CENTER FOR COMPUTER RESEARCH IN MUSIC AND ACOUSTICS
DEPARTMENT OF MUSIC, STANFORD UNIVERSITY
REPORT NO. STAN-M-112

CCRMA OVERVIEW

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EDITED BY
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Contents

1 General Information

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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: Composition, 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, 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, visiting researchers and composers, and industrial associates. Departments actively represented at CCRMA include Music, Electrical Engineering, Mechanical Engineering, 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, including exchange concerts with area computer music centers and 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, the Journal of the Acoustical Society of America, and various transactions of the Institute of Electrical and Electronic Engineers (IEEE). Compositions are presented in new music festivals and radio broadcasts throughout the world and have been recorded on cassette, LP, and compact disk.

CCRMA is affiliated with the Center for Computer Assisted Research in the Humanities (CCARH), also located at Stanford. CCARH conducts research on constructing computer databases for music, and on creating programs that allow researchers to access, analyze, print, and electronically perform the music. This focus is complementary to research at CCRMA in several ways.

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, ATR Human Information Processing Research Labs, Aureal Semiconductor, Bio Control, Crystal Semiconductor, Digidesign, Dynacord, E-mu, Fast Mathematical Algorithms and Hardware, Fender Musical Instruments Corporation, Hewlett Packard, IBM Computer Music Center, Interval Research, ITRI CCL Taiwan, Kind of Loud Technologies, Korg, Matsushita, Media Vision, McDSP, NEC, NeXT Computer, Nokia Group, NTT Communication Science Laboratories, Opcode Systems, Philips Semiconductors, Rockwell International, Roland, Symbolics, Texas Instruments, Xerox Palo Alto Research Center, Yamaha, Young Chang R&D Institute, Zeta Music Partners, and private gifts.

2 Roster

For the latest information on the denizens of CCRMA, see their individual home pages. Below is a tabulation organized by group. The home page URL for each person is constructed from the login name as "http://www-ccrma.stanford.edu/~login".

2.1 Staff and Faculty

Login	Name	Position
oded	Oded Ben-Tal	Concert Organizer
brg	Jonathan Berger	Associate Professor of Music
mab	Marina Bosi	Consulting Professor of Music
cc	Chris Chafe	Professor of Music, CCRMA Director
jc	John Chowning	Professor of Music, Emeritus
vibeke	Vibeke Cleaver	Administrative Associate
n/a	Walter B. Hewlett	Consulting Professor of Music
mortimer	Richard Humphrey	Assistant System Administrator
jay	Jay Kadis	Audio Engineer / Lecturer
nando	Fernando Lopez-Lezcano	System Administrator / Lecturer
mvm	Max V. Mathews	Professor of Music (Research)
gary	Gary Scavone	Technical Director / Lecturer
bil	William Schottstaedt	Research Associate
tricia	Tricia Schroeter	Administrative Associate
esf	Eleanor Selfridge-Field	Consulting Professor of Music
malcolm	Malcolm Slaney	Lecturer
jos	Julius O. Smith III	Associate Professor, Music and Electrical Engineering
lcs	Leland Smith	Professor of Music, Emeritus
verplank	Bill Verplank	Researcher and Lecturer

2.2 Engineering Graduate Students

Login	Name	Degree Program
rje	Ryan Cassidy	PhD Electrical Engineering
pj97	Pamornpol (Tak) Jinachitra	PhD Electrical Engineering
arvindh	Arvindh Krishnaswamy	PhD Electrical Engineering
jacobliu	Yi-Wen Liu	PhD Electrical Engineering
asmaster	Aaron Steven Master	PhD Electrical Engineering
harv23	Harvey Thornburg	PhD Electrical Engineering
jhw	Jeff Walters	PhD Electrical Engineering

2.3 Music PhD Graduate Students

Login	Name	Degree Program
cburns	Christopher Burns	PhD Computer-Based Music Theory and Acoustics
pchordia	Parag Chordia	PhD Computer-Based Music Theory and Acoustics
lonny	Lonny Chu	PhD Computer-Based Music Theory and Acoustics
pdelac	Patricio de la Cuadra	PhD Computer-Based Music Theory and Acoustics
gurevich	Michael Gurevich	PhD Computer-Based Music Theory and Acoustics
pph	Patty Huang	PhD Computer-Based Music Theory and Acoustics
kglee	Kyogu Lee	PhD Computer-Based Music Theory and Acoustics
randal	Randal Leistikow	PhD Computer-Based Music Theory and Acoustics
unjung	Unjung Nam	PhD Computer-Based Music Theory and Acoustics
cnichols	Charles Nichols	PhD Computer-Based Music Theory and Acoustics
norton	Jonathan Norton	PhD Computer-Based Music Theory and Acoustics
juan	Juan Carlos Pampin	PhD Computer-Based Music Theory and Acoustics
rsegnini	Rodrigo Segnini	PhD Computer-Based Music Theory and Acoustics
serafin	Stefania Serafin	PhD Computer-Based Music Theory and Acoustics
tamara	Tamara Smyth	PhD Computer-Based Music Theory and Acoustics
leigh	Leigh VanHandel	PhD CCRMA-cology
rswilson	Scott Wilson	PhD Computer-Based Music Theory and Acoustics
woony	Woon Seung Yeo	PhD Computer-Based Music Theory and Acoustics

2.4 Music MA/MST Graduate Students

Login	Name	Degree Program
jeffyb	Jeff Bernstein	MA Science and Technology
kirstinc	Kirstin Cummings	MA Science and Technology
gzh	Gregor Hanuschak	MA Science and Technology
dfl	David Lowenfels	MA Science and Technology
jmccarty	John McCarty	MA Science and Technology
shiraiwa	Hiroko Shiraiwa	MA Science and Technology
quasar	Timothy Pearce Stonehocker	MA Science and Technology (co-term)
vwoo	Vivian Woo	MA Science and Technology
bzimring	Bradley Zimring	MA Science and Technology

2.5 Visiting Scholars

Login	Name	Home Affiliation	Term
oded	Oded Ben-Tal	Visiting Scholar, Israel	through 6/2003
ching	Ching-Wen Chao	Visiting Scholar, Taiwan	through 7/2003
peer	Peer Landa	Composer, Norway	ongoing
senylee	Seungyon Lee	Visiting Scholar, S. Korea	through 9/2003
juanig	Juan Reyes	Composer/Researcher, Columbia	ongoing
ptraub	Peter Traub	Visiting Researcher, USA	through 6/2003
tzeng	Shing-Kwe Tseng	Visiting Scholar, Taiwan	through 1/2003

2.6 Undergraduate Students

Login	Name	Degree Program
gha04	Gha-is Abduljaami	Music, Science and Technology
dpboat	Daniel Patrick Boatman	Music, Science and Technology
danielsm	Michelle Daniels	Music, Science and Technology
sandyg	Sanford Greenfield	Music, Science and Technology
djack	Damondrick Jack	Music, Science and Technology
eking	Eric Kingsley	Music, Science and Technology
grace	Grace Leslie	Music, Science and Technology
rlugo	Robert Lugo	Music, Science and Technology
ericao	Erica Wayching O'Young	Music, Science and Technology
ods	Owen Smith	Music, Science and Technology
jtrevino	Jeffrey Treviño	Music, Science and Technology
dwalling	Daniel Walling	Music, Science and Technology
zarrillo	Katerina Michela Zarrillo	Music, Science and Technology

2.7 Recent Graduates

Login	Name	Degree Program
oded	Oded Ben-Tal	DMA Composition (2002)
mburtner	Matthew Burtner	DMA Composition (2002)
castelli	Luigi Paolo Castelli	MA Science and Technology (2002)
ching	Ching-Wen Chao	DMA Composition (2002)
duruoz	Cem Duruoz	MA Composition (1996)
be	Brook Eaton	MA Science and Technology (2000)
colfax	Timothy Colfax Hankins	MA Science and Technology (2002)
vickylu	Hui-Ling Lu	PhD Electrical Engineering (2002)
dmerrill	David Merrill	MS Computer Science (2002)
jdmiller	Joel David Miller	MA Science and Technology (2002)
carmenng	Carmen Ng	MA Science and Technology (2002)
cotto	Chris Otto	MA Science and Technology (2002)
mromaine	Matthew Romaine	MA Science and Technology (2002)
anrew	Andrew Roper	MA Science and Technology (2002)
bschiett	Bert Schiettecatte	MA Science and Technology (2002)
senylee	Seungyon Lee	DMA Composition (2002)
jhw	Jeff Walters	MA Science and Technology (2002)
carrlane	Carr Lane Wilkerson	MA Science and Technology (2002)

2.8 Collaborators

Login	Name	Affiliation
prc	Perry R. Cook	Associate Professor, Computer Science and Music, Princeton University
dhuron	David Huron	Professor, School of Music, Ohio State University
daj	David Jaffe	Composer/Engineer
levitin	Daniel Levitin	Assistant Professor of Psychology and Music, McGill University
n/a	James A. Moorer	Senior Computer Scientist, Adobe Systems
dex	Dexter Morrill	Professor, Composition, Colgate University
xjs	Xavier Serra	IUA-MTG, Universitat Pompeu Fabra, Barcelona, Spain
hkt	Rick Taube	Assistant Professor, Composition, University of Illinois

2.9 Industrial Affiliates

Company	Address
Digidesign	Palo Alto, CA
Universal Audio / Kind of Loud Technologies	Santa Cruz, CA
McDSP	Palo Alto, CA
Nokia Group	Helsinki, Finland
NTT Communication Science Laboratories	Kanagawa, Japan
Yamaha Corporation	Hamamatsu-shi, Japan

3 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 space with multichannel sound for teaching, concerts, and acoustic experimentation, an adjoining control room/studio, a digital multi-track recording studio with adjoining control room, two additional studios with digital editing facilities, 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 underlying network. A gateway connects the network to the campus at large and also to the Internet. A description of the hardware and software environment follows below.

The CCRMA computing environment is supported by more than 40 machines that include single and dual processor Intel and AMD based PCs running Linux (with some of the older ones still dual-booting Linux and NEXTSTEP), a few Silicon Graphics workstations, NeXT workstations (for old time's sake) and PowerPC Macintosh computers. All machines are connected through a switched high speed backbone and several servers provide shared services and resources to all computers in a way that is transparent to the users. A high speed connection to the Stanford University Network (SUNET) provides connectivity with the rest of the world, including direct access to the new Internet 2 high speed network. Soundfile manipulation and MIDI input and output are supported on all platforms. Digital multichannel playback is supported on some Linux workstations and on the Macs through several Pro Tools systems. Almost all Linux workstations have high quality 24bit/96KHz soundcards installed. Digital audio processors include a Studer-Editech Dyaxis II system, two Digidesign Pro-Tools systems with CD-R drives, digital i/o cards on Linux systems, and several Panasonic DAT recorders. Text and graphics are handled by an HP 4c color scanner on the unix-based systems and by high resolution network connected printers.

The recording studio consists of a control room and an adjoining recording studio. Equipment available currently includes three Tascam DTRS 8-track digital recorders (one DA-78HR and two DA-38s), a Tascam 80-8 1/2" analog 8-track recorder (with dbx), an Ampex ATR-104 analog 1/2" 4-track recorder (with dbx and/or Dolby A), a Mackie Digital Eight Bus (D8B) mixing console, a Presonus M80 eight-channel mic preamp, a Panasonic SV-3800 DAT recorder, a Waves L2 UltraMaximizer, a Lexicon 224XL digital reverberator, an Eventide Orville processor, Westlake BBSM-10 and JBL 4206 monitors, and outboard gear including equalizers, LA-2A and 1176 compressors, and digital effects processors. A Linux PC-based computer system is available in the control room and has a digital multichannel conenection to the mixer. Recorders may be linked together via SMPTE time code, which will also synchronize the Mac sequencer software. Microphones available in the recording studio include a Neumann TLM-193, two AKG C414B/ULSs, two AKG C460s (with interchangeable cardioid and omni capsules), a Beyer M-500, a Sennheiser MD-421, two Sennheiser E604s, two Electrovoice RE-20s, an Electrovoice N/D868, two Shure Beta-57s, and several Shure SM-57s. There is a Yamaha C7 Disklavier MIDI grand piano in the studio.

The MIDI part of Studio C is organized around a PowerMac G4 computer and an Opcode Studio 5 MIDI interface/MIDI patcher. There is a Yamaha KX-88 weighted-key controller and MIDI equipment including Yamaha SY-99 and VL-1 synthesizers, TX-802 module, Korg Wavestation A/D and X3R modules and Wavedrum synthesizer, E-Mu Proteus/2 module and ESI-32 sampler, and Kurzweil K2000R. There is a Yamaha Disklavier upright piano as well. The Studio C audio system includes a Mackie 24-8 analog mixer, Tascam DA-38, Panasonic SV-3700 DAT recorder, Denon DN-600F CD player, and ProTools MIXplus with 888 I/O and many TDM plug-ins. Monitoring is via four JBL LSR-28P powered speakers. Signal processing is available from a Korg A-1 multi-effects processor. A Plextor 8/20 CD writer is part of the studio as well and CD-Rs can be written from Toast and Jam software from files edited in ProTools or Peak programs.

Studio E is a ProTools-based room with some MIDI capability. Audio equipment includes a Tascam DA-88 recorder, Tascam DM-24 digital mixer, and Genelec 1030A monitors. The ProTools system running on a PowerMac G3 features a ProTools MIXplus with 888 I/O module. Several ProTools TDM plug-ins are available and may be shared by Peak software. MIDI equipment includes an E-Mu Emulator IV, Korg X3R, and a Kurzweil K2000 keyboard connected to an Opcode Studio 5LX interface. A Linux

workstation is also available with a Midiman Delta 1010 / 1010AI combination providing 8-channel digital I/O to the system.

Studio D is CCRMA's digital editing and 3D sound facility. Equipment available includes a Studer-Editech Dyaxis II digital editing processor running on a PowerMac G3, a Roland VM-7100 digital mixing system and a Z-systems digital patchbay connecting a Tascam DA-88 with TDIF-to-lightpipe converter, a Panasonic SV-3700 DAT recorder, a Denon CD player with digital output, and a Linux workstation with Midiman Delta 1010 / 1010AI digital 8-channel interface. Eight channel monitoring is through Mackie HR824 speakers and stereo monitoring is through Meyer Sound Labs Model 833 loudspeakers.

The CCRMA software has been developed over more than twenty-years, and consists of a vast set of programs and system tools for editing, viewing, synthesizing, and analyzing sound. Much of the software was originally written in SAIL, a sophisticated Algol-like language for use on the previous mainframe and has been ported to the new workstation environment and developed further. The programs currently in use include a comprehensive environment written in Common Lisp that includes Common Lisp Music (CLM) for music synthesis and signal processing,Common Music (CM) and STELLA for compositional programming and Common Music Notation (CMN) for creation of common music notation scores. The lisp-based world closely interacts (on the X windows environments) with Snd, a very complete sound editor and mixing tool also developed at CCRMA. Recent projects in music recognition, real-time performance, audio, signal processing, acoustics, psychoacoustics and physical modeling have been developed in languages native to the workstations, primarily Common Lisp, C, C++, Objective-C, Matlab, Mathematica, and Smalltalk. A multi-platform environment for real-time DSP research, STK, is being jointly developed at CCRMA and Princeton University. Of course there is a wide variety of public domain software for text, image and sound processing installed on all workstations.

4 Courses

CCRMA is a part of the Department of Music 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, e.g., Music, Computer Science, Electrical Engineering, Psychology, etc. Graduate degree programs offered in music include the MA/MST in Music, Science, and Technology, 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 both an undergraduate major and minor in Music, Science, and Technology (MST). The MST specialization 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 programs are available from the Stanford Music Department.

4.1 University Courses at CCRMA

For complete information on the following classes, please see the Stanford Bulletin for the current academic year. Most courses at CCRMA also have their own websites (see `http://www-ccrma.stanford.edu/courses/`).

Courses offered at CCRMA include:

- **Music 120: Introduction to Sonification** (Winter 2002)

  Principles and application development of auditory display of complex data.

- **Music 120: Musique Concrète in the Digital Era** (Fall 2002)

  Introduction to experimental music composition using computer software (Pro Tools). For music majors or non-majors, novice or experienced composers alike; geared toward computer music beginners. Topics include: compositional techniques; sound editing; basic signal processing; stereo and multi-channel diffusion; electronic music performance practice; historical overview of related electronic music; discussion of the meaning of sound, the aesthetic and legal ramifications of plunderphonics, and metaphor in electronic music. Students will complete regular weekly composition etudes and share them via the web. Larger projects, including a work involving live improvisation and a class collaboration, will be presented in concert.

- **Music 150: Musical Acoustics.**

  Elementary physics of vibrating systems, waves, and wave motion. Time- and frequency-domain analysis of sound. Room acoustics, reverberation, and tuning systems. Acoustics of musical instruments - voice, strings, winds, and percussion. Emphasis on practical aspects of acoustics in music making. Hands-on and computer-based laboratory excercises.

- **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 192: Theory and Practice of Recording**
  - **Music 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, microphone selection and placement, grounding and shielding techniques.
  - **Music 192B: Advanced Sound Recording Technology.**
    Topics: digital audio including current media, formats, editing software, post-processing techniques, noise reduction systems, advanced multi-track techniques, dynamic range processing and delay-based effects.
  - **192C: Session Recording.**
    Independent engineering of recording sessions.
- **Music 220: Computer-Generated Music**
  - **Music 220A: Fundamentals of Computer-Generated Sound.**
    Techniques for digital sound synthesis, effects, and reverberation. Topics: summary of digital synthesis techniques (additive, subtractive, nonlinear, modulation, wavetable, granular, spectral-modeling, and physical-modeling); digital effects algorithms (phasing, flanging, chorus, pitch-shifting, and vocoding); and techniques for digital reverberation.
  - **Music 220B: Compositional Algorithms, Psychoacoustics, and Spatial Processing.**
    Use of high-level programming 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.
  - **220C: Seminar in Computer Music Research.**
    Individual projects in composition, psychoacoustics, or signal processing.
  - **220D: Research.**
    Independent research projects in composition, psychoacoustics, or signal processing.
- **Music 250: Computer-Human Interaction Technology**
  - **Music 250A: HCI Theory and Practice.**
    Human-computer interface (HCI) issues as they relate to music applications in composition and performance. Project-oriented, examining issues from the technical and theoretical perspectives of computer science, haptics, and music theory.
  - **Music 250B: HCI Performance Systems.**
    Continuation of 250A, concentrating on interactive computer-music performance systems.
- **Music 253: Musical Information - An Introduction.**

  Explores the diverse kinds of the musical information used in sound, graphical, and analytical applications. Device-independent concepts and principles in music representation and musical research objectives (repertory analysis, performance analysis, theoretical models, similarity and stylistic simultaion) will be emphasized. Examples will be drawn primarily from Western art music.
- **Music 254: Music Query, Analysis, and Style Simulation.**

  This seminar takes traditional areas of musical analysis (melody, rhythm, harmony) and puts them to use in a variety of application areas. The most popular areas of research in recent years have been melodic simiilarity, methods of music query (information retrieval), and style simulation. Some attention is also given to interchange standards and copyright issues in the use of musical data. The Humdrum Toolkit is used in the lab.

- **Music 255: Orchestration and Timbre Analysis.**

  An introduction to timbre analysis methods with emphasis on analysis of formant characteristics of musical instruments and application to orchestration.

- **Music 319: Research Seminar on Computational Models of Sound Perception.**

  CCRMA hosts a weekly Hearing Seminar. All areas related to perception are discussed, but the group emphasizes topics that will help us understand how the auditory system works. Speakers are drawn from the group and visitors to the Stanford area. Most attendees are graduate students, faculty, or local researchers interested in psychology, music, engineering, neurophysiology, and linguistics. To sign up for the seminar mailing list, send an e-mail request to hearing-seminar-request@ccrma.stanford.edu. Include the word subscribe in the body of that message.

- **Music 320: Introduction to Digital Audio Signal Processing.**

  A first course in digital signal processing for music and audio research. Topics: complex numbers, sinusoids, spectrum representation, sampling and aliasing, digital filters, frequency response, z-transforms, transfer-function analysis, and associated Matlab software. See web site: `http://www-ccrma.stanford.edu/courses/320/`.

- **Music 420: Audio Applications of the Fast Fourier Transform (FFT).**

  Spectrum analysis and signal processing using the FFT, with emphasis on audio applications. Topics: DFT filter bank; Fourier theorems; spectrum analysis parameters; FFT windows; cyclic and acyclic convolution using the FFT; FIR filter design; phase and channel vocoders; the overlap-add and filter-bank-summation methods for short-time Fourier analysis, modification, and resynthesis; sinusoidal modeling; sines+noise+transients modeling; perfect-reconstruction filter banks. See web site: `http://www-ccrma.stanford.edu/courses/420/`. Prerequisite: Music 320 or equivalent.

- **Music 421: Signal Processing Methods in Musical Acoustics.**

  Computational methods in digital audio effects and sound synthesis based on acoustic models. Topics: sampled traveling waves; acoustic simulation with delay lines, digital filters, and non-linear elements; comb filters; allpass filters; artificial reverberation and spatialization; delay-line interpolation and sampling-rate conversion; phasing, flanging, and chorus effects; efficient computational models of strings, woodwinds, brasses, and other musical instruments; finite difference schemes; modal synthesis; waveguide meshes; wave digital filters; and virtual analog. See web site: `http://www-ccrma.stanford.edu/courses/421/`. Prerequisites: Music 320 or equivalent.

- **Music 422: Perceptual Audio Coding.**

  The need for significant reduction in data rate for wide-band digital audio signal transmission and storage has led to the development of psychoacoustics-based data compression techniques. In this approach, the limitations of human hearing are exploited to remove inaudible components of audio signals. The degree of bit rate reduction achievable without sacrificing perceived quality using these methods greatly exceeds that possible using lossless techniques alone. Perceptual audio coders are currently used in many applications including Digital Radio and Television, Digital Sound on Film, and Multimedia/Internet Audio. In this course, the basic principles of perceptual audio coding will be reviewed. Current and future applications (e.g. AC-3, MPEG) will be presented. In-class demonstrations will allow students to hear the quality of state-of-the-art implementations at varying data rates and they will be required to program their own simple perceptual audio coder during the course.

- **Music 423: Graduate Seminar in Signal Processing Research.**

  Ongoing seminar for graduate students pursuing research in DSP applied to music or audio. See web site: `http://www-ccrma.stanford.edu/courses/423/`.

4.2 Workshops

CCRMA also offers a series of one- or two-week summer workshops open to participants outside the Stanford community. Information regarding courses to be offered during the coming summer can be accessed at `http://www-ccrma.stanford.edu/`. Courses offered during the last few summers have included the following:

- **Linux Sound: Open Source Music Synthesis, Composition, and Audio Programming**

  CCRMA has been using the Linux operating system for music composition, synthesis, and audio DSP research since 1996. This workshop will focus on currently available open source tools and environments for computer music research and composition using Linux. The workshop will include an overview of some of the most popular linux distributions and a brief installation clinic with specific focus on audio, midi and real-time performance (dealing with both hardware and software). Low level sound and midi drivers reviewed will include oss, oss-free, alsa. Environments for sound synthesis and composition will include the Common Lisp based clm system, STK (c++), and pd (c). Many other interesting tools like the snd sound editor (and its internal scheme programming environment) will also be covered. Due to the very dynamic nature of the open source community and software base more programs will probably be included by the time the workshop starts. The workshop will also include a brief tour of sound processing and synthesis techniques. Familiarity with computers and programming languages is helpful.

- **Digital Signal Processing for Audio: Spectral and Physical Models**

  This course will cover analysis and synthesis of sounds based on spectral and physical models. Models and methods for synthesizing real-world sounds as well as musical sounds will be presented. The course will be organized into morning lectures covering theoretical aspects of the models, and afternoon labs. The morning lectures will present topics such as Fourier theory, spectrum analysis, the phase vocoder, digital waveguides, digital filter theory, pitch detection, linear predictive coding (LPC), high-level feature extraction, and various other aspects of signal processing of interest in sound applications.

  The afternoon labs will be hands-on sessions using SMS and the Synthesis ToolKit in C++ , and other software systems and utilities. Familiarity with engineering, mathematics, physics, and programming is a plus, but the lectures and labs will be geared to a musical audience with basic experience in math and science. Most of the programs used in the workshop will be available to take home.

  Given the short duration of the workshop and the broad spectrum of topics to cover, the lectures will necessarily be fairly high level in nature. However, a full complement of in-depth readings will be provided for those who wish to investigate the details of the material. Also, the last two days of the workshop will include a more detailed treatment of some advanced topics and the corresponding afternoon labs will give the students a chance to solve some specific problems of their interest.

- **Physical Interaction Design for Music**

  This workshop integrates programming, electronics, interaction design and interactive music. Focus will be on hands-on applications using sensors and microcontrollers in conjunction with real-time DSP to make music. Specific technologies will include C-programming for the Atmel AVR mega16, and PD or Max/MSP. Participants will design and build working prototypes using a kit that can be taken home at the end of the workshop.

  This workshop will consist of half-day supervised lab sessions, and half-day lectures, classroom exercises and discussions. Classroom sessions will feature live demos and/or concerts of interactive music and instruments. Participants are encouraged (but by no means required) to bring their own laptop computers with any music software/hardware they already use.