., and Julius O. Smith. "Extensions of the Karplus-Strong Plucked-String Algorithm." *Computer Music Journal,* 7(2):56–69, 1983.

Karplus, Kevin, and Alex Strong. "Digital Synthesis of Plucked-String and Drum Timbres." *Computer Music Journal,* 7(2):43–55, 1983.

Loy, D. Gareth. "Notes on the Implementation of MUSBOX: a Compiler for the Systems Concepts Digital Synthesizer." *Computer Music Journal,* 5(1):34–50, 1981.

Mattox, Janis, Elliot Mazer, Andy Moore, and Loren Rush, *The Digital Domain,* compact disk, Elektra Records, 1983.

McAdams, Stephen. "Spectral Fusion, Spectral Parsing and the Formation of Auditory Images," Ph.D. Thesis Department of Hearing and Speech, Stanford University, Stanford California, May 1984. Department of Music Technical Report STAN–M–22.

McNabb, M. "'Dreamsong': The Composition." *Computer Music Journal,* 5(4):36–53, 1981.

Moore, F. Richard. "Real Time Interactive Computer Music Synthesis." Ph. D. Dissertation, Department of Electrical Engineering, Stanford University, Department of Music Technical Report STAN–M–7, 1977.

Moorer, James A. "On the Segmentation and Analysis of Continuous Musical Sound by Digital Computer." Doctoral Dissertation, Department of Computer Science, Stanford University, 1975. Department of Music Report STAN–M–3.

Moorer, James A., John M. Grey, and John Snell. "Lexicon of Analyzed Tones. Part 1: A Violin Tone." *Computer Music Journal,* 1(2):39–45, 1977.

Moorer, James A., John M. Grey, and John Strawn. "Lexicon of Analyzed Tones. Part 2: Clarinet and Oboe Tones." *Computer Music Journal,* 1(3):12–29, 1977.

Moorer, James A., John M. Grey, and John Strawn. "Lexicon of Analyzed Tones. Part 3: The Trumpet." *Computer Music Journal,* 2(2):23–31, 1978.

Moorer, James A. "The Use of the Phase Vocoder in Computer Music Applications." *Journal of the Audio Engineering Society,* 26(1/2):42–45, 1978.

Moorer, James A. "The Use of Linear Prediction of Speech in Computer Music Applications." *Journal of the Audio Engineering Society,* 27(3):134–140, 1979.

Samson, Peter R. "A General-Purpose Digital Synthesizer." *Journal of the Audio Engineering Society,* 28(3):106–113, 1980.

Schloss, W. Andrew. "On the Automatic Transcription of Percussive Music — From Acoustic Signal to High–Level Analysis," Ph.D. Thesis, Department of Hearing and Speech, Stanford University, Stanford California, May 1985. Department of Music Technical Report STAN–M–27.

Schottstaedt, Bill. "The Simulation of Natural Instrument Tones using Frequency Modulation with a Complex Modulating Wave." *Computer Music Journal,* 1(4):46–50, 1977. Reprinted in Curtis Roads and John Strawn, eds. *Foundations of Computer Music,* Cambridge, Massachusetts: MIT Press, 1985.

Schottstaedt, Bill. "Automatic Species Counterpoint," Stanford University Department of Music Technical Report STAN–M–19, May 1984.

Schottstaedt, Bill. “Pla: A Composer’s Idea of a Language.” ***Computer Music Journal,*** 7(1):11–20, 1983.

Schottstaedt, Bill. “PLA – A Tutorial and Reference Manual,” Stanford University Department of Music Technical Report STAN–M–24, December 1984.

Sheeline, Christopher. “An Investigation of the Effects of Direct and Reverberant Signal Interactions on Auditory Distance Perception,” Ph.D. Thesis, Department of Hearing and Speech, Stanford University, Stanford California, November 1982. Department of Music Technical Report STAN–M–13.

Smith, Julius O. “Techniques for Digital Filter Design and System Identification with Application to the Violin,” Ph. D. Dissertation, Department of Electrical Engineering, Stanford University, Department of Music Technical Report STAN–M–14, 1983.

Smith, Leland C., “ Score, A Musician’s Approach to Computer Music.” ***J. Audio Eng. Soc.,*** Jan. 1972.

Smith, Leland C., “Editing and Printing Music by Computer.” ***Journal of Music Theory,*** Fall, 1973.

Strawn, John. “Modeling Musical Transitions,” Ph.D. Thesis, Department of Music, Stanford University, Stanford California, June 1985. Department of Music Technical Report STAN–M–26.

contributed by Patte Wood, ***Administrative Director***

CCRMA ROSTER

PPN	Name
Staff & Faculty	
JC	John Chowning, Director
PAT	Patte Wood, Administrative Director
HMK	Heidi Kugler, Secretary
MVM	Max Mathews, Professor (Research)
LCS	Leland Smith, Professor
JRP	John Pierce, Visiting Professor Emeritus
EDS	Earl Schubert, Professor Emeritus
BMR	Bernard Mont-Reynaud, Senior Research Associate
CC	Chris Chafe, Technical Coordinator/Research Associate/Lecturer
BIL	Bill Schottstaedt, Research Associate
JOS	Julius Smith, Research Associate/Lecturer
EG	Emmanuel Gresset, Research Assistant
TVR	Tovar, Programmer/Analyst
JAY	Jay Kadis, Audio Engineer

Student Research Assistants

		Degree
PRC	Perry Cook	PhD EE
DK	Douglas Keislar	PhD Music
STK	Stanislaw Krupowicz	DMA Music (Composition)
DKM	David Mellinger	PhD CS
XJS	Xavier Serra	PhD Music
BOB	Bob Shannon	PhD EE

Graduate Students

			Project
ECB	Emily Brant	DMA Music (Voice)	Computer Music Seminar
	Michael Cohen	PhD Computer Science	MIDI Seminar
EZC	Estrella de la Cruz	DMA Music (Composition)	Composition
GRD	Glen Diener	PhD Music	Research
YIE	Young-Iee Eom	Masters Music(Composition)	Computer Music Seminar
JON	Jonathan Franklin	PhD VTSS	Computer Music Seminar
HMH	Martin Herman	Music/U.C. Berkeley	Computer Music Seminar
HBH	Harlan Hokin	DMA Music (Voice)	Research
	Brent Johnson	PhD EE	Signal Processing Seminar
RSK	Richard Karpen	DMA Music (Composition)	Composition
LEH	Ben Knapp	PhD EE	Research
TOS	Steven Lakatos	PhD Music	Research
CCL	Chris Lanz	DMA Music (Conducting)	MIDI Seminar
LFT	Alfred Leung	PhD Music	Research
	Todd Mozer	GSB	MIDI Seminar
DCO	Chris Overton	Math	Computer Music Seminar
DVO	Daniel Oppenheim	DMA Music (Composition)	Composition
DAV	David Perry	PhD Psychology	Research
AMI	Ami Radunskaya	PhD Math	Research
TKA	Alex Tkaczevski	DMA Music (Composition)	Computer Music Seminar
CYW	Cheng Wang	DMA Music (Composition)	Composition

XSK	Xu Sika	Masters Music (Composition)	Computer Music Seminar
DDZ	David Zicarelli	PhD Hearing and Speech	Research

Undergraduates

	Robert Armas	Undeclared	MIDI Seminar
	Joseph Belfiore	Undeclared	MIDI Seminar
WCC	Wendy Chow	Symbolic Systems	Computer Music Seminar
	Gregory Cohen	Undeclared	MIDI Seminar
PVC	Peter Commons	EE/Music	Computer Music Seminar
DJC	Daniel Culbert	CS/work study	MIDI Seminar
SCD	Scott Douglas	EE	Computer Music Seminar
SBF	Steven Fram	Philosophy	Computer Music Seminar
TFG	Tim Gallagher	Undeclared	MIDI Seminar
	Peter Habicht	Undeclared	MIDI Seminar
	David Hornik	Undeclared	MIDI Seminar
	Martha Horst	Music,VTSS	Computer Music Seminar
DEB	Deborah Jue	Undeclared	Signal Processing Seminar
ABS	Andrew Leary	Music/work study	Computer Music Seminar
	Jeffrey Neal	Undeclared	MIDI Seminar
	Eric Ranelletti	Undeclared	
SAV	Sean Varah	Music/CS	Computer Music Seminar
	William Wallace	Music	MIDI Seminar
	Carl Wescott	Undeclared	MIDI Seminar
	Timothy Westergren	PolySci	MIDI Seminar
CPW	Chanel Wheeler	Computer Science	Computer Music Seminar

Visiting Scholars/Composers

JWB	James Beauchamp	Professor; University of Illinois (sabbatical Jan-June)
BRG	Jonathan Berger	Assistant Prof. Music; Yale University (sabbatical 87)
AB	Al Bregman	Professor of Psychology, McGill University (sabbatical 86-87)
	Diana Deutsch	Professor of Psychology; UC San Diego 1988 (spring 88)
PEF	Pablo Furman	Visiting Professor,Music; UC Berkeley 1988
GEG	Guy Garnett	Visiting scholar
JEG	Johannes Goebel	Composer; German government fellowship (1987-88)
JH	Jonathan Hallstrom	Professor of Music, Colby College, Rockefeller fellowship
DAJ	David Jaffe	Composer
FLM	Fred Malouf	Composer
JRM	Janis Mattox	Composer; NEA fellowship
MMM	Mike McNabb	Composer
	Simon Millward	Composer; English fellowship (1987)
DEX	Dexter Morrill	Prof. of Music; Colgate University NEA fellowship
IJM	Ira Mowitz	Composer; Guggenheim fellowship (Sept. 87 for 1 year)
ARP	Arnaud Petit	Composer; French fellowship (March 88 for 1 year)
MUZ	Loren Rush	Composer
TAK	Teiichi Takenaka	Prof. of Music; Japanese fellowship (Sept. 87 for 1 year)
LEO	Leonello Tarabella	Italian fellowship
HKT	Rick Taube	Composer; Rockefeller fellowship
PAW	Pascal Willequet	Visiting scholar; French Government/Renault fellowship
AYW	Amnon Wolman	Composer; Lecturer, UC Berkeley

RESEARCH

Introduction

Computer music is inherently an interdisciplinary field. Accordingly, the research mentioned in this section spans such areas as engineering, computer science, and psychology, as applied to various musical topics. Some of the papers include substantial work in all these fields. It should be added that much effort, not necessarily reported here, continues to go into general software development and the creation of suitable environments for composition and research. This section does not pretend to be a comprehensive description of the research being done at CCRMA. For a more complete description a list of recent publications is included in section 9 of this report and a complete list of CCRMA research publications is available upon request.

Although most of the research is interdisciplinary, the following rough categorization of the articles presented here may be useful. Engineering research at CCRMA includes both hardware development (Mathews) and various aspects of digital signal processing (Cook, Garnett, Serra, Shannon, Smith). One active area is physical modelling of musical sounds (Chafe, Cook, Garnett, Smith). Research in computer science includes representations for music (Diener). Various types of work have been done in psychoacoustics and neuropsychology (Keislar, Lo, Perry, Pierce). The NSF project in machine perception (Mont-Reynaud and Gresset) couples the work of a computer scientist and that of an engineer. The researchers contributing to this section include graduate students, faculty, staff, and guests.

Simulating Performance on a Stringed Instrument

Chris Chafe
Research Associate

I've been involved with a continuing project in which music is synthesized from a physical model controlled by simulated physical performance gestures. This report presents some issues in designing a control system for such a synthesizer with illustrations of a running system. The present system runs considerably slower than real-time and can be viewed as an enviroment for answering questions about live control of an eventual real-time system. The kinds of control in a playable real-time instrument are similar to those used here, where the computer interprets the musical score.

The present method is specific to synthesis from a physical model of a bowed string. The simulated performances are used to generate five time-varying control signals for the model. Its externally controlled parameters are: string length, string damping and bow speed, pressure and position. Other instrument types could be tested using a similar approach. The set of parameters and articulation rules would be adapted to fit their synthesis models.

Time-varying envelopes for the parameters are created by concatenation of short envelope segments corresponding to performance gestures. Gestures themselves are not represented in actual physical terms, so there is no notion of the extent or rate of motion of the fingers or bow. Instead, the system represents gestures in terms of their effect on the string parameters.

Musical scores are coded as lists of gestures. The method is a variant of tablature notation, in which a score is described from the point of view of hands manipulating the instrument, rather than pitches on a stave. For example, events described in this fashion include ***martele attack on string III*** in the right hand or ***hammered pitch at the fifth on string I*** in the left hand.

When creating a performance, the system adds details that cause gestures to conform to the changing state of the musical phrase. The intended result is consistency in the complex gestures that perform multiple notes as well as some amount of expressiveness in the rendition.

It should be mentioned that though computer music synthesis using physical models is promising, it is still largely a theoretical field. Commonly restricted to running in software, sound generation is many times slower than real-time. Real time systems require either a new type of synthesizer hardware or general purpose super computers. The bowed string algorithm used in the present work runs in software. Since the purpose here is to discuss control of the cello model, background concerning the algorithm itself should be found by referring to the following sources: Cremer, McIntyre and Woodhouse, Smith and Weinreich.

A physical model of an acoustic source can represent a vibrating system of arbitrary complexity. A complete cello-like synthesizer is constructed by coupling together a number of bowed string models that simulate each string's internal reverberation and the bow's frictional driving mechanism, and which are further coupled to the bridge, the sound box and the air. Weinreich has termed the bowed string algorithm a method for "synthesis from first principles." It is a simplified, but nonetheless accurate, description of a dynamic physical system. The algorithms representing the four cello strings are iterated in time from some initial state, eg. an open string at rest. As the bow excites string motion, waves begin to circulate that are emitted as sound at the model's output. Events in the musical score, through the intermediary control system, cause changes to parameters controlling the bow and string.

A cellist develops skill at manipulation of five basic parameters. ***String length,*** controlled by fingers on the player's left hand, determines the round-trip time of the recirculating waves and the resulting pitch of the sound. The right hand controls ***bow speed, pressure and contact position,*** affecting loudness and tone quality. A fifth control, ***string damping,*** controls the amount of wave recirculation and varies with movement of the fingers and bow touching the string.

In synthesis experiments with a physical model of the cello, a number of advantages have become clear:

- Regimes of oscillation are correct in the time domain. Self-sustained oscillators such as bowed strings are ***dynamical systems.*** The system's ***attractor*** (equilibrium state) under normal bowing conditions is a waveform exhibiting ***Helmholtz motion,*** named after the acoustician who first described the periodic mechanism of string capture and release by the bow.
- As in the real instrument, transient behavior of the system is state-dependent. Response to a particular articulation depends on what the system was doing in the recent past.
- The model has the same external controls as the physical system. These are the same parameters a cellist develops skill at manipulating.
- There is an "intuitive feel" to the system's response. A cellist can recognize and imitate a synthetic articulation and recommend improvements in the control values. The complete range of cello articulations can be synthesized.

The most important restriction concerning control of the model, is that the model's state should persist through successive articulations and events, allowing the system to produce real-sounding transients. Traditional speech or music synthesis techniques, eg. linear predictive coding, formant synthesis, additive synthesis, frequency modulation or sampling methods, don't easily produce real-sounding transients. In physical models, finely detailed transients are achieved when new events interact with the reverberation of previous events. A particular articulation, played twice, may sound different as it interferes with a system that is already in motion. The state of the system at any given point in time is a result of complex interactions between external control parameters and recent system "memory." Due to this accurate transient behavior, dynamical system models are useful in a wide range of real-world simulations [Campbell].

This accuracy creates, in music synthesis, recognizable instruments. A wide range of acoustic cues contribute to the dynamic signature of an instrument in play, especially features that are co-varying. It doesn't matter particularly ***what*** is being performed. For instance, the model can produce tones or passages that are recognizably the sort produced on the instrument by unskilled players. Refining the performance of the control system is reminiscent of early exercises on the instrument. When something is amiss, the best approach has been to compensate the controls as if listening to the actual instrument. Tone quality, for example, might be improved by specifying something like, "...use more bow pressure at that point."

Music is performed on the cello synthesizer by a control system that replaces the cellist. It is gesture-based, and imitates the effect of the player's actions on the strings. The system also attempts to reproduce some of the interpretive functions of the player such as musical phrasing. Time-varying envelopes for the synthesis parameters are calculated by rules that correspond to basic gesture segments. It takes a few of these to form the complete envelope of a musical note.

The system operates from musical scores coded in common notation and enhanced with explicit markings for fingering (which string) and bowing. These markings are often added by players to their parts, indicating fingering and bowing choices for performance of a particular passage. Each succeeding pitch is associated with either a fingering change, bow change, or both. The old forms of tablature style scores for lute are reminiscent of this approach, in that they notated the time-varying placement of the hands on the strings.

The gestures that the hands can perform vary in complexity. The simplest items are those that initiate a bow stroke or finger a new pitch. More intricate operations are possible which result in coordinated activity across multiple strings, such as rolled (broken) chords. The system breaks each gesture into strings of smooth sequences of short envelope segments, for example, those resulting in string release, bow accleration, pitch sustain or vibrato. The larger gestures described by the musical notation, such as a note sequence, trill or slur, are formed by compounds of these "atomic" segments.

For each gesture in the score, sequences of segments are cued up in a time ordered list by the control system. In most cases this sequence contains one or more transition segments paired with a sustain. For example, a change of bow is comprised of a quick deacceleration, a re-attack and a sustain segment.