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OVERVIEW

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A major American contribution to present and future music exists in the application of a rapidly developing computer technology to the art and science of music. The extraordinary results already obtained have occurred in those few instances where scientists and musicians have taken the opportunity to bring their respective skills to bear on problems of common interest in a rich interdisciplinary environment. It is an example of cooperation, but more, an expression of the freedom of intellect and invention, where creative minds from diverse disciplines have joined in a common goal to produce fundamental knowledge which must be the source for new music, and to produce works of art which reflect the scientific-technological riches of the present.

At Stanford University, such cooperation has been commonplace over the past twelve years. In the beginning, progress was made in the analysis, synthesis, and psychology of sound perception in largely unsupported work by professors, graduate students, and staff members. In June of 1975, the Center for Computer Research in Music and Acoustics (CCRMA) was formed with funding provided jointly by the National Science Foundation for research and teaching in computer techniques of interactive sound production and the perception of timbre, and by a one-time grant from the National Endowment for the Arts for computing equipment for musical purposes. One aim of the Center was to establish an international facility where researchers, composers, and students could work with strong computer-based technological support.

The status of the facility as it now stands is a multi-faceted topic. As a musical instrument, the computer system is possibly the most flexible of all instruments. To speak of it as a conventional musical instrument, however, is somewhat misleading because the system is capable of simultaneously producing a large number of independent voices having arbitrary timbral characteristics. It is much more general than a conventional musical instrument in that it can generate any sound that can be produced by loudspeakers, modify and transform real sounds entered into the system by means of microphone and digital-to-analog converters, remember and modify articulated musical input, and simulate the location and movement of sounds in a variety of illusory reverberant spaces. Equally important, the facility is capable of serving a number of composers and researchers simultaneously, providing for each a direct control over the medium to a degree which was never before possible.

As a research tool, the computer has shown itself to be uniquely useful in generating precisely controlled stimuli for perceptual research. The analysis-synthesis techniques developed here allow for direct experimentation with the sounds of natural instruments. By modifying the sounds of these instruments in systematic ways, then testing the perceptual effects of the modifications, a great deal of information has been produced on the way musical timbre is perceived. Several papers and technical reports have been produced describing the techniques and results of this research.

RESEARCH

The research program at CCRMA crosses several disciplines and is highly interactive. The projects involved are digital recording and mixing, analysis of natural tones through digital signal processing, psychoacoustic research, advanced synthesis techniques, and the automatic production of musical scores. The distinctive aspect of the first four of these projects is that they find their roots at a level of sound complexity which is of fundamental interest in music composition and performance.

The main objectives are 1) to represent natural sound through high-quality recording - *digital recording, editing and processing*, 2) to capture through analysis a complete physical representation of a sound - *digital signal processing*, 3) to extract from the physical representation the information which has perceptual significance and thereby create a perceptual representation - *psychoacoustic research*, 4) to use the perceptual information in formulating efficient generalized models for the synthesis of various classes of sound - *advanced*

synthesis techniques, 5) the production of musical scores by graphical definition and manipulation of music-notational information and hard copy output - *automatic production of musical manuscripts.*

Digital recording, editing and processing - research directed by Rush: Using A/D and D/A converters designed and built by Moorer, this project is based on a highly flexible set of programs which allow detailed editing and mixing of digitized acoustical signals. Once edited the signals are analyzed for psychoacoustical research or processed directly for the purpose of musical composition. The implementation of this work represents the first all-digital recording studio designed for recording musical instruments.

Digital signal processing - research directed by Moorer: Powerful programs have been developed for the analysis of acoustical signals of arbitraty complexity. The programs yield a physical representation of the signals in three dimensions - time, amplitude, and frequency. In the case of quasi-periodic signals, analysis is straight forward; however, in the case of aperiodic signals analysis has been elusive. The program which is inclusive of the latter case, then, represents a major break-through in signal processing.

Psychoacoustic research - research directed by Grey: The three-dimensional physical representation of a signal is analyzed through subjective testing and scaling for the purpose of uncovering a perceptual representation. The process involves, first, the exclusion of any data in the physical representation which has insignificant or no perceptual effect. Inferences are then made and tested about the classification of a large number of different signals with the aim of achieving a multi-dimensional perceptual representation.

Advanced synthesis techniques - research directed by Chowning, Grey and Moorer: Using the most powerful synthesis techniques and programs, all developed at CCRMA, faithful replications of natural sounds are synthesized for the manipulation of perceptual data in the psychoacoustic research, for musical composition based on the natural sound, and for composition where natural sound is a rich point of departure for new and novel sounds.

Automatic production of musical manuscripts - research directed by Smith: A highly interactive program is well under development for the specification, storage, and manipulation of notational information required for the production of musical scores. The output of the program is a large scale page of music produced by the computer controlled plotter. This page is then photo-reduced for the final high quality copy. The format of the output page can range from a single line in 15th century notation to a full orchestral score in modern notation. The

program will also produce performance parts including transposition and page arrangement optimized for page turns. The implications of this research are great for future music publishing.

PUBLICATIONS

CCRMA publishes technical papers describing the results of the most recent research done at Stanford. Some of these papers have or will be published in national journals. The usefullness of CCRMA's internal publications is that research results can be obtained quickly by other researchers having a special interest. The Center has so far filled more than 1000 requests for these publications from this country and abroad at an average cost of $5.00 per paper to cover publication costs and mailing.

CCRMA PUBLICATIONS

Chowning, J.M., Grey, J.M., Moorer, J.A., and Rush, L., *Computer Simulation of Music Instrument Tones in Reverberant Environments.* STAN-M-1, 99pp, 1974.

Grey, J.M., *An Exploration of Musical Timbre.* STAN-M-2, 133pp, 1975.

Moore, F.R., *Real Time Interactive Computer Music Synthesis.* STAN-M-7, 109pp, 1977.

Moorer, J.A., *On the Segmentation and Analysis of Continuous Musical Sound by Digital Computer.* STAN-M-3, 165pp, 1975.

Moorer, J.A., *On the Loudness of Complex, Time-Variant Tones.* STAN-M-4, 18pp, 1975.

Moorer, J.A., *The Synthesis of Complex Audio Spectra by Means of Discrete Summation Formulae.* STAN-M-5, 23pp, 1975.

PAPERS PUBLISHED

Chowning, J.M., *The Simulation of Moving Sound Sources.* J. Audio Eng. Soc., 2-6, 1971. Reprinted in Computer Music Journal, Vol. 1, #3, 1977.

Chowning, J.M., *The Synthesis of Complex Audio Spectra by Means of Frequency Modulation.* J. Audio Eng. Soc. 21, 526-534, 1973. Reprinted in Computer Music Journal, Vol 1, #2, 1977.

Gordon, J.W., and Grey, J.M., *Perception of Spectral Modifications on Orchestral Instrument Tones.* Computer Music Journ. July, 1978.

Grey, J.M., *Multidimensional Perceptual Scaling of Musical Timbres.* Journal of the Acoustical Society of America, May 1977.

Grey, J.M., and Moorer, J.A., *Perceptual Evaluation of Synthesized Musical Instrument Tones.* Journal of the Acoustical Society of America, August 1977.

Grey, J.M., and Gordon, J.W., *Perceptual Effects of Spectral Modifications on Musical Timbres.* Journal of the Acoustical Society of America, May, 1978.

Grey, J.M., *Timbre Discrimination in Musical Patterns.* Journal of the Acoustical Society of America, August, 1978.

Grey, J.M., *Experiments in the Perception of Instrumental Timbre.* invited paper for the Bulletin of the Council for Research in Music Education, (in press) 1978.

Le Brun, Marc, *A Derivation of the Spectrum of FM with a Complex Modulating Wave.* Computer Music Journal, Vol 1, #4, 1977.

Le Brun, Marc, *Digital Waveshaping Synthesis.* Journal of the Audio Engineering Society, to appear.

Moore, F.R., *Table Lookup Noise for Sinusoidal Digital Oscillators.* Computer Music Journal, Vol. 1, #2, 1977.

Moorer, J.A., *The Optimum Comb Method of Pitch Period Analysis of Continuous Digitized Speech.* IEEE Trans. on Acoustics, Speech, and Signal Processing, Vol. ASSP-22, #5, October 1974, pp330-338.

Moorer, J.A., *The Use of the Phase Vocoder in Computer Music Applications.* presented at the 55th Convention of the Audio Engineering Society, October 29-November 1, 1976, available as Preprint number 1146 (E-1).

Moorer, J.A., *The Synthesis of Complex Audio Spectra by Means of Discrete Summation Formulae.* J. Audio Eng. Soc., Vol. 24, #9, November 1976, pp717-727.

Moorer, J.A., *Signal Processing Aspects of Computer Music - A Survey.* Invited Paper, Proceedings of the IEEE, July, 1977. Reprinted in Computer Music Journal, Vol. 1, #1, 1977.

Moorer, J.A. and Grey, J.M., *Lexicon of Analyzed Tones (Part I: A Violin Tone).* Computer Music Journal, Vol. 1, #2, 1977.

Moorer, J.A. and Grey, J.M., *Lexicon of Analyzed Tones (Part II: Clarinet and Oboe Tones).* Computer Music Journal, Vol. 1, #3, 1977.

Schottstaedt, W.G., *The Simulation of Natural Instrument Tones using Frequency Modulation with a Complex Modulating Wave.* Computer Music Journal, Vol 1, #4, 1977.

Smith, L.C., *Score, A Musician's Approach to Computer Music.* J. Audio Eng. Soc., Jan. 1972.

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

Smith, L.C., *Henry Cowell's 'Rhythmicana.'* Yearbook for Inter-American Research, 1973.

PAPERS IN PREPARATION

Grey, J.M., *Categorical versus Continuous Perception of Musical Timbre.* For the Journal of the Acoustical Society of America.

Loy, G., *Reference Manual and Tutorial for the Systems Concepts Digital Synthesizer.* STAN-M-6.

TEACHING

Instruction is carried out by the entire staff of CCRMA through the academic year including a Summer Workshop in Computer Music. The Computer Music Seminar, offered during three quarters of the year, is open to both advanced undergraduates and graduates. The seminar enrollment has been limited to 15 and the summer workshop to 20 because of the restricted computer time. In addition to the Computer Music Seminar students currently enrolled, there are 9 graduate students working on advanced projects.

The Computer Music Seminar is the introductory course to computer applications in music and assumes competence in music composition or a related field such as psychology or engineering. The course is divided into several streams including sound-synthesis techniques, signal processing, psychoacoustics, and programming. The aim is to develop in the students the required skills for successful use of the medium in composition and a sensitivity to the importance of related technical and perceptual issues.

The advanced graduate students work directly with the staff on the research projects. Two of these students are supported by the NSF grants. The remaining are supported by the graduate support program in the Department of Music.

As an addition to the normal teaching and research function during the academic year, the Center holds special summer workshops for musicians and scientists from outside the university. These workshops have been held every summer since 1969 with students attending from this country and abroad. In a four-week session, the students are able to learn basic computer programming, fundamentals of acoustics and psychoacoustics, and produce a composition. These summer sessions draw from 20 to 30 people each year. One of the pieces from a summer session was chosen for performance at the 1976 Computer Music Conference in Boston.

The Center can support a limited number of composers in residence. Every year, at least two composers, from Europe and the US, take advantage of this facility and use the computer system over an extended period of time to produce major compositions. One major composition resulting from this residence is a piece for computer generated tape with live orchestra and chorus, by Irmfried Radauer of Austria.

ASSOCIATIONS WITH OTHER CENTERS

The Center has served as a prototype computer music system. Several other installations have now chosen to pattern their computer systems after those of the center, thus allowing extensive program sharing so that the results of the research done at Stanford can be distributed throughout a number of basically compatible sites.

The relationship with IRCAM, Paris, the institute directed by Pierre Boulez, has developed as proposed by Boulez in 1974: *the two centers should have a strong interaction through the exchange of research ideas, results, and personnel.* In a special summer session in August, 1975, a team of thirteen people from IRCAM in Paris attended a ten-day intensive in the use of the computer. Those attending and using the computer included Pierre Boulez, Luciano Berio, Jean-Claude Risset, Max Mathews. Each visiting member made extensive use of the computer in a "hands-on" environment, receiving instruction in the usage of the computer. The members were encouraged to experiment with synthesis techniques. In September 1976, the CCRMA team participated in an IRCAM conference in Baden-Baden, Germany. As guest researcher at IRCAM during the spring and summer of 1977, Leland Smith adapted his music printing program to the IRCAM computer system. James A. Moorer has just returned from serving a two-year appointment, beginning in the fall of 1977, as Scientific Advisor to IRCAM, where he took part in directing the initial stages of the IRCAM research program. John Chowning has just returned from a 6 month stay using the IRCAM system as a compositional tool and Leland Smith has just left for a visit to adapt some of his programs to the IRCAM computer system.

CCRMA has aided the Hochschule fur Musik and the University of Hamburg in the equipment and research planning for a major computer music center patterned after the Stanford center proposed to begin in 1978. The support for this center is expected to be 3,000,000 DM from the DFG (German national research foundation). Members of the CCRMA team have been asked to direct the center in its initial stages.

DEMONSTRATIONS, CONFERENCES, AND PERFORMANCES

Throughout the academic year, CCRMA gives a monthly demonstration which is open to the public, but not widely publicised. The average attendance is ca. 50 people. Each of the team presents his special research area explaining its relationship to the musical goals. Compositions utilizing the research results are presented during the two hour presentation. These

demonstrations have been very successful and are a very efficient means of communicating the center's work to the outside world.

Since 1974, members of CCRMA have given or will give papers and lectures at a number of conferences and colloquia in the U.S. and abroad.

Grey, Lecture, Center for Music Experiment, U.C. San Diego, Apr. 1974.
Moorer, Colloquium, Carnegie-Mellon University, Nov. 1974
Rush, Colloquium, Center for Music Experiment, U.C. San Diego, Mar. 1975.
Chowning, IRCAM Conference, La Rochelle, France, July 1975.
CCRMA group, Course for IRCAM group, Stanford, Aug. 1975.
Chowning, Grey and Moorer, one week course for DAAD, Berlin, Sept. 1975.
Moorer and Grey, Computer Music Conference, Michigan State Univ., Oct. 1975.
Moorer, Colloquium, University of Georgia, Feb. 1976.
Chowning, Physics Colloquium, Calif. Institute of Technology, Feb. 1976.
Chowning, Computer Music Presentation with Pierre Boulez, New York, Mar. 1976.
Moorer, Colloquium, Center for Music Experiment, U.C. San Diego, June 1976.
Chowning, Grey, Moore, Moorer and Rush, IRCAM Conference, Baden-Baden, Sept. 1976.
Moorer and Rush, Audio Engineering Society Convention, New York, Oct. 1976.
Moorer and Rush, Computer Music Conference, MIT, Oct. 1976.
Moorer, Colloquium, Boston University, Oct. 1976
Chowning, Colloquium, Calif. Institute of Technology, Nov. 1976.
Chowning and Smith, Computer Arts Society, Los Angeles, Feb. 1977.
Chowning, Lecture, Columbia University, Feb. 1977.
Moorer and Rush, Audio Engineering Society Convention, Los Angeles, May. 1977.
CCRMA group, IRCAM Psychoacoustic Conference, Paris, July 1977.
CCRMA group, 1977 International Computer Music Conference, San Diego, Oct. 1977.
Chowning, lecture and workshop, Tanglewood, Aug. 1978.
Chowning, lecture and workshop, Wittenberg Univ., Sept. 1978.

Performances of compositions from CCRMA have been numerous in the U.S. and abroad.

Chowning, *Sabelithe*, a computer-generated quadraphonic tape.

Apr.	1972	Stanford	Mar.	1973	Marseille
June		Vancouver	Mar.		Utrecht
July		Berlin	Sep.	1974	Berlin
Aug.		Darmstadt	Apr.	1975	Bourges
Nov.		Michigan State	Aug.	1976	Stanford
Feb.	1973	Stockholm	Feb.		CalTech

Chowning, *Stria*, a computer-generated quadrophonic tape.
Commissioned by IRCAM for presentation in Luciano Berio's exhibition of electronic music. Premiere: IRCAM, Paris, Oct. 1977.

Oct.	1977	IRCAM, Paris	Oct.	1978	Urbana-Champagne, Ill.
Oct.		U.C.,San Diego	Nov.		Stanford
Nov.		Berkeley			

Chowning, *Turenas*, a computer-generated quadraphonic tape.

Apr.	1972	Stanford	Oct.		Metz
June		Vancouver	Feb.	1976	CalTech
July		Berlin	Feb.		Colgate Univ.
Aug.		Darmstadt	Feb.		Utica, N.Y.
Nov.		Michigan State	Mar.		Melbourne
Feb.	1973	Stockholm	Apr.		Syracuse, N.Y.
Mar.		Marseille	June		Binghampton, N.Y.
Mar.		Utrecht	Aug.		Stanford
Oct.		De Anza, Ca.	Oct.		Univ. of Las Vegas
Jan.	1974	GRM, Paris	Oct.		Univ. of Lousiville
Sep.		Berlin	Oct.		Richmond, Ind.
Oct.		Fest. d'Automne, Paris	Oct.		Winchester, Va.
Feb.	1975	Elec. Mus. Week, Basel	Oct.		Univ. of Virginia
Apr.		Bourges	Nov.		Harvard
July		La Rochelle	Feb.	1977	New York
Aug.		Avignon	Apr.		IRCAM, Paris
			Oct.		U.C.,San Diego
			Nov.		Berkeley
			May	1978	Glasgow, Scotland

Cowell/Smith, *Rhythmicana*, for orchestra with computer-generated stereo tape.
Computer realization by Smith of Cowell's part for Rhythmicon (an early electronic instrument now in the Smithsonian Institution).

Dec.	1971	Stanford Symphony, Sandor Salgo cond.
Aug.	1974	Tanglewood Orchestra, Gunther Schuller cond.
May	1975	Buffalo Philharmonic, Michael Tilson Thomas cond.

Erickson/Grey, *Loops*, a computer-generated stereo tape.
Computer realization by Grey of R.E. Erickson's composition for unspecified instruments.

Apr.	1974	Mich. State Univ.	Oct.		Univ. of Lousiville
Feb.	1976	Colgate Univ.	Oct.		Richmond, Ind.
Feb.		Utica, N.Y.	Oct.		Winchester, Va.
Apr.		Syracuse, N.Y.	Oct.		Univ. of Virginia
Jun.		Binghampton, N.Y.	Oct.	1977	U.C.,San Diego
			Nov.		Berkeley

Kirk, *Hues in Blue*, for tape and bassoon.

	1978	New York.
	1979	Los Angeles Stanford.

Kirk, *Desert Dance*, computer-generated stereo tape.

Feb.	1979	Dallas.

Kirk, *Passages - Dreams and Nightmares*, Four-channel computer-generated tape.

Nov.	1978	Stanford.	Feb.	1979	Stanford.
Dec.		Los Angeles			

Kirk, *War of the Mellinnium*, computer-generated stereo tape.
This is the soundtrack for an animated film on space exploration, produced and written by Hommel, an independent film producer.
Dec. 1978.

Kirk, *Trident*, A 4-channel computer tape.

Feb.	1978	New York.	Jul.		Chicago.

McNabb, *Dreamsong*, computer-generated stereo tape.
1978 ISCM Composers Competition winner

Aug.	1978	Marin, Ca.	Nov.		Northwestern Univ.
Oct.		Univ. of Iowa	Nov.		Stanford Univ.
Jan.	1979	New York	Apr.	1979	Los Angeles.

Moorer, *Perfect Days*, computer generated stereo tape.
Study for first part of 5-part piece using computer techniques for modification of speech and music. This study features human speech and flute.

Oct.	1977	U.C.,San Diego	Oct.	1978	Marin, Ca.
Nov.		Berkeley	Nov.		Stanford

Moorer, *Lions are Growing*, computer generated stereo tape.
Study for second part of 5-part piece using computer techniques for modification of speech and music. This study features human speech.

Oct.	1978	Marin, Ca.	Nov.		Stanford

Rush, *A Little Traveling Music*, for amplified piano with computer-generated quadraphonic tape.
Recorded on Serenus Records. In press, General Music Co., Dobbs Ferry, N.Y.
Dwight Peltzer, pianist:

Apr.	1974	New York	July		Univ. of Indiana
Feb.	1976	Univ. of Utah	Nov.		York Univ., U.K.
Feb.		C.W. Post College	Nov.		Bradford Univ., U.K.
Feb.		Washington, D.C.	Apr.	1977	IRCAM, Paris
Feb.		Colgate Univ.	Oct.		U.C.,San Diego

Rush, *Song and Dance*, for orchestra with computer-generated quadraphonic tape.
Commissioned by Seiji Ozawa and the San Francisco Symphony Orchestra.
San Francisco Symphony Orchestra, Seiji Ozawa cond., San Francisco, December 3-6, 1975; national radio broadcast, National Public Radio, November 1976.
St. Louis Symphony Orchestra, Leonard Slatkin cond., St. Louis, December, 1977.
Minnesota Orchestra, Leonard Slatkin cond., Minneapolis, April, 1978.
Also scheduled for performance by the following orchestras: Cincinatti, Detroit (Feb. 1978), Pittsburgh, and National.

Schottstaedt, *Sandcastle*, computer-generated quadraphonc tape.

May	1978	Bourges, France	Oct.		Urbana-Champagne, Ill.
Aug.		Stockholm	Nov.		Stanford
Aug.		San Francisco, Ca.			
Feb.	1979	Bourges, France			

Schottstaedt, *Sinfornia for Computer*, computer-generated quadraphonc tape.

Oct.	1977	U.C.,San Diego	Sept.	1978	E. Lansing, Mich.
Nov.		Berkeley			

Schottstaedt, *The Gong-Tormented Sea*, computer-generated quadraphonc tape.

Nov	1978	Stanford

Schottstaedt, *The New Music Liberation Army Computer Chorus and Marching Band*, computer-generated quadraphonic tape.

Aug.	1978	San Francisco, Ca.	Aug.		Stockholm

Schottstaedt and McNabb, Music for *Mars in 3-d*, NASA film on Viking project, computer generated stereo tape.

Mar.	1979	Stanford, Ca.	Apr.		various cities in U.S.

Smith, *Machines of Loving Grace*, for bassoon and narrator with computer-generated tape.

Oct.	1970	Palo Alto	Nov.	1973	New York
Apr.	1971	Mich. State Univ.	Jan.	1975	Philadelphia

Smith, *Rhapsody for Flute and Computer*, flute and computer-generated stereo tape. Published in *Schirmer Scores, a repertory of Western music*, G. Schirmer & Co., 1975.

Apr.	1971	Palo Alto	May		Santa Rosa, Ca.
May		U.C.,San Diego	Apr.	1976	Las Vegas
May	1972	Zagreb	Jan.		So. Carolina
June		Paris	June		Conn. State College
Nov.		Colgate Univ.	July		Peabody Conservatory
Apr.	1973	Reno	July		Concordia College
Nov.	1974	Philadelphia	Apr.	1977	IRCAM, Paris

Wieneke, *Oracle - 4am*, computer-generated stereo tape

Aug.	1978	Marin, Ca.	Nov.	Northwestern Univ.
Oct.		Urbana-Champagne, Ill.	Nov.	Stanford