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Stanford Center for Computer Research in Music and Acoustics (CCRMA)

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Contents

1. Introduction

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

Areas of ongoing interest at CCRMA include: Applications Hardware, Applications Software, Synthesis Techniques and Algorithms, Physical Modeling, Real-Time Controllers, Signal Processing, Digital Recording and Editing, Psychoacoustics and Musical Acoustics, Music Manuscripting by Computer, Composition, and Real-Time Applications.

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. Departments actively represented at CCRMA include Music, Electrical Engineering, Mechanical Engineering, Computer Science, and Psychology.

Center activities include academic courses, seminars, small interest group meetings, summer workshops and colloquia. Concerts of computer music are presented several times each year 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 periodically.

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 late Doreen B. Townsend, Walter Hewlett, the California Arts Council, the Ann and Gordon Getty Foundation, the Mellon Foundation, the National Endowment for the Arts, the National Science Foundation, the Rockefeller Foundation (for artists-in-residence), the System Development Foundation, Apple Computer, Bio Control, Crystal Semiconductor, E-mu, Dynacord, ITRI CCL Taiwan, Korg, Matsushita, Media Vision, NEC, NeXT Inc., Opcode, Rockwell Internaional, Roland, Symbolics, Xerox Palo Alto Research Center, Yamaha, Zeta Music Partners, and private gifts.

2. Facilities

CCRMA is located on the Stanford University campus in a building that was refurbished in 1986 to meet its unique needs. The facility includes a large quadraphonic experimental space with adjoining control room/studio, an all-digital recording studio with adjoining control room, a MIDI-based small systems studio, several work areas with workstations, synthesizers and speakers, a seminar room, an in-house reference library, classrooms and offices. The building has been wired so that any office or workspace can connect with the workstation network. A gateway connects the workstations to the campus at large and also to national and international networks. A description of the hardware and software environment follows below.

The CCRMA hardware environment consists of an Ethernet network of workstations running the NextStep operating system (both NeXTs and Intel based PCs) and Macintosh computers. Digital signal processing is possible on the NeXT computers, both via built-in Motorola 56001 DSP hardware and on three Ariel Quint Processor boards which contribute five additional 56001 processors each. The Macintosh systems also provide DSP via Digidesign Sound Accelerator boards. MIDI input and output are supported from Macintosh and NeXT computers. Digital audio processors include a Studer-Editech Dyaxis II system which can convert all popular digital audio formats as well as store and edit audio digitally, a Sony PCM-1610 3/4" video PCM system for mastering Compact Disks, several Singular Solutions analog and digital audio input systems for the NeXTs, and several Panasonic and Sony DAT recorders. Text and graphics are handled by an HSD color scanner on the NeXT system and by two NeXT Laser printers and an Apple Laserwriter 630 Pro.

The MIDI-based systems include various Macintosh computers with Yamaha, Roland and Korg equipment including Yamaha DX, TX, SY, TG and VL synthesizers, KX88 keyboard controller, Korg WaveStations, an E-mu Systems Emulator III sampler, and digital delays and reverberation.Other equipment available includes IVL pitch trackers, a Buchla Lightning MIDI controller, a Mathews Radio Drum controller, a JL Cooper MIDI patcher, Akai 32 channel MIDI-controlled audio patchbay and drum machines from Yamaha and Roland.

Studio recording equipment includes a 24 track mixer, an 8 track TEAC analog recorder, a Yamaha DMR8 digital recorder and mixing console, a TEAC 8 track digital recorder, various signal processing devices, Westlake monitor speakers and an assortment of high quality microphones.

3. Teaching

CCRMA is a part of the Music Department at Stanford University. Classes and seminars taught at the center are open to registered Stanford students and visiting scholars. The facility is also available to registered Stanford students and visiting scholars for research projects which coincide with ongoing work at the center.

Prospective graduate students especially interested in the work at CCRMA should apply to the degree program at Stanford most closely aligned with their specific field of study, i.e., Music, Computer Science, Electrical Engineering, Psychology, etc. Graduate degree programs offered in music are the DMA in Composition, and the PhD in Computer-Based Music Theory and Acoustics. Acceptance in music theory or composition is largely based upon musical criteria, not knowledge of computing. Admission requirements for degree programs can be obtained directly from each particular department. CCRMA does not itself offer a degree.

The Music Department offers an undergraduate major in Music, Science, and Technology. The specialization in Music, Science and Technology is designed for those students with a strong interest in the musical ramifications of rapidly evolving computer technology and digital audio and in the acoustic and psychoacoustic foundations of music. The program entails a substantial research project under faculty guidance and makes use of the highly multi-disciplinary environment at CCRMA. This program can serve as a complementary major to students in the sciences and engineering. Requirements for the undergraduate major are available from the Stanford Music Department.

Courses offered at CCRMA include:

♦ **Music 120. Introduction to Composition and Programming Using MIDI-Based Systems** - Composition projects demonstrate participant's own software for voicing and controlling MIDI synthesis.

♦ **Music 151. Psychophysics and Cognitive Psychology for Musicians** - Basic concepts and experiments relevant to use of sound, especially synthesized, in music. Introduction to elementary concepts; no previous background assumed. Listening to sound examples important. Emphasis on salience and importance of various auditory phenomena in music.

♦ **Music 154. Introduction to Computer Music** - Survey of recent works and computer-based techniques.

♦ **Music 192. Theory and Practice of Recording**

> **192A. Foundations of Sound Recording Technology** - Topics: elementary electronics, physics of transduction and magnetic recording of sound, acoustic measurement techniques, operation and maintenance of recording equipment, recording engineering principles.
>
> **192B. Advanced Sound Recording Technology** - Topics: digital audio including current media, formats, editing software, and post-processing techniques. Also, microphone selection and placement, grounding and shielding techniques, noise reduction systems and advanced multi-track techniques.
>
> **192C. - Session Recording** - Independent engineering of recording sessions.

♦ **Music 220. Computer-Generated Music**

> **220A. Fundamentals of Computer-Generated Sound** - Introduction to computer--sound generation, composition, acoustics, and computer programming.
>
> **220B. Compositional Algorithms, Psychoacoustics, Spatial Processing & Digital Audio Signal Processing** - Use of high-level programming language as a compositional aid in creating musical structures. Studies in the physical correlates to auditory perception, and review of psychoacoustic literature. Simulation of a reverberant space and control of the position of sound within the space.

19937

Introduction into digital filtering theory, spectrum analysis, and audio signal processing techniques.

220C. Research - Research projects in composition, psychoacoustics, or signal processing.

♦ **Music 242. Seminar: Topics in Computer Music** - Various topics according to interest.

♦ **Music 320. The Discrete Fourier Transform (DFT)** - Fundamentals of spectrum analysis for discrete-time signals, with emphasis on digital audio applications. Topics: complex numbers, signal theory, the DFT, fundamental Fourier theorems, and basic Fourier pairs.

♦ **Music 420. Applications of the Fast Fourier Transform (FFT)** - Spectrum analysis and signal processing using the FFT, emphasizing audio applications. Topics: FFT, cyclic and acyclic convolution, zero padding, spectrum analysis of deterministic and stochastic signals, the overlap-add and filterbank-summation methods for short-time Fourier analysis, modification, and resynthesis; transform coders, tracking sinusoidal peaks across FFT frames, and modeling time-varying spectra as sinusoids plus filtered white noise using the FFT for both analysis and resynthesis.

♦ **Music 421. Signal Processing Methods in Musical Acoustics** - Computational models of musical instruments in the wind and string families based on physically accurate mathematical models. Models are designed to capture the ''audible physics" of musical instruments using computationally efficient algorithms and signal processing techniques. Topics: mass-spring systems, discrete-time simulation, the one-dimensional wave equation, traveling waves, wave impedance, signal energy and momentum, lumping of losses and dispersion, simulation of one-dimensional waveguides such as vibrating strings and woodwind bores, allpass techniques for tuning and stiffness simulation, scattering theory, lattice/ladder digital filter theory, and complete models of winds and strings using delay lines, scattering junctions, low-order digital filters, and nonlinear junctions implementing oscillation sources such as bow--string and reed--bore couplings. Techniques are outlined for calibrating model parameters to recordings of real instruments.

CCRMA also offers a series of ***summer workshops***. Courses offered recently were:

♦ **Introduction to Yamaha VL Synthesizers and Algorithmic Composition in Common LISP** - This course covers the basic principles and techniques of algorithmic composition. Sound synthesis as used in course examples include MIDI, the (realtime) Music Kit and (non-realtime) Common Lisp Music and Common Music Notation. Yamaha synthesizers used in the course will include the VL-1 and SY-77.

♦ **Advanced Projects in Algorithmic Composition** - A continuation of the above course, emphasis is placed on developing programming skills while working on individual projects.

♦ **Intensive Music/Audio Digital Signal Processing and Spectral Modeling Synthesis** - This course covers analysis and synthesis of music signals based on physical and spectral models.

♦ **Music Printing with Small Computers Using SCORE** - This course covers the details of the use of the SCORE software program for the creation of publication--quality music typography on PC campatible computers. Emphasis is placed on individual projects.

4. Compositional Software

The CCRMA software has been developed over a twenty-year period, and consists of a vast set of programs and system tools for editing, viewing, synthesizing, and analyzing sound. Since the late 60's most of the work in composition at CCRMA has been done in a software environment which evolved from the Music V program originally developed at Bell Labs by Max Mathews and his research group. Much of the software was originally written in SAIL, a sophisticated Algol-like language for use on the previous mainframe computer and has been ported to the new workstation environment consisting of PC's running the NEXTSTEP operating system.

The programs currently in use are Common Lisp Music (CLM), for instrument compiling; and Common Music (CM), STELLA, and DMIX, for compositional programming. Common Music (CM) and STELLA (written in Common Lisp by Rick Taube), are software packages that can write scores by listing parameters and their values, or by creating algorithms which then automatically determine any number of the parameters' values. Common Music (CM) can write scores in several different syntaxes (currently CLM, CMN, MusicKit, MIDI, CSound and Paul Lansky's real-time mixing program RT). The scores can then be rendered on workstations using any of the target synthesis programs. For example, CLM (Common Lisp Music, written by Bill Schottstaedt) is a widely used and fast software synthesis and signal processing package that can make use of multiple Motorola 56001 DSP's. CCRMA has also become the maintainer and distributor of NeXT's MusicKit, a real time toolkit for computers running NEXTSTEP that merges the MIDI and real time synthesis paradigms and can also be the target of Common Music generated scores.

Recent projects in music recognition, audio, signal processing, acoustics, psychoacoustics and physical modeling have been developed in languages native to the workstations, primarily Common Lisp, Objective-C, and Smalltalk. A graphical environment for realtime DSP research, SynthBuilder, is currently under development. Several composers have realized pieces utilizing the results of these research projects and also have made extensive use of MIDI equipment, especially Yamaha synthesizers controlled via Macintosh computers. The acquisition of a Dyaxis II Digital Audio Processor and several Macintosh II computers has brought renewed interest in real-time control and computer-based ''musique concrete.''

5. Research

Computer music is inherently a multi-disciplinary field. Accordingly, the areas of research at CCRMA include a wide variety of topics such as psychoacoustics, digital synthesis, signal processing, interactive composition, MIDI performance, graphics, machine recognition, physical modeling, and real-time controllers.

Those contributing to the research effort at CCRMA include graduate students, faculty, staff, and guests. The following is a summary of current research projects. A more complete overview of research projects at CCRMA is available upon request.

Music composition software development continues (Bill Schottstaedt, Common Lisp Music and Common Music Notation; Rick Taube, Common Music / Stella: A Music Composition Language in Common Lisp and CLOS; Fernando Lopez Lezcano, A Dynamic Spatial Sound Movement Toolkit; Daniel Oppenheim, DMIX)

New systems have been created for rapid prototyping of signal processing and sound synthesis algorithms (Julius Smith, David Jaffe, The CCRMA MusicKit and DSP Tools Distribution; Nick Porcaro, The Design of SynthBuilder: A Graphical SynthPatch Development Environment for NeXTSTEP).

Research in physical modeling of musical instruments and reverberant environments continues to grow (Julius Smith, Digital Waveguide Modelling of Acoustic Signals; R. J. Fleck, Waveguide Reverberators and Real-Time Implementations, Davide Rocchesso, Feedback Delay Networks; Scott Van Duyne, Julius Smith, The 2-D Digital Waveguide Mesh, The Wave Digital Hammer; Brent Gillespie, Scott Van Duyne, Julius Smith, The Haptically Controlled Waveguide Piano; Perry Cook, Synthesis of the Singing Voice Using a Physically Parameterized Model of the Human Vocal Tract; Chris Chafe, Adding Pulse Noise to Wind Instrument Physical Models; David Berners, Physical Modelling of Brasses; Gary Scavone, Synthesis and Research on Reed Driven Woodwind Instruments with Particular Emphasis on the Saxophone; John Pierce, Scott Van Duyne, A passive Nonlinear Filter for Physical Models; Wen-Yu Su, Physical Modelling of Music Instruments using Neural Networks).

Innovative signal processing approaches are being studied (Julius Smith, FFT-Based Signal Processing and Spectral Modelling Synthesis; Avery Wang, Instantaneous and Frequency Warped Signal Processing Techniques for Pitch Tracking and Source Separation, Fast Linear Phase FIR Filter Theory and Design; Scott Levine, Time-Frequency Analysis of Audio).

Much attention is currently being given to the problem of human control of computers and sound synthesis algorithms running on computers (Chris Chafe, Perry Cook, Real Time Controllers for Physical Models; Perry Cook, Dexter Morrill, Ongoing Work in Brass Instrument Synthesizer Controllers; Timothy Stilson, Performer Oriented Brass Instrument Synthesis and Control; Sile O'Modhrain, Brent Gillespie, Haptic User Interfaces for the Blind; Brent Gillespie, The Touchback Keyboard; Max Mathews, The Stanford Radio Drum, The New Conductor Program; Fernando Lopez Lezcano, PadMaster: an Improvisation Environment for the Radio Drum; David Jaffe, The Computer Extended Ensemble; Atau Tanaka, Biocontrol Interfaces as Musical Instruments; Bill Putnam, Real-Time Control Using Biological Signals).

In the psychoacoustics area, work continues in sound perception research and its applications (Steve Trautmann, Applying Psychoacoustic Phenomenon to the Coordination of Large Speaker Arrays; Jan Chomyszyn, Distance of Sound in Reverberant Fields; John Pierce, Pitch and Repetition Rate Perception; Enrique Moreno,Embedded Pitch Spaces and the Question of Chroma;Daniel Levitin, Musical Perception and Memory, Statistical Models for Phychoacoustic Research; Roger Shepard, Perry Cook, Daniel Levitin, Psychological Representation of English Vowel Sounds; Albert Bregman, The Perceptual Organization of Sound).

In addition, CCRMA now houses two archival research libraries in electroacoustic music and in acoustics (Max Mathews, Marcia Bauman, The International Digital Electroacoustic Music Archive; Max Mathews, Gary Scavone, The Catgut Acoustical Society Research Library).