

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

CCRMA OVERVIEW

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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
jeffy	Jeff Bernstein	MA Science and Technology
kirstinc	Kirstin Cummings	MA Science and Technology
gzh	Gregor Hanuschak	MA Science and Technology
dfi	David Lowenfels	MA Science and Technology
jmccarty	John McCarty	MA Science and Technology
shirajwa	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)
carlane	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 connection 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 exercises.

- **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 similarity, 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, alsaa. 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.

5 Compositional Activities

5.1 Overview

Since the late 1960's, much of the compositional work at CCRMA has involved a software environment which evolved from the Music V program, which was originally developed at Bell Labs by Max Mathews and his research group. The hardware and software has changed and improved greatly over the decades. Ported to a PDP10, Music V became the Mus10 music compiler system and played scores composed in Leland Smith's SCORE language. The compiler was replaced in 1977 with dedicated synthesis hardware in the form of the Systems Concepts Digital Synthesizer (built by Peter Samson and known as the "Samson Box"). The Samson Box was capable of utilizing many types of synthesis techniques such as additive synthesis, frequency modulation, digital filtering and some analysis-based synthesis methods. The PLA language, written by Bill Schottstaedt, allowed composers to specify parametric data for the Samson Box as well as for other sound processing procedures on the PDP10 mainframe (and on its eventual replacement, a Foonly F4). On April 3, 1992, the Foonly and Samson Box were officially retired. CCRMA has transitioned to a network of workstations (Intel based PCs, SGI's, and NeXTs) running Linux, Irix, and NEXTSTEP operating systems. The functionality of PLA exists now in the form of Common Music (CM) (written in Common Lisp by Rick Taube), a software package 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, Music Kit, 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 run in real time on fast workstations.

Continuity has been maintained over the entire era. For example, scores created on the PDP10 or Samson Box have been recomputed in the Linux and NeXTStep computing environments, taking advantage of their increased audio precision. To summarize all these names for CCRMA's composing environment, the synthesis instrument languages have been, in chronological order, MUS10, SAMBOX, CLM/MusicKit and the composing language succession has been SCORE, PLA, Common Music. Other computers and software are also used for composition. Several composers have realized pieces which make extensive use of MIDI equipment. Readily available commercial software for manipulation of digital audio has brought renewed interest in real-time control and computer-based "musique concrète." The programming environments being used for composition and developmental research include MAX, Patchwork, Smalltalk, Common Lisp, STK, C/C++, and Pd.

Since its beginning, works composed at CCRMA have been highlighted at music festivals, concerts and competitions around the world. Compositions realized at CCRMA have been performed at nearly every International Computer Music Conference; at the Society for Electro-Acoustic Music (SEAMUS) in the U.S.; at the Bourges Festival of Electroacoustic Music in France; at ISCM World Music Days; at The Warsaw Autumn Festival in Poland; at the Computers and Music Conference in Mexico City; at the Primera Muestra Internacional de Musica Electroacustica in Puerto Rico; and in concerts throughout the world. Compositions from CCRMA have also won major electroacoustic music prizes over the years, including the NEWCOMP contest in Massachusetts, the Irino Prize for Chamber Music in Japan, the Ars Electronica in Austria, and the Noroit Prize in France. Works composed at CCRMA have been recorded on compact disks by Mobile Fidelity, Wergo, Harmonia Mundi, Centaur, Allegro, and others. CCRMA is publishing with Wergo/Schott *Computer Music Currents*, a series of 14 CDs containing computer music by international composers. *Computer Music @ CCRMA*, volumes one and two, represent music production by twelve composers working at CCRMA during the period 1992 to 1996.

5.2 Composers and Works

Recent compositional works realized at CCRMA include the following:

Oded Ben-Tal

- *Tangents* (2002) for flute, piano and tape.

Commissioned by the Calliope duo, *tangents* originates from my research in sonification. Methods similar to the ones we used to sonify stock market data were used to construct the tape part. The title refers to nature of the interaction between the 3 elements of the piece.

- *Cholophilosophy* (2002) for large ensemble.

This single movement piece for 15 musicians is related to some electronic studies/sketches I did in 1999. The piece narrates a process of clarification in both the frequency time domains.

- *Des Silences, Des Nuits* (2002-) for voice and 2- or 4-channel tape.

Des Silences, Des Nuits is an ongoing project for baritone Nicholas Isherwood and 4-channel or stereo tape. Based on selections from the writings of Rimbaud, the first of these songs was premiered at CCRMA in May of 2002.

Jonathan Berger

- *Diameters* (2003) for mezzo-soprano and computer.

Performed at Stanford, New London and New York.

- *Eli Eli* (2002) for string quartet.

Composed for the Daniel Pearl memorial music day. Performed by the St Lawrence String Quartet. Adopted by the Pilobolus Dance Company.

- *Last Letters* (2002) for baritone and piano.

- *Sink or Swim* (2002) for violin solo.

Commissioned by Livia Sohn. Performances include Atlanta, Washington DC, Mexico.

- *Haiku* (2001) for trombone and computer.

Performed in New York, Paris, Tel Aviv, Stanford.

- *Miracles and Mud* (2001) for String Quartet.

Commissioned by the St Lawrence String Quartet. Over 60 performances throughout the world.

- *My Lai* (2001) for solo piano, premiered at the United Nations General Assembly, January 24 2001.

Christopher Burns

- *Hero and Leander* (2003) for multichannel tape.

- *Weave* (2002) for string trio.

Weave is a string trio composed of three independent solos: *Weft* for violin, *Shuttle* for viola, and *Warp* for cello. The violin and cello pursue radically divergent paths, the violin disruptive and mercurial, the cello obstinate and repetitive. The viola, the only part aware of the history and future of the trio's music, moves back and forth between violin and cello materials, gradually braiding the ensemble into a unified whole. Guided by the mediating presence of the viola, the profusion of solos proves to be a conversation between three voices.

- *Shuttle* (2003) for viola solo.

Shuttle, for viola solo, is the last work in a sequence of three solo pieces; each of these pieces serves not only as a solo, but also as one part of a string trio titled *Weave*. In the trio, the viola serves as a mediator between the fiercely independent violin and cello parts, drawing them together over the course of the work.

Played alone, the viola solo still conjures and refers to the larger trio. As the work opens the viola oscillates between the polar attractions of the shifting, angular lines which refer to the violin's music, and the rotating, repetitive elements which characterize the cello. Gradually, the viola braids these disparate features into a unified whole, discovering and constructing its own broadly flowing music as a result of the encounter with these contrasting foils.

- *Warp* (2002) for cello solo.

Warp, for cello solo, is the second in a sequence of three solo string pieces; each work serves not only as a solo, but also as one part of a string trio titled *Weave*. The cello music begins by obsessively shuffling a series of fragments. Eventually, the musical energies built up through repetition bloom into a kaleidoscopic profusion of materials.

- *Weft* (2001) for violin solo.

Weft is the first work in a larger project; the piece serves not only as a solo, but also as the violin part in a string trio (titled *Weave*). Obeying its own internal dictates, while also responding to the logic of its unheard viola and cello counterparts, the violin's spiky, angular gestures gradually knit themselves into a more sustained music.

Weft is dedicated to Mark Menzies.

C. Matthew Burtner

- *Ukiuq Tulugaq (the Winter Raven)* (1998-2002).

Ukiuq Tulugaq, a multimedia electroacoustic work for instrumental ensemble, surround sound electronics, dance and movement art, video projection and theatrical staging was performed on March 28, 2003 in Charlottesville at the University of Virginia. The piece is based on ecological and anthropological studies of the Arctic. In *Winter Raven*, natural forces such as sun, wind and ice take on dramatic musical personas in a dream-like sequence of staged movements. The composition metaphorically connects an Inuit creation story, in which the World is created by Raven (*Tulugaq*) from snow, with the seasonal approach of winter.

- *S-Morphe-S* for singing bowl/soprano saxophone (2002).

S-Morphe-S explores the coupling of a disembodied soprano saxophone with the virtual body of a singing bowl. The saxophone signal is used as an impulse to the physically modeled bowl. The result is a hybrid instrument with the articulatory characteristics of a soprano saxophone but the body of a singing bowl. The saxophone uses varied articulations such as key clicks, breath, trills and sustained tones. The shape and material properties of the bowl are varied in real time creating a continuously metamorphosing body. In Greek *Morphe* means form and in Greek mythology *Morpheus* was the god of sleep, of disembodied forms. The English word commonly used for a transformation between two objects is *morph*, a shortening of *metamorphosis*, derived from the Greek. The title of this piece is meant to evoke all of these meanings – dreamed images, transformative bodies, and disembodied forms. *S-Morphe-S* was first performed in Pitea, Sweden in 2002.

- *(dis)Appearances* for a disembodied string trio (2003).

(dis)Appearances, a trio for amplified acoustic violin, electric violin, and computer violin/multi-controller, explores the nature of disembodiment and physical acoustic reality through the use of computer controllers and physical modeling synthesis. The piece is scored for a string trio in which the ensemble is not defined by register (as with a traditional string trio) but by states of embodiment/disembodiment. *(dis)Appearances* was first performed in Venice, Italy in 2003.

- *Polyrhythmicana* (2002) for flute, cello, guitar, percussion and 4-channel computer-generated click track.

The form of *Polyrhythmicana* is generated by macro-level geometric rhythmic relationships arising from the interplay between the individual instrumental lines. In order for the performers to follow the constantly changing tempi (which are both independent from and closely related to one another)

a computer-program was created that generates independent multichannel click tracks under one global clock. The piece is in five movements each with a different rhythmic organization: I: Metal YX; II: Split/Joined Diamonds (in Wood); III: C Acceleration Phase; IV: Slow 2:3 (in Noise); V: Melody Triangles. *Polyrhythmicana* was first performed in San Diego by Ensemble Noise who commissioned the work.

- *Snowprints* for flute, cello, piano, electronics and three video projections (2002).

Snowprints (2002) for flute, cello, piano and electronics explores snow both metaphorically and sonically. Snow relates to bodies through the analogy of “impressions” or “prints”. In snow, prints of bodies are captured and transformed by wind and changing temperature. The wind leaves impressions in the form of drifts; changing light creates shadow prints on its surface; and animals seeking shelter also leave fading tracks.

In Alaska, photographs, video and recordings of snow were gathered. Many different movements were recorded in varying snow conditions. The sounds were then mixed into the electronic part, combined with three digital prints of the acoustic trio. The digital prints were created from a Scanned Synthesis string (by Max Mathews), a Physical Modeling Synthesized flute (controlled by a Theremin in Miller Pucket’s PD), and a Granular Synthesis piano. Macintosh and Linux computers were used to create the piece. The orchestration of the composition is thus an acoustic trio of flute, cello, piano; and a digital trio of flute, cello, piano. The expressive noisy sounds of the snow bind the sonic world, creating a background environment for the instrumental/digital prints. The video uses images of the snow prints and the city lights of Anchorage.

Snowprints was commissioned by Trio Ascolto with support from the German Ministerium of Culture, Heidelberg. It was first performed in Munich, Germany in 2003.

- *Somata/Asomata* (2002) for electric string quartet and computer-generated sound.

Somata/Asomata (2002) for electric string quartet and computer-generated sound deals with notions of embodiment and disembodiment, questioning the musical perception of physical and non-physical reality. This is accomplished in the musical context through the use of electric and computer-generated instruments.

Somata/Asomata extends my work in compositions such as *Animus/Anima* for voice and electronics, *Snowprints* for flute, cello, piano and electronics, and *S-Trance-S* for computer metasaxophone. In these pieces, the performed instruments are treated as “real” or embodied states and the electronics are used to extend the notion of corporeality by transforming performative qualities of the instruments through sound synthesis. In *Somata/Asomata*, the acoustic instruments are not really acoustic but are actually electric instruments, played exactly as their acoustic counterparts by the performers. The sound is electroacoustic, and originates from speakers rather than from the bodies of the instruments. The computer-generated sound also originates from the speakers and this creates a dialectic between instrument as body and instrument as sound synthesis.

Somata/Asomata was commissioned by Musik i Nordland for the MiN Quartet. It was first performed at the ILIOS Festival in Norway in 2003.

Chris Chafe

- *Tangent* (2002) for clavichord and CD.
- *Oxygen Flute* music installation, San Jose Museum of Art (2001–2002), UC Berkeley Kroeber Museum (2002–03)
- *Ping* (2001)

Created by composer and researcher Chris Chafe and digital artist Greg Niemeyer, *Ping* is a site-specific sound installation that is an outgrowth of audio networking research at Stanford University’s Center for Computer Research in Music and Acoustics and interactive and graphic design experiments originating from the Stanford University Digital Art Center. *Ping* is a sonic adaptation of a network tool commonly used for timing data transmission over the Internet. As installed

in the outdoor atrium of SFMOMA, *Ping* functions as a sonar-like detector whose echoes sound out the paths traversed by data flowing on the Internet. At any given moment, several sites are concurrently active, and the tones that are heard in *Ping* make audible the time lag that occurs while moving information from one site to another between networked computers.

Within the *Ping* environment, one can navigate through the network soundscape while overlooking San Francisco, a cityscape itself linked by the same networks that constitute the medium. Visitors to the installation can expand or change the list of available sites as well as influence the types of sound produced, choosing different projections of the instruments, musical scales, and speaker configurations in the surround-sound environment.

Current explorations pertaining to sound synthesis and Internet engineering are the foundation of the *Ping* installation. The research that led to this installation is, however, just one part of a larger effort to investigate the usefulness of audio for internetworking and, reciprocally, ways in which the Internet can abet audio.

Ching-Wen Chao

- *Requiem Moksa* (2002)
 - I. *Elegy in Flight* - for solo violin
 - II. *Moksa* - for 12 vocalists and 4-channel tape
 - III. *Spiritus Intus Alit* - for solo bass and live electronics

Requiem Moksa is dedicated to the victims of the 9/21 earthquake in Taiwan. It embraces three movements, each of which owns its distinct instrumentation. There is no pause in between these movements. The use of three distinct languages in the second movement is intended not only to present intricate timbral combinations and various sound images in composition, but to also delineate a global compassion for the subject matter.

Elegy in Flight starts with a statement of a 59-note set, which is derived from a 59-syllable Buddhist mantra used in recitation for the dead. The set subsequently expands itself through the multiplication of its own intervals and then it is compressed in register. This expansion/compression process is stated 6 times over the course of the piece with variations of speed and emphasis. The six journeys through this material denote the Buddhist "wheel of life," or the 6 realms of existence chosen by the dead in their next incarnation (based upon their karmic activity). The other material in the piece is a quasi chant melody that acts as an insertion that deliberately distances itself from the turning of the wheel, and it presents an alternative to this process: the ceasing of time and the presentation of an entirely different space.

Spiritus Intus Alit, meaning "the spirit drinks deep," serves as the postlude in this requiem. It speaks to the depth of the spiritual and philosophical struggle between faith in the afterlife and the finality of death. The two textual fragments are drawn from *The Aeneid* of Virgil, depicting a dialogue between Aeneas and his deceased father. One is to underscore the faith in rebirth through the process of metempsychosis, while the other reinforces the finality of death. This also results in two sets of musical materials which alternate throughout the piece. A profoundly beautiful portion of Virgil's texts - translated as "With full hands, give me lilies. Let me scatter these purple flowers, with these gifts, at least, be generous to my descendant's spirit, complete this service, although it be useless" - deeply expresses the sorrow loss of the living and the unchangeable ultimatum of death. Toward the end this element leads to the depart of the two worlds, sung by a distinctive diphonic technique.

The making of the 4-channel tape is realized under CLM (Common Lisp Music) environment via utilization of ATS (analysis transformation Synthesis), SMS (spectral Modeling Synthesis), dlocsigs (multi-channel spatialization) and granular synthesis.

- *Elegy in Flight* (2002) for violin.
Elegy in Flight was recently premiered by Mark Menzies on January 22, 2002.

Damián Keller

- *Paititi: a multimodal journey to El Dorado*, (2003) an installation.

Paititi is a multidisciplinary project encompassing historical research, software development, and artistic creation. The main objective of this project is the elaboration of a work involving literary, visual and sonic elements inspired and documented on the historical records of the legend of El Dorado.

The temporal frame for this piece is the Spanish-Inca war (1532-1572). The geographical region includes the paths taken by the first Spanish explorers and some of the important Inca cities, such as Cuzco, Quito and Cajamarca. The visual material includes reproductions of historical documents from the Archivo General de Indias (AGI) in Seville and original footage taken at the sites of the explorations. The sonic material features recordings on site and oral reports by people from the region. The literary material encompasses documents written by the conquistadores, oral reports by aboriginals, and original prose inspired on historical facts.

The composition will be created by means of digital processing and synthesis of environmental sounds modelled after the collected material. The format of the piece will be an installation space combining video, still digital images, and multichannel sound. Two types of software will be developed for this work: sound synthesis and multichannel spacialization, and interactive controllers for triggering images and sounds in the installation space.

Seungyon-Seny Lee

- *Dante's Inferno* (2002–2004) for dance, video and electro-acoustic music.

Dante's Inferno is a collaborative work with Fellow Travelers Performance Group, making use of 4 dancers, video images, installations, and electro-acoustic music. It will be performed at the ODC Theater, San Francisco, CA in September 2004.

Throughout history, humans have attempted to decipher what comes after this life through myth and religion, guesses, stories passed down, and rational thought. Ancient myths offer ideas as do more modern writers from Hamlet's soliloquy, to George Bernard Shaw and Sartre. Fear of death and, through this, fear of evaluating one's life have haunted and inspired people through the ages. Perhaps none took it so far as Dante who mixed local politics, religion and Aristotelian ethics, created an afterlife and went for a visit.

Dante's Inferno provides a wide backdrop of history by which to examine life today. The many layered splendors of hell hold many surprises, including the number of Greek and Roman gods and mythological creatures which parallel the superstitions, rationalizations and allowances made in today's supposedly rational society. Rather than trying to create a stage copy of the Inferno, the collaborators are seeking to look at societal issues of today through the looking glass of the past. Many of the excesses of medieval Florence are the excesses of today: sex, greed, power.

Through the Inferno Project (working title) Fellow Travelers Performance Group's Artistic Directors Ken James and Cynthia Adams (choreographers of dance and performance), Matthew Antaky (scenic, costume and lighting design), Lawrence LaBianca (sculptor) and Seungyon-Seny Lee (electronic music composer), will create a new series of interdisciplinary works. Designed to create a sense of enigma, like a feeling of peril in which the elements and textures of the experience shift, slide and recombine unpredictably, we are striving to create a synthetic response where all parts of the environment stimulate full body and mental reactions in the audience.

- *Helix* (2002) for baritone, real-time interaction and video.

There are four basic layers to *Helix*; a monologue on tape, tape sounds that utilize non-verbal voice and instrumental sounds (transformed via computer), voice and video. In January, February, and March of 2001, I kept a diary of thoughts on unanswerable questions and endless conundrums. The issues of reality and imagination and their relationship to the Self and Other appeared at times. The monologue part on the tape is drawn from my diary, and it incorporates these elements.

The other tape sounds explore the world of explication, while the voice part is more implicit in substance. The video image is meant to enhance and redefine the experience of the sonic realm of *Helix*. Many thanks to Cyrille Brissot who collaborated for video images.

- *13* (2002) sound installation.

13 is a real-time interactive collaboration work by the composer, Seny Lee and the scientist, Jeffrey Walters. Craig Sapp provided invaluable assistance with the hardware interfaces.

13 is one of composers' imagined numbers – one step beyond the end of a common cycle. Simple additions leading to “13” create short episodes of sound. The desired additions are expressed by grasping the plastic panel on the numbered sensors. Vibration sensors are also placed on the panels, and the vibrations caused by the users' interaction produce another layer of sound. The mirrored surfaces project desired and undesired self images, distorted in ways reflected by the sounds.

- *Silo Installation* (2002)

Silo Installation had an exhibition on the silo container at Ghent, NY, and it is a real-time interactive work which is based on the idea of *13* installation.

FSR sensors are used to randomly trigger pre-recorded sounds, allowing 48 different combinations of sound caused by the users' interaction which produces another layer of live processing sound.

- *Sang-Yeo-So-Ri* (2002) for tape, in memory of John Pierce.

Sang-Yeo-So-Ri roughly means “bier-carriers song”. When someone dies in Korea, it is a tradition that men carry a colorfully decorated bier on their shoulders while walking towards to the grave. A man leads the singing accompanied with a hand bell or a drum, and the bier-carriers sing a refrain following the tune. People believe the song keeps the dead safe until he gets to Heaven. Using granular synthesis, the tune resembles echoes from the higher world.

Fernando Lopez Lezcano

- *iICEsCcRrEeAaMm*

iICEsCcRrEeAaMm is a beta, er.. I mean alpha version of a new multichannel tape piece I'm still working on. As in the software world, Marketing informs me that in future versions bugs will be squashed and new features will be added for the benefit of all listeners. *iscream* refers to the origin of most of the concrete sound materials used in the piece. Screams and various other utterances from all of Chris Chafe's kids were digitally recorded in all their chilling and quite upsetting beauty. They were latter digitally fed into the “grani” sample grinder, a granular synthesis instrument developed by the composer. ICECREAM refers to the reward the kids (and myself) got after the screaming studio session. The piece was composed in the digital domain using Bill Schottstaedt's Common Lisp Music. Many software instruments and quite a few other samples of real world sounds made their way into the bitstream.

Jonathan Norton

- *Return to C* (2003) for solo harp
- *Traffic Islander* (2002) for string orchestra with harp and piano.

Even on crowded roads every person is their own little oasis in a sea of traffic. Often times while being stuck in traffic one cannot physically escape the present circumstances. However, the mind is free to roam and imagine. The three movements of *Traffic Islander* mirror traffic patterns observed in everyday life.

- *Kitty Waltz* (2002) for nine MIDI controlled toy pianos.

What does it sound like when kittens dance across a piano? When they waltz up and down the keys? This composition attempts to emulate the pitter-patter of little paws dancing across the

piano. The arrangement of the nine toy pianos allows the kittens to spatially dance around the room. *Kitty Waltz* was written especially for the Klavier Nonette installation at the New Music Gallery, Seattle WA.

- *Three Sides of a Coin* (2002) for flute, clarinet, percussion, piano, violin and cello.
- *Newspaper Music: German Edition* (2002) for solo piano. Part of a series of MAX/MSP algorithmically composed compositions based on newspaper articles from around the world.
- *Stop Thief!* (2002) for tape.
This text-sound music piece is based on a text about the return of a “new legitimate” Napster as a subscription music service.

Juan Reyes

- *Feather Rollerball* (2002-03)
Feather Rollerball is a live piece for piano, Radio Baton and Scanned Synthesis. This piece was composed using CM and Max Mathews’ Scanned Synthesis program on the Linux environment.
- *Freddy the Friedlander* (2003)
This is a multichannel piece using Expression Modeling with the Physical Model of the Bowed String not in real time. In this case the advantage of a rendered sounds results in musical gestures which are unique but carry-on with the timbral characteristic of bowed string instruments. This piece was composed using CLM on the Linux environment.
- *Chryseis* (2002) for 4-channel tape.
Scattering of names like Achilles, Braiseis or Chryseis can only come from the old world. The probability of selecting such a name while in Ibero America might well be very odd. This is like choosing characters for a play or a novel, a login name for haut mail, a password or perhaps a new weather phenomenon in the Caribbean. Nevertheless, this name sounds like two syllables barely pitched if whispered but very flexible if shout. Achilles, Braiseis or Chryseis are expressive while sung in bossa nova or at la cosa nostra.
This is yet another composition for systems which mimic the vibrational properties of a musical sound. In this case Scanned Synthesis developed by Bill Verplank and Max Mathews at CCRMA during the last years of the past century, was used as the underlying material. The process for achieving this timbre was solved by scanning and manipulating several types of springs which give different and time mutant spectra. Control is achieved by mathematical modeling the haptics of the spring.
Scanned Synthesis is based on the psychoacoustics of how we hear and appreciate timbres and on our motor (haptic) abilities to manipulate timbres during performance. It involves a slow dynamic system whose frequencies of vibration are below 15Hz. The system is directly manipulated by motions of the performer. The vibrations of the system are a function of the initial conditions, the forces applied by the performer and the dynamics of the system.
This piece was composed using the Common Lisp Music and Common Music environments on Linux at CCRMA.

Gary Scavone

- *Pipe Dream* (2003) for custom MIDI wind controller and realtime computer synthesis.
Pipe Dream is the second in a set of compositions exploring subtle wind instrument overblowing effects. In this work, all sounds are generated using real-time computer-based saxophone-like physical modeling algorithms implemented with the Synthesis ToolKit in C++. The algorithms are performed with a new MIDI wind controller called *The Pipe*. The controller makes use of a

variety of sensors, including buttons, potentiometers, and accelerometers which respond to breath pressure, finger pressure and tilt. Spatialization effects in a four-channel sound environment are created through various panning strategies.

- *Air Study I* (2002) for alto saxophone and stereo tape.

This work is an exploration of subtle overblowing effects using two virtual “blowed string” physical models and a live saxophonist. The physical model algorithms were created and controlled using the Synthesis ToolKit in C++, a software environment by Perry Cook and Gary Scavone.

The saxophonist in *Air Study I* fingers a low B-flat for the entire piece (clamps may be desirable). The pitch/timbre variations are completely controlled via embouchure and oral cavity manipulations. The tape part for *Air Study I* was generated with two independent physical models, each assigned to a single stereo track. Phasing effects were created by slight variations in vibrato rates and pitches. Overblowing effects were controlled via reed and breath pressure parameters.

An alto saxophone body without holes was used for the premiere of *Air Study I* on 25 July 2002. Gary expresses his sincerest gratitude to The Selmer Company and Tom Burzycki for their donation of this instrument.

Kotoka Suzuki

- *QM* (work-in-progress)

Sound and video installation in collaboration with Ann-Sofi Sidén. The Modern Museum, Stockholm, Sweden (2004).

- *Papier Konzept* (2003)

Sound and sculpture installation in collaboration with Yaeko Osono. Burgkolster in Lübeck, Germany (Jan. 26 - Mar. 2, 2003).

- *Umidi Soni Colores* (2002) for 8-channel surround tape and 3 videos (video by Claudia Rohrmoser).

The focus of this collaboration work is to portray closely the relationship between sound and vision (their movement, shape, and color), in a three dimensional spatial environment, while giving both of them equal importance. It is important that both of these two mediums serves not only to enhance the materials of the other medium, but also to lead, dominate, and at times, even to express completely contrasting and independent ideas from the other. This work consists of three contrasting movements that are simultaneously played without any interruption. These three movements are each based on the same main sound and visual materials that recur and transform throughout the piece.

This work was realized at Technical University of Berlin Electronic Studio and was commissioned by DAAD and TU-Berlin Electronic Studio.

- *Slipstream* (2002) for 7-channel surround tape and flute.

I imagine sounds that are visible, that constantly transform into different forms, sizes, and colors, as they travel through the air at different speeds. The timber of the tape material is based on my personal characterization of the flute: metallic, sensitive, fragile, light, and warm, but cool at the same time. These sounds of the tape are at times as small and gentle as grains of sand, and at times, as unyielding as a mass of metal. The transformations of both tape and flute take place as they react to the sound of one another. The tape material react especially to the air pressure of the flute, as if the air that emerges from the instrument physically blows away and breaks the tape sounds into small particles. At the same time, the traveling force of the tape material in the air causes the flute to react back.

Influenced by Japanese traditional music writing, this work also focuses on the relationship between two elements of sound: noise and pitch, using the sound of the flute as the basis of the piece. The transformations of a single key-click into long sustained notes can be heard through out the piece.

This work was realized at Technical University of Berlin Electronic Studio and was commissioned by Sender Freies Berlin Radio. This work received a Musica Nova Honor Prize 2002, and was selected as a Finalist in the Russolo Electroacoustic Music Competition 2002.

- *Sift* (2001) for violin and computer-generated tape

Sift was commissioned by MATA and is dedicated to Carla Kihlstedt. This piece conveys the relationship between two elements of sound: noise and pitch. These two elements are emphasized as separate voices by assigning each to an instrument: noise to tape and pitch to violin. Throughout the piece, the exchange of these elements, and the transformation from one element to another can be heard. All computer-generated sounds are derived from the sounds of the violin used in this work. Similarly, the violin often imitates the sound of the computer-generated material on the tape. The violin sounds were manipulated and recorded for the music of the tape using sound editing programs such as CLM, Snd, and Pro Tools.

Peter Traube

- *retour* (2002) for 8 channel tape.

retour was composed using a combination of Perl, Csound, and Common Lisp Music. Various Perl driven Csound routines were used to transform short acoustic samples into longer rhythmic and arhythmic events. CLM was used to generate the final mix of the various sound objects. The work, besides being my first foray into eight channel sound, involves the exploration of rhythm, randomness, and the points in between.

- *etude no. 4* (2002)

Composed using Csound, Snd, and Protools. As titled, it was a study in which I experimented with various Csound opcodes and methodologies that I had not used before. The result is a work in which acoustic sounds are transformed into insect-like timbres, creating a rainforest soundscape. As in *retour*, there is an emphasis on the contrasting of rhythmic and arhythmic sounds, and points in between. I chose to do this work in two channels, and arranged it using ProTools, as I wanted a more "immediate" composition experience than the one I had creating *retour*.

- *untitled* (2003)

This work, still in progress, will be based on source recordings of an interview with my wife. During the interview we went through virtually all of my electronic compositions since my days as an undergraduate at the University of Florida. As the works play in the background, she comments on them, attempts to interpret them, and gives her opinions on electro-acoustic music in general. For this work, I am learning SuperCollider 2, and intend to use it to modify and transform the various sound clippings from our interview. The finished work will be in at least four channels.

6 Research Activities

Computer music is a multi-disciplinary field. The research summarized in this overview spans such areas as engineering, physics, computer science, psychology, and music (including performance, analysis, and composition). Any given research topic may require sophistication in several of these fields. This document can only contain a brief review of the work being done at CCRMA. For a more complete description of the research, a list of CCRMA research publications is included. Copies of reports are available upon request.

The researchers working at CCRMA include graduate students, faculty, staff, and visiting scholars. Email may be sent to any of these people by mailing to *login@ccrma.stanford.edu* where *login* names are listed in the roster at the beginning of this publication.

6.1 Computer Music Hardware and Software

6.1.1 *grani*, a granular synthesis instrument for CLM

Fernando Lopez Lezcano

grani.ins is a quite complete CLM (Common Lisp Music) granular synthesis instrument designed to process (ie: mangle) input soundfiles. Almost all parameters of the granulation process can be either constant numbers or envelopes so that a note generated with *grani* can have very complex behavioral changes over its duration. Parameters can control grain density in grains per second, grain duration, grain envelope (with up to two envelopes and an interpolating function), sampling rate conversion factor in linear or pitch scales, spatial location of grains, number of grains to generate or duration of the note, etc. Almost all the parameters have a companion "spread" parameter that defines a random spread around the central value defined by the base parameter (both can be envelopes).

The first "grani" instrument was originally created as an example instrument for the 1996 Summer Workshop. In its present form it has been used to teach granular synthesis in the 1998 Summer Workshop and 220a (Introduction to Sound Synthesis Course). It has become a pretty popular instrument at CCRMA and was used by its author to compose *iCEsCcRrEeAaMm*, a four channel tape piece that was premiered in the 1998 CCRMA Summer Concert.

Complete details can be found at: <http://www-ccrma.stanford.edu/~nando/clm/grani/>

6.1.2 A Dynamic Spatial Sound Movement Toolkit

Fernando Lopez Lezcano

This brief overview describes a dynamic sound movement toolkit implemented within the context of the CLM software synthesis and signal processing package. Complete details can be found at <http://www-ccrma.stanford.edu/~nando/clm/dlocsig/>.

dlocsig.lisp is a unit generator that dynamically moves a sound source in 2d or 3d space and can be used as a replacement for the standard *locsig* in new or existing CLM instruments (this is a completely rewritten and much improved version of the old *dlocsig* that I started writing in 1992 while I was working at Keio University in Japan).

The new *dlocsig* can generate spatial positioning cues for any number of speakers which can be arbitrarily arranged in 2d or 3d space. The number of output channels of the current output stream (usually defined by the `:channels` keyword in the enclosing `with-sound`) will determine which speaker arrangement is used. In pieces which can be recompiled from scratch this feature allows the composer to easily create several renditions of the same piece, each one optimized for a particular number, spatial configuration of speakers and rendering technique.

dlocsig can render the output soundfile with different techniques. The default is to use amplitude panning between adjacent speakers (between two speakers in 2d space or three speaker groups in 3d space). dlocsig can also create an Ambisonics encoded four channel output soundfile suitable for feeding into an appropriate decoder for multiple speaker reproduction. Or it can decode the Ambisonics encoded information to an arbitrary number of output channels if the speaker configuration is known in advance. In the near future dlocsig will also be able to render to stereo soundfiles with hrtf generated cues for heaphone or speaker listening environments. In all cases doppler shift is also generated as well as amplitude scaling due to distance with user-defined exponents and ratio of direct to reverberated sound.

The movement of sound sources is described through paths. These are CLOS (Common Lisp Object System) objects that hold the information needed by dlocsig to move the source in space and are independent of the unit generator itself. Paths can be reused across many calls to dlocsig and can be translated, scaled and rotated in space as needed. There are several ways to describe a path in space. Bezier paths are described by a set of discrete points in 2d or 3d space that are latter joined by smoothly curved bezier segments. This description is very compact and easy to specify as a few points can describe a complex trajectory in 3d space. Paths can also be specified in geometric terms and one such implementation (spirals) is currently provided.

The dlocsig unit generator uses the same interface as all other CLM unit generators. make-dlocsig creates a structure for a given path and returns (as multiple values) the structure and the beginning and ending samples of the note. dlocsig is the macro that gets compiled inside the run loop and localizes the samples in space.

6.1.3 Planet CCRMA at Home

Fernando Lopez-Lezcano

Planet CCRMA at Home is an ever-growing rpm package collection that includes almost all the extra software that is installed at CCRMA on top of a normal RedHat Linux operating system install. RPM, or RedHat Package Manager, is a set of programs that make it easy to install, remove, and update software packages in an rpm-based linux system (rpm is used by RedHat, Mandrake and SuSE amongst others). The latest version is managed through apt for rpm, a tool for dependency control that enables easy installation of packages, with automatic dependency tracking and retrieval from a network accessible repository. Packages include a recent linux kernel with low latency patches installed, a current version of the ALSA sound driver packages, a wealth of music, sound, midi and office applications and various updates and additions to some packages that are part of the standard RedHat install.

The goal of *Planet CCRMA at Home* is to provide an easy way to “upgrade” a RedHat install to include most (if not all) of the custom software that makes up the Linux based sound and music computing environment at CCRMA.

For more information, see <http://www-ccrma.stanford.edu/planetccrma/software/>.

6.1.4 Planet CCRMA

Juan Reyes and Fernando Lopez-Lezcano

Planet CCRMA is an HTML document for the purpose of illustrating and informing new CCRMA users and visitors about the computer resources, the Linux environment, and applications which might be helpful for doing research and compositional work at CCRMA. It also briefly describes the meaning of “open source” as a part of a laboratory and community philosophy at CCRMA. It is also a brief history of hardware at CCRMA and descriptions of Linux as an operating system, the Unix environment, useful shell commands and many X windows applications in addition to Gnome and KDE desktops. In the applications section there are descriptions of programs and information provided by the developers’ documentation and direct links to the application web page. *Planet CCRMA* focus is as the first stepping stone for a particular command, program or application but nevertheless the reader is encouraged to

find more in-depth information on the Unix manual pages, on the web or in the links to home pages which will be also provided. During the 2001 autumn quarter at Stanford the web page was visited by more than 80% of new and old users of the CCRMA network and community. *Planet CCRMA* is also updated on a regular basis as per users suggestions and because of new software, upgrades, or updates to the system.

6.1.5 Additive Synthesis by Subtractive Resonant Filters

Juan Reyes

Resonant filters can be fine tuned to a very narrow frequency band thereby isolating a tone even from a non-pitched sound source. "Maxf.ins" is Max Mathews' new filter (2002) described as a high-Q, 2-integrator filter with two poles, and one zero at the origin. This Common Lisp Music (CLM) implementation renders equal tempered frequencies, integer and just scales out of a wide-band input signal. The filter might be used for Modal Synthesis but also might be Additive Synthesis in which a resonator is initialized to generate the exponentially decaying sinusoids at the desired phase. Different filters which are bound in parallel are defined in a structure which contains various frequencies and tunings for resonant modes. In this algorithm the filter is recurrent over the source signal by iterating the number of desired frequencies in a state. States can be defined as containing at least one frequency and can go up to the CPU processing power.

6.1.6 Strad.ins: A Bowed String Implementation in CLM

Juan Reyes

"Strad.ins" is a Common Lisp Music (CLM) instrument implementation of the bowed string physical model with stiffness based on previous research by Serafin, Smith, Woodhouse, and others. It is specially suited for algorithmic composition and expression modeling of stringed instrument gestures because of its modular qualities inside the Lisp environment.

The instrument features non-real time rendering of bowed string sounds with variables such as string stiffness, bow force and friction interaction between the bow and the string. It also accounts for the effect of torsional waves on the bridge side and on the finger side and dispersion simulation plus Helmholtz motion. The algorithm is based on recent research done by Serafin, et al. using Matlab, Pd and STK implementations. The instrument is optimized for frequencies or rather tones inside a 100Hz and 600Hz range and are function of the ratio of its parameters. Its design allows for timed envelope style manipulation of most of CLM instrument parameters.

Strad.ins is part of the CLM-2 distribution at the CCRMA software ftp site.

Reference:

- Serafin, S. J.O. Smith, and J. Woodhouse, *An Investigation of the Impact of Torsion Waves and Friction Characteristics on the Playability of Virtual Bowed Strings*, Proc. 1999 IEEE Workshop on Applications of Signal Processing to Audio and Acoustics, New Paltz, New York, USA, 1999.

6.1.7 The Synthesis ToolKit in C++ (STK)

Perry R. Cook and Gary P. Scavone

The Synthesis ToolKit in C++ (STK) is a set of open source audio signal processing and algorithmic synthesis classes written in C++. STK was designed to facilitate rapid development of music synthesis and audio processing software, with an emphasis on cross-platform functionality, realtime control, ease of use, and educational example code. The Synthesis ToolKit is extremely portable (it's mostly platform-independent C and C++ code), and it's completely user-extensible (all source included, no unusual

libraries, and no hidden drivers). We like to think that this increases the chances that our programs will still work in another 5-10 years. In fact, the ToolKit has been working continuously for nearly 8 years now. STK currently runs with "realtime" support (audio and MIDI) on SGI (Irix), Linux, Macintosh OS X, and Windows computer platforms. Generic, non-realtime support has been tested under NeXTStep, Sun, and other platforms and should work with any standard C++ compiler.

The Synthesis ToolKit is free for non-commercial use. The only parts of the Synthesis ToolKit that are platform-dependent concern real-time audio and MIDI input and output, and that is taken care of with a few special classes. The interface for MIDI input and the simple Tcl/Tk graphical user interfaces (GUIs) provided is the same, so it's easy to experiment in real time using either the GUIs or MIDI. The Synthesis ToolKit can generate simultaneous SND (AU), WAV, AIFF, and MAT-file output soundfile formats (as well as realtime sound output), so you can view your results using one of a large variety of sound/signal analysis tools already available (e.g. Snd, Cool Edit, Matlab).

The Synthesis Toolkit is not one particular program. Rather, it is a set of C++ classes that you can use to create your own programs. A few example applications are provided to demonstrate some of the ways to use the classes. If you have specific needs, you will probably have to either modify the example programs or write a new program altogether. Further, the example programs don't have a fancy GUI wrapper. If you feel the need to have a "drag and drop" graphical patching GUI, you probably don't want to use the ToolKit. Spending hundreds of hours making platform-dependent graphics code would go against one of the fundamental design goals of the ToolKit - platform independence.

For those instances where a simple GUI with sliders and buttons is helpful, we use Tcl/Tk (which is freely distributed for all the supported ToolKit platforms). A number of Tcl/Tk GUI scripts are distributed with the ToolKit release. For control, the Synthesis Toolkit uses raw MIDI (on supported platforms), and SKINI (Synthesis ToolKit Instrument Network Interface, a MIDI-like text message synthesis control format).

Perry Cook began developing a pre-cursor to the Synthesis ToolKit (also called STK) under NeXTStep at the Center for Computer Research in Music and Acoustics (CCRMA) at Stanford University in the early-1990s. With his move to Princeton University in 1996, he ported everything to C++ on SGI hardware, added real-time capabilities, and greatly expanded the synthesis techniques available. With the help of Bill Putnam, Perry also made a port of STK to Windows95. Gary Scavone began using STK extensively in the summer of 1997 and completed a full port of STK to Linux early in 1998. He finished the fully compatible Windows port (using Direct Sound API) in June 1998. Numerous improvements and extensions have been made since then.

For more information about STK, see <http://www-ccrma.stanford.edu/software/stk/>.

References:

- Cook, P.R. and Scavone, G.P. *The Synthesis ToolKit (STK) in C++*, in Audio Anecdotes: A Cookbook of Audio Algorithms and Techniques, edited by Ken Greenbaum, A.K. Peters, 2003.
- Cook, P.R. and Scavone, G.P. *The Synthesis ToolKit (STK)*, Proceedings of the 1999 International Computer Music Conference, Beijing, China, 1999.
- Cook, P. R. *Synthesis ToolKit in C++, Version 1.0*, In SIGGRAPH 1996, Course #17 and 18, Creating and Manipulating Sound to Enhance Computer Graphics, May 1996.

6.1.8 RtAudio: A Cross-Platform C++ Class for Realtime Audio Input/Output

Gary P. Scavone

RtAudio is a C++ class which provides a common API (Application Programming Interface) for real-time audio input/output across Linux (native ALSA and OSS), Macintosh OS X, SGI, and Windows (DirectSound and ASIO) operating systems. *RtAudio* significantly simplifies the process of interacting with computer audio hardware. It was designed with the following goals:

- object oriented C++ design
- simple, common API across all supported platforms
- single independent header and source file for easy inclusion in programming projects
- blocking functionality
- callback functionality
- extensive audio device parameter control
- audio device capability probing
- automatic internal conversion for data format, channel number compensation, de-interleaving, and byte-swapping
- control over multiple audio streams and devices with a single instance

RtAudio incorporates the concept of audio streams, which represent audio output (playback) and/or input (recording). Available audio devices and their capabilities can be enumerated and then specified when opening a stream. When allowed by the underlying audio API, multiple streams can run at the same time and a single device can serve multiple streams.

The *RtAudio* API provides both blocking (synchronous) and callback (asynchronous) functionality. Callbacks are typically used in conjunction with graphical user interfaces (GUI). Blocking functionality is often necessary for explicit control of multiple input/output stream synchronization or when audio must be synchronized with other system events.

Reference:

- Scavone, G. P. (2002) *RtAudio: A Cross-Platform C++ Class for Realtime Audio Input/Output*, Proceedings of the 2002 International Computer Music Conference, Göteborg, Sweden.

6.1.9 Common Lisp Music, Snd and Common Music Notation

William Schottstaedt

Common Lisp Music (CLM) is a sound synthesis package in the Music V family written primarily in Common Lisp. The instrument design language is a subset of Lisp, extended with a large number of generators: *oscil*, *env*, *table-lookup*, and so on. The run-time portion of an instrument can be compiled into C or Lisp code. Since CLM instruments are lisp functions, a CLM note list is just a lisp expression that happens to call those functions. Recent additions to CLM include support for real-time interactions and integration with the Snd sound editor.

Snd is a sound editor modeled loosely after Emacs and an old, sorely-missed PDP-10 editor named Dpysnd. It can accommodate any number of sounds, each with any number of channels. Each channel is normally displayed in its own window, with its own cursor, edit history, and marks; each sound has a control panel to try out various changes quickly; there is an overall stack of 'regions' that can be browsed and edited; channels and sounds can be grouped together during editing; and edits can be undone and redone without restriction.

Common Music Notation (CMN) is a music notation package written in Common Lisp; it provides its own music symbol font.

CLM, CMN, and Snd are available free, via anonymous ftp at <ftp://ftp-ccrma.stanford.edu> as [pub/Lisp/clm-2.tar.gz](ftp://pub/Lisp/clm-2.tar.gz), [pub/Lisp/cmn.tar.gz](ftp://pub/Lisp/cmn.tar.gz), and [pub/Lisp/snd-5.tar.gz](ftp://pub/Lisp/snd-5.tar.gz).

6.1.10 Common Music

Heinrich Taube

Common Music (CM) is an object-oriented music composition environment. It produces sound by transforming a high-level representation of musical structure into a variety of control protocols for sound synthesis and display: MIDI, Csound, Common Lisp Music, Music Kit, C Mix, C Music, M4C, RT, Mix and Common Music Notation. Common Music defines an extensive library of compositional tools and provides a public interface through which the composer may easily modify and extend the system. All ports of Common Music provide a text-based music composition editor called Stella. A graphical interface called Capella currently runs only on the Macintosh. See <http://www-ccrma.stanford.edu/software/cm/cm.html> for more information.

Common Music began in 1989 as a response to the proliferation of different audio hardware, software and computers that resulted from the introduction of low cost processors. As choices increased it became clear that composers would be well served by a system that defined a portable, powerful and consistent interface to the myriad sound rendering possibilities. Work on Common Music began in 1989 when the author was a guest composer at CCRMA, Stanford University. Most of the system as it exists today was implemented at the Institut fr Musik und Akustik at the Zentrum fr Kunst und Medientechnologie in Karlsruhe, Germany, where the author worked for five years. Common Music continues to evolve today at the University of Illinois at Urbana-Champaign, where the author is now a professor of music composition. In 1996 Common Music received First Prize in the computer-assisted composition category at the 1er Concours International de Logiciels Musicaux in Bourges, France.

Common Music is implemented in Common Lisp and CLOS and runs on a variety of computers, including NeXT, Macintosh, SGI, SUN, and i386. Source code and binary images are freely available at several internet sites. In order to compile the source code you need Common Lisp. The best implementations are commercial products but there are also several good public domain implementations available on the Internet.

To receive email information about software releases or to track developments in CCRMA's family of Lisp music programs: CM, CLM and CMN please join cmdist@ccrma.stanford.edu by sending your request to cmdist-request@ccrma.stanford.edu.

6.2 Physical Modeling

6.2.1 From Physics of Piano Strings to Digital Waveguide

Julien Bensa, Stefan Bilbao, Richard Kronland-Martinet, and Julius Smith

Several models of transverse wave propagation on a piano string, of varying degrees of complexity, have appeared in the literature. These models are always framed in terms of a partial differential equation (PDE), or system of PDEs; usually, the crude starting point for such a model is the one-dimensional wave equation, and the more realistic features, such as dispersion, frequency-dependent loss and nonlinear hammer excitation, are incorporated through several perturbation terms. Chaigne and Askenfelt have proposed the most advanced such model, and used it as the basis for a sound synthesis technique, through the use of finite differences—the time waveform on a struck piano string is simulated in this way to a remarkable degree of fidelity.

Digital waveguides, on the other hand, are filter-like structures which model one-dimensional wave propagation as purely lossless throughout the length of the string, with loss and dispersion summarized in terminating lumped filters. They are thus simulations of slightly modified physical systems, but are highly efficient structures in the context of musical sound synthesis. The aim of this paper is to bridge the gap between PDE models and digital waveguides, and to explicitly show the relationship between the lumped filters used to model loss and dispersion and the parameters which define the model PDE, which,

in this case, is a carefully chosen variant of Chaigne and Askenfelt's model system. The calibration of the filters to experimentally measured data is also discussed.

References:

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- Bilbao, S. (2001) *Wave and Scattering Methods for the Numerical Integration of Partial Differential Equations*, Ph.D. thesis, Electrical Engineering Department, Stanford University (CCRMA), June 2001. Available online at <http://www-ccrma.stanford.edu/~bilbao/>.
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- J. O. Smith, *Digital Waveguide Modeling of Musical Instruments*, <http://www-ccrma.stanford.edu/~jos/wg.html>.

6.2.2 Ongoing Research in Flute Acoustics

Patricio de la Cuadra

This research is currently being conducted at the Laboratoire d'Acoustique Musicale in Paris, France. The work focuses on the following three tasks:

1. Moving from a simple recorder into a flute model:

- Schlieren visualization of jet and image processing analysis to include its results in the model.
- Include in the current model the two operational regimes of the jet (laminar and turbulent) observed in the flute. And make dynamic calculation of filter coefficients involved.
- Include the geometry of the mouthpiece.
- Include toneholes.

2. Human control signal:

- In order to compliment our study we want to elaborate on a description of the way a flutist would excite the instrument. For that we plan to measure relevant variables for a vast set of musical events found in the flute repertoire, such as articulations, use of vibrato, dynamics and extended techniques including flutter-tonguing, whistle tones and aeolian sounds. Interesting visualizations based on the Schlieren technique will complement our description.
- Measuring the flow through a pressure signal using a Venturi pipe and the same pressure sensors. The idea here is to capture the musical gesture of blowing, learned by performers after years of training, and use it to control any other virtual instrument.

3. Inverting the model:

Given a particular "real" sound try to find the parameters of the model that would create the "closest" possible synthetic sound. This has been done by creating a database with sounds made by combinations of the parameters of the model in reasonable ranges. Then calculate physical quantities from the signals (like centroids, attack time etc) and map them into a three dimensional perceptual space. Do the same with the desire "real" sound and find the synthetic sound that produces the small vectorial distance in the perceptual space.

6.2.3 Acoustic Research and Synthesis Models of Woodwind Instruments

Gary P. Scavone

The modeling of musical instruments using digital waveguide methods has proven to be both an accurate and efficient technique for synthesis. Because such models are based on physical descriptions, they further provide a useful tool for acoustical explorations and research.

Current efforts are directed toward the modeling of vocal tract influence in wind instruments [Scavone, 2003] and the reed mechanism of single-reed woodwind instruments.

development of simplified models of conical woodwind instruments and their excitation mechanisms [Scavone, 2002]. This work is being performed in conjunction with the *Categorical Perception of Sound Sources* project, which is described in the *Psychoacoustics and Cognitive Psychology* research section of this document.

Models of wind instrument air columns have reached a high level of development. An accurate and efficient means for modeling woodwind toneholes was described in [Scavone and Cook, 1998]. Another model of the tonehole was developed with Maarten van Walstijn [van Walstijn and Scavone, 2000]. It uses wave digital filter techniques to avoid a delay-free path in the model, thus allowing shorter tonehole heights than is possible with the distributed model of [Scavone and Cook, 1998]. Recently, a study comparing tonehole radiation measurements to digital waveguide and frequency-domain model results was conducted [Scavone and Karjalainen, 2002].

Previous work focused on modeling the direction-dependent sound radiation from woodwind and brass instruments [Scavone, 1999]. The current acoustic theory regarding sound radiation from ducts and holes can be implemented in the digital waveguide context using properly designed digital filters. Each radiating sound source or hole requires a first- or second-order digital filter to account for angular- and frequency-dependent pressure distribution characteristics. Sound propagation delay from the source to the pickup is modeled with a delay line and possibly a fractional-delay interpolation filter. An additional digital filter to model attenuation in free space can also be used. The results of this model compare well with frequency-domain polar radiation calculations and measurements performed by Antoine Rousseau and René Caussé (1996) at the Institut de Recherche et Coordination Acoustique/Musique (IRCAM). A simplified system appropriate for real-time synthesis was developed using The Synthesis ToolKit (STK) that allows continuous pickup movement within an anechoic 3D space.

References:

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6.2.4 The Sound of Friction

Stefania Serafin

This research investigates the use of different friction models with applications to real-time sound synthesis of musical instruments and sound effects in general. In collaboration with Federico Avanzini and Davide Rocchesso, the latest state-of-the art friction models used in robotics and haptics, such as the elasto-plastic model, have been implemented in real-time and connected to audio simulations of different rubbed surfaces such as squeaking doors and rubbed wineglasses.

The behavior of the different friction models has been investigated both in terms of sound quality and in terms of playability studies. In particular, the elasto-plastic model has been compared to the plastic model developed by Jim Woodhouse for bowed strings' simulations. The more general elasto-plastic model behaves like the plastic model when applied to the simulation of a bow excited by a string.

Reference:

- F. Avanzini, S. Serafin, and D. Rocchesso, (2002) *Modeling Interactions Between Rubbed Dry Surfaces Using an Elasto-Plastic Friction Model*, in Proc. COST-G6 Conf. Digital Audio Effects (DAFx-02), Hamburg, 2002, pp.111-116.

6.2.5 Digital Waveguide Modeling of Acoustic Systems

Julius Smith

Digital Waveguide Filters (DWF) have proven useful for building computational models of acoustic systems which are both physically meaningful and efficient for applications such as digital synthesis. The physical interpretation opens the way to capturing valued aspects of real instruments which have been difficult to obtain by more abstract synthesis techniques. Waveguide filters were initially derived to construct digital reverberators out of energy-preserving building blocks, but any linear acoustic system can be approximated using waveguide networks. For example, the bore of a wind instrument can be modeled very inexpensively as a digital waveguide. Similarly, a violin string can be modeled as a digital waveguide with a nonlinear coupling to the bow. When the computational form is physically meaningful, it is often obvious how to introduce nonlinearities correctly, thus leading to realistic behaviors far beyond the reach of purely analytical methods.

In this context, a *waveguide* can be defined as any medium in which wave motion can be characterized by the one-dimensional wave equation. In the lossless case, all solutions can be expressed in terms of left-going and right-going *traveling waves* in the medium. The traveling waves propagate unchanged as long as the wave impedance of the medium is constant. At changes in the wave impedance, a traveling wave partially transmits and partially reflects in an energy conserving manner, a process known as "scattering." The wave impedance is the square root of the "massiness" times the "stiffness" of the medium; that is, it is the geometric mean of the two sources of resistance to motion: the inertial resistance of the medium due to its mass, and the spring-force on the displaced medium due to its elasticity.

Digital waveguide filters are obtained (conceptually) by *sampling* the unidirectional traveling waves which occur in a system of ideal, lossless waveguides. Sampling is across time and space. Thus, variables in a DWF structure are equal exactly (at the sampling times and positions, to within numerical precision) to variables propagating in the corresponding physical system. Signal power is defined instantaneously with respect to time and space (just square and sum the wave variables.) This instantaneous handle on signal power yields a simple picture of the effects of round-off error on the growth or decay of the signal energy within the DWF system, as well as other nonlinearities. Because waveguide filters can be specialized to well studied lattice/ladder digital filters, it is straightforward to realize any digital filter transfer function as a DWF. Waveguide filters are also related to "wave digital filters" (WDF) which have been developed primarily by Fettweis. Using a "mesh" of one-dimensional waveguides, modeling can be carried out in two and higher dimensions. In other applications, the propagation in the waveguide is extended to include frequency dependent losses and dispersion. In still more advanced applications, nonlinear effects are introduced as a function of instantaneous signal level.

Digital waveguide filters can be viewed as an efficient discrete-time "building material" for acoustic models incorporating aspects of one-dimensional waveguide acoustics, lattice and ladder digital filters, wave digital filters, and classical network theory.

References:

- J. O. Smith, *Digital Waveguide Modeling of Musical Instruments*, <http://www-ccrma.stanford.edu/~jos/waveguide/>.
- J. O. Smith, "Physical Modeling Synthesis Update", *Computer Music Journal*, vol. 20, no. 2, pp. 44–56, Summer, 1996. Available online at <http://www-ccrma.stanford.edu/~jos/pmupd/>.
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- Berners, D. P., *Acoustics and Signal Processing Techniques for Physical Modeling of Brass Instruments*, Ph.D. thesis, Electrical Engineering Department, Stanford University (CCRMA), June 1999. Available online at <http://www-ccrma.stanford.edu/~dpberner/>.
- Music 421 (EE 367B) Lecture Overheads: <http://www-ccrma.stanford.edu/CCRMA/Courses/421/>
- J. O. Smith, *Introduction to Digital Filters*, <http://www-ccrma.stanford.edu/~jos/filters/>.

6.2.6 Applications of Bioacoustics to the Creation of New Musical Instruments

Tamara Smyth

Animal sound production mechanisms are remarkably similar to those of many musical instruments. Though vibrating membranes, plates and shells, and acoustic tubes and cavities, are important components of any acoustic system, in musical and bioacoustic systems these components enable the production of sound that is undeniably captivating to human listeners.

There are, however, intriguing and potentially musical sounds produced by bioacoustic mechanisms that do not exist in traditional musical instruments. This research concentrates on these particular bioacoustic systems, and through the development of mechanical and computational models, aims to determine whether any aspect of the system is suitable for musical instrument design (either in sound production, acoustic output, or user control).

There are two aspects of instrument design that are being addressed: sound production, which involves the use of physical modeling techniques to develop quality sound synthesis models of animal sound

production mechanisms, and sound control, building haptic human interfaces to the computer synthesized instrument, based on these same mechanisms.

A mechanical model of the cicada's unique and efficient sound excitation mechanism was built to determine whether or not such a mechanism could also be used by a human (who has more limited muscular control). In addition to providing an accurate input signal (one that represents the buckling ribs of the cicada) to the physical model, it serves as a mechanical haptic interface, facilitating the user's ability to control the instrument's sound. The mechanical controller is being used for both scientific understanding of the cicada's buckling mechanism and for musical experimentation.

Another bioacoustic system currently being researched is the bird's syrinx. This system is of particular interest because, in addition to being a musical inspiration to many composers, it has a unique structure that allows for rapid shifts from low to high registers in the bird's, often virtuosic, song.

Far too often, parameter-rich physical models are developed with no means of controlling them. Likewise, musical controllers are often built with nothing to control. In both cases, the music is lost. This research intends to bridge the separation between the development of parametric sounds and the development of the devices used for controlling them, while offering new and intriguing musical instruments to contemporary musicians.

Reference:

- Smyth, T. and Smith, J. O. (2002) *Creating Sustained Tones with the Cicada's Rapid Sequential Buckling Mechanism*. Proceedings of the 2002 Conference on New Instruments for Musical Expression (NIME-02), Dublin, Ireland, May 2002.

6.3 Digital Signal Processing

6.3.1 Distributed Internet Reverberation for Audio Collaboration

Chris Chafe

Low-latency, high-quality audio transmission over next-generation Internet is a reality. Bidirectional, multichannel flows over continental distances have been demonstrated in musical jam sessions and other experimental situations. The dominating factor in delay is no longer system issues, but the transmission time bounded by lightspeed. This paper addresses a method for creating shared acoustical spaces by "echo construction." Where delays in bidirectional paths are sufficiently short and "room-sized," they can be used to advantage as components in synthetic, composite reverberation.

The project involves setting up two collaborating audio hosts (e.g., Seattle and San Francisco locations) separated by short internet delay times (e.g., in this example $RTT = 20ms$). Monitoring on both ends includes a composite reverberation in which the round-trip delay is used to construct multipath echoes, corresponding to multiple "rays" in a composite room.

The first implementation involves two identical rooms with identical monitoring (microphone and speaker locations). For simplicity, the rooms can be thought of as small, 10ft on a side. Using the technique described, a composite room is heard which incorporates the 10ms network delay in a synthetic reverberation circuit running in software as part of the audio transmission system. The added 10ms roughly corresponds to an additional 10ft inserted between the monitoring locations. The listener's have the impression of communicating with each other in the same 30ft room.

A recent paper describes the audio transmission techniques, multichannel monitoring and reverberation circuit and initial subjective evaluation of this "echo construction" method.

References:

- Chafe, C. (2002) *Oxygen Flute, A Computer Music Instrument that Grows*. Proceedings of the 2002 Keihanna Multimedia Festival, Kyoto, Japan.
- Chafe, C. (2003) *Distributed Internet Reverberation for Audio Collaboration*. Proceedings of the 24th Audio Engineering Society, Banff, Canada.

6.3.2 Watermarking Parametric Representations for Synthetic Audio

Yi-Wen Liu and Julius Smith

Synthesized multimedia objects are emerging everywhere now. One can talk on the phone to a virtual representative that speaks a synthesized tongue, drink soda of synthesized taste, such as Coke, or even fall in love with Simone, a synthesized character. It becomes urgent to protect such objects as intellectual properties, for the synthesis of them often involves a lot of computational power and human labor.

In this research, we propose to watermark parametric representations for synthetic audio. Our watermark system combines quantization index modulation at the encoder and maximum likelihood parameter estimation at the decoder. To guarantee error-free data hiding under expected types of attacks, knowledge of Fisher information and Cramer-Rao bounds is applied to the system design. Experiments show that, merely by quantizing the frequency of sinusoidal tones, one can achieve 50b/s of data hiding that is robust to perceptually shaped additive attacks such as an MP3 compression.

We would like to apply this method to more complex synthesis models in the near future, as well as to explore hierarchical embedding of multiple watermarks using the current method for low-rate, robust, watermarking and superposing a spread spectrum pseudorandom code as a fragile watermark.

Reference:

- Liu, Y. and Smith, J.O. (2003) *Watermarking parametric representations for synthetic audio*, Proceedings of the 2003 IEEE International Conference on Acoustics, Speech, and Signal Processing, Hong Kong. Available online at <http://www-ccrma.stanford.edu/~jacobliu/DWM/>.

6.3.3 Virtual Analog Synthesis with the Comb Filter

David Lowenfels

The bandlimited digital synthesis model of Stilson and Smith is extended with a single feed-forward comb filter. Comb filter techniques are shown to produce a variety of classic analog waveform effects, including waveform morphing, pulse-width modulation, harmonization, frequency modulation, and hard-sync. Unlike previous techniques for hard-sync, the computational load of this method does not increase with frequency. The techniques discussed do not guarantee perfect bandlimiting; however, they are generally applicable to any waveform synthesis method.

6.3.4 Sound Source Separation of N Sources from Stereo Signals via Fitting to N Models Each Lacking One Source

Aaron Master

We present a system to perform sound source separation of an arbitrary number of speech or music sources from a stereo signal. We build on the work of other authors' DUET system, which uses a histogram technique to estimate the mixing parameters of the time-frequency sparse sources, before using a nearest-neighbor approach to demix the sources. Herein, we describe a new demixing method called Delay and Scale Subtraction Scoring (DASSS) that is less erratic than the nearest-neighbor method, and highlights when the sparsity assumptions of the DUET system are not valid. We also utilize a demixing technique to be used in cases where multiple sources are present, and propose an additional source-aware demixing technique for such cases. We demonstrate psychoacoustically convincing results on an example signal.

Reference:

- Aaron Master, *Sound Source Separation of N Sources from Stereo Signals via Fitting to N Models Each Lacking One Source*. EE 391 Technical Report, March 2003, Stanford University.

6.3.5 Nonstationary Sinusoidal Modeling

Aaron Master and Yi-Wen Liu

The sinusoidal model has been a fundamentally important signal representation for coding and analysis of audio. We present an enhancement to sinusoidal modeling in the form of a linear frequency chirp parameter estimator applicable to Hann-windowed quasi-sinusoidal signals. The estimator relies on models of the phase curvature and peak width of a given chirp signal's FFT magnitude domain peak. We show that different models are applicable for smaller and larger values of the chirp parameter, derived respectively from Taylor series and Fresnel integral analysis of the signal. We construct an estimator for the transition region between the two models via a neural net. Results indicate that the estimator is robust to noise and outperforms any known chirp parameter estimators for Hann windowed signals.

References:

- Aaron S. Master and Yi-Wen Liu, (2003) *Robust Chirp Parameter Estimation for Hann Windowed Signals*, Proceedings of the 2003 IEEE International Conference on Multimedia and Exposition (ICME), Baltimore Maryland.
- Aaron S. Master and Yi-Wen Liu, (2003) *Nonstationary Sinusoidal Modeling with Efficient Estimation of Linear Frequency Chirp Parameters*, Proceedings of the 2003 IEEE International Conference on Acoustics, Speech, and Signal Processing, Hong Kong.
- Aaron Master, (2002) *Nonstationary Sinusoidal Modeling*. Proceedings of the 2002 IEEE International Conference on Acoustics, Speech, and Signal Processing, Orlando, FL.

6.3.6 Doppler Simulation and the Leslie

Julius Smith, Jonathan Abel, Stefania Serafin, and Dave Berners

The Doppler effect causes the pitch of a sound source to appear to rise or fall due to motion of the source and/or listener relative to each other. The Doppler effect has been used to enhance the realism of simulated moving sound sources for compositional purposes, and it is an important component of the "Leslie effect." The Leslie is a popular audio processor used with electronic organs and other instruments. It employs a rotating horn and rotating speaker port to "choralize" the sound. Since the horn rotates within a cabinet, the listener hears multiple reflections at different Doppler shifts, giving a kind of chorus effect. Additionally, the Leslie amplifier distorts at high volumes, producing a pleasing "growl" highly prized by keyboard players.

In this research, an efficient algorithm for simulating the Doppler effect using interpolating and de-interpolating delay lines was developed. The Doppler simulator is used to simulate a rotating horn to achieve the Leslie effect. Measurements of a horn from a real Leslie were used to calibrate angle-dependent digital filters which simulate the changing, angle-dependent, frequency response of the rotating horn.

Reference:

- Julius O. Smith, Jonathan Abel, Stefania Serafin, and David Berners, *Doppler Simulation and the Leslie*, in Proceedings of the International Conference on Digital Audio Effects (DAFx-02), Hamburg, Germany, September 26 2002, pp. 13-20.

6.3.7 FFT-Based DSP and Spectral Modeling Synthesis

Julius Smith

The Fast Fourier Transform (FFT) revolutionized signal processing practice in the 1960s. Today, it continues to spread as a practical basis for digital systems implementation. Only in the past decade or so has it become cost-effective to use the short-time FFT in real-time digital audio systems, thanks to the availability of sufficiently powerful, low-cost, single-chip solutions.

In the digital audio field, FFT-based techniques are useful in digital mixing consoles, post-production editing facilities, and top-quality digital audio gear. Many music and digital audio “effects” can be conveniently implemented in a unified way using a short-time Fourier analysis, modification, and resynthesis facility.

In the music synthesis field, obtaining better control of sampling synthesis requires more general sound transformations. To proceed toward this goal, transformations must be understood in terms of what we hear. The best way we know to understand a sonic transformation is to study its effect on the short-time spectrum, where the spectrum-analysis parameters are tuned to match the characteristics of hearing as closely as possible. Thus, it appears inevitable that sampling synthesis will migrate toward *spectral modeling*.

In contrast with physical modeling synthesis, which models the *source* of a sound, spectral modeling techniques model sound at the *receiver*, the human ear. Spectral modeling is more immediately general than physical modeling since it is capable of constructing an arbitrary stimulus along the basilar membrane of the ear. While complex coarticulation effects are more naturally provided by physical models, the short-time Fourier transform can be applied to any sound demonstrating any desired effect to determine what must happen in a spectral sequence to produce that effect.

FFT-based techniques play an important role in (1) the practical implementation of general signal processing systems (fast convolution), (2) advanced effects such as “cross synthesis,” time compression/expansion, duration-invariant frequency shifting, and other “phase vocoder” type techniques, (3) noise reduction, and (4) novel synthesis systems based on the direct creation and transformation of spectral events and envelopes.

References:

- Levine, S., *Audio Representations for Data Compression and Compressed Domain Processing*, Ph.D. thesis, Electrical Engineering Department, Stanford University (CCRMA), December 1998. Available online at <http://www-ccrma.stanford.edu/~scottl/thesis.html>.
- Serra, X., and J. O. Smith, “Spectral Modeling Synthesis: A Sound Analysis/Synthesis System Based on a Deterministic plus Stochastic Decomposition,” *Computer Music J.*, vol. 14, no. 4, pp. 12–24, Win., 1990. The latest free Spectral Modeling Synthesis (SMS) software can be obtained from the SMS home page at <http://www.iua.upf.es/~sms>.
- Smith, J. O., “Music 420 (EE 367A) Bibliography: Audio Spectral Modeling,” <http://www-ccrma.stanford.edu/CCRMA/Courses/420/References.html>.
- Smith, J. O., *Mathematics of the Discrete Fourier Transform*, <http://www-ccrma.stanford.edu/~jos/mdft/>.

6.3.8 Transient Detection and Modeling

Harvey Thornburg

Transient events are regions not “well-modeled” by a locally stationary sinusoidal model. Examples include abrupt changes or fast decays/modulations in mode amplitudes/frequencies. Transient regions usually follow onsets, which are preceded by an abrupt change. This suggests a twofold approach for transient detection:

- *Segmentation*: Find boundaries of abrupt change in the underlying signal model (e.g. sinusoidal, Gaussian AR, or some physically-informed model)
- *Transient Characterization*: Classify each region depending on some predetermined cost criteria (e.g. expected bitrate).

Segmentation – Bayesian Approach:

- The classical approach concerns a piecewise constant signal model, with statistically independent segments. We have recently adopted a more general, unified Bayesian framework, as follows: Let $\delta_t \in \{0, 1\}$, $\delta_t = 1$ indicate change at time t . Then, the model for the signal y_t is described:

$$\begin{aligned} \theta_{t+1} &= \begin{cases} \theta_t + u_t & \delta_t = 0 \\ v_t \sim p(v_t|\theta_t) & \delta_t = 1 \end{cases} \\ y_t &\sim f(y_t|\theta_t, y_{1:t-1}), t \in \{1 \dots T\} \end{aligned}$$

- This framework allows us to exploit additional prior information and information about musical structure, according to the specifications:
 - *Prior probability of change*: The distribution $p(\delta_{1:T})$ may encode information about the structure of rhythm.
 - *Markov evolution of parameter jumps*: The distribution $\{p(\theta_0); p(v_{1:T}|\theta_{1:T})\}$ may encode information about melodic/timbral evolution.
 - *Allowance for slow parameter variations*: The distribution $p(u_t)$ may be used to allow for slow, continuous variations in the model parameter within a segment, to emphasize the “abruptness” of change.

Applications:

- *Joint Rhythm Tracking and Onset Detection*:
 - A three-layer switching state space model (rhythm tracker) is used to learn the pattern of onsets. The top layer S_t encodes the discrete rhythmic interval and metrical position; middle layer X_t encodes tempo and inherent onset position; bottom layer y_t gives the observed onset position.
 - The rhythm tracker produces the posterior distributions about the next segment points given segments observed so far, e.g. $P(X_{t+k}|y_{1:t}), k \in \{1, 2, \dots\}$. The segmenter uses these distributions as local priors to detect the next batch of segments, which provide subsequent observations for the rhythm tracker. The net effect is improved segmentation performance about musically relevant changes (onsets); spurious changes are ignored or suppressed. The behavior mimics somewhat the cognitive activity of the human listener, though rigorous parallels are not yet established.
- *Harmonic Comb Models for Piano Transcription*: To improve segmentation performance for specific musical signals, we wish to exploit a higher degree of structure than is available from generic (unconstrained) AR or sinusoidal models. Additional structure allows us to support a high model order, or high number of sinusoids modeled, because the model is highly constrained in a probabilistic sense. The additional structure may be motivated by explicit knowledge of the physics of a particular instrument, say, piano.
- *Changeograms*: The changeogram gives a nonparametric view of the posterior probability that an abrupt change occurs at a particular time based only on information in local windows. Uses and properties are as follows:

- The changeogram may be peak-picked/thresholded to yield a “quick and dirty” estimation of change points
- The changeogram itself serves as an “empirical Bayes” prior for further offline Bayesian segmentation. The inherent structural assumption is that changes are infrequent but occur in clumps.
- Changes spaced far enough apart with respect to the window size appear resolved as “peaks” in the representation. The height of the peaks corresponds to the intensity of the change.
- The size of the window limits resolution: When two changes are spaced at less than the window size, the change with less intensity does not survive.
- A kernel may be chosen such that peaks are dilated in the representation. For the “empirical Bayes” approach, the kernel expresses uncertainty that additional change points have been masked by the main peaks.

6.4 Controllers and Musical Instruments

6.4.1 Haptic Interactions for Audio Navigation

Lonny Chu

Recent studies in haptics have shown that force-feedback interfaces can improve user efficiency and accuracy while decreasing the cognitive load required to accomplish computer tasks. One specific musical application that may benefit from these devices is the task of audio navigation as found in digital sound editing software since current users rely heavily on the keyboard and mouse while performing editing tasks.

The TouchSound project consisted of two major phases. The first phase included need-finding and technology exploration. This process provided insights leading to the development of a haptic scrubbing interaction model in which users could feel tactile sensations mapped to audio frequency content while hearing and seeing representations of the original sound.

The second phase involved an experiment to collect user performance data. Users were asked to locate the onset of a tone under conditions in which it was difficult to locate visually. With haptic feedback mapped to the spectral content of the tone, users were able to target the tone 20.8% more quickly and 52.7% more accurately than without haptic feedback. Additionally, each trajectory of movement was recorded and revealed a consistency in user behavior for both the haptic and non-haptic conditions. These findings suggest that the incorporation of haptic devices into sound editing systems may provide significant benefits to the user.

6.4.2 The Accordiatron: A New Gestural MIDI Controller

Michael Gurevich

The Accordiatron is a MIDI controller for interactive performance based on the paradigm of a conventional squeeze box or concertina. It senses and encodes the gestures of a performer using the standard communication protocol of MIDI, allowing for flexible mappings of performance data to sonic parameters. When used in conjunction with a real-time signal processing environment, the Accordiatron can become an expressive, versatile musical instrument. It features a combination of discrete and continuous sensory data, providing the subtle expressiveness and control necessary for interactive music.

6.4.3 The Bento-Box: Ergonomic Design of A Portable Musical Instrument

Motohide Hatanaka

A handheld electronic musical instrument, named the Bento-Box, was developed. The motivation was to develop an instrument which one can easily carry around and play in moments of free time, for example when riding public transportation or during short breaks at work. The device was designed to enable quick learning by having various scales programmed for different styles of music, and also be expressive by having hand controlled timbral effects which can be manipulated while playing. Design analysis and iteration lead to a compact and ergonomic device. This paper focuses on the ergonomic design process of the hardware.

Reference:

- Motohide Hatanaka. (2003) *Ergonomic Design of a Portable Musical Instrument*. Proceedings of the 2003 Conference on New Instruments for Musical Expression (NIME-03), Montreal, Canada, May 2003.

6.4.4 THE PIPE: Explorations with Breath Control

Gary P. Scavone

The Pipe is an experimental, general purpose music input device designed and built in the form of a compact MIDI wind controller. The development of this device was motivated in part by an interest in exploring breath pressure as a control input. *The Pipe* provides a variety of common sensor types, including force sensing resistors (FSRs), momentary switches, accelerometers, potentiometers, and an air pressure transducer, which allow maximum flexibility in the design of a sensor mapping scheme. *The Pipe* uses a programmable BASIC Stamp 2sx microprocessor which outputs control messages via a standard MIDI jack.

Further information is available at: <http://www-ccrma.stanford.edu/~gary/ThePipe.html>.

Reference:

- Gary P. Scavone. (2003) *THE PIPE: Exploration with Breath Control*. Proceedings of the 2003 Conference on New Instruments for Musical Expression (NIME-03), Montreal, Canada, May 2003.

6.4.5 Sound Kitchen: Designing a chemically controlled musical performance

Hiroko Terasawa, Rodrigo Segnini, and Vivian Woo

This paper presents a novel use of a chemical experiments' framework as a control layer and sound source in a concert situation. Signal fluctuations from an electrolytic battery made out of household chemicals, and acoustic samples obtained from an acid/base reaction are used for musical purposes beyond the standard data sonification paradigm. The batteries are controlled in handy ways such a warming, stirring and pouring that are also visually engaging. Audio mappings include synthetic and samples sounds completing a recipe that concocts a live performance of computer music.

Reference:

- Hiroko Terasawa, Rodrigo Segnini, and Vivian Woo. (2003) *Sound Kitchen: Designing a chemically controlled musical performance*. Proceedings of the 2003 Conference on New Instruments for Musical Expression (NIME-03), Montreal, Canada, May 2003.

6.4.6 THE PLANK: simple force-feedback

Bill Verplank, Michael Gurevich, and Max Mathews

Active force-feedback holds the potential for precise and rapid controls. A high performance device has been built from a surplus disk drive and controlled from an inexpensive microcontroller. *The Plank*, has only one axis of force-feedback with limited range of motion. It is being used to explore methods of feeling and directly manipulating sound waves and spectra suitable for live performance of computer music. Last year, we presented it at NIME. This year, John McCarty is looking into using for sound editing.

Reference:

- Bill Verplank, Michael Gurevich, Max Mathews, *THE PLANK: Designing a simple haptic controller*. Proceedings of the Conference on New Instruments for Musical Expression (NIME-02), Dublin, Ireland, May 24-26, 2002.

6.4.7 Designing Controllers: The evolution of our Computer-Human Interaction Technology Course

Bill Verplank

Over the last several years, with support of the CS department, we have developed a series of lectures, labs and project assignments aimed at introducing enough technology so that students from a mix of disciplines can design and build innovative interface devices. We have come to focus less on theory and more on practical skills leading to a four-week project: designing and building a working controller.

Reference:

- Scott Wilson, Michael Gurevich, Bill Verplank, and Pascal Stang. (2003) *A Microcontroller Technology Upgrade at CCRMA*. Proceedings of the 2003 Conference on New Instruments for Musical Expression (NIME-03), Montreal, Canada, May 2003.

6.4.8 The Mutha Rubboard Controller

Carr Wilkerson, Carmen Ng, and Stefania Serafin

The Mutha Rubboard is a musical controller based on the rubboard, washboard or frottoir metaphor commonly used in the Zydeco music genre of South Louisiana. It is not only a metamorphosis of a traditional instrument, but a modern bridge of exploration into a rich musical heritage. It uses capacitive and piezo sensing technology to output MIDI and raw audio data.

This new instrument is meant to be easily played by both experienced players and those new to the rubboard. It lends itself to an expressive freedom by placing the control surface on the chest and allowing the hands to move uninhibited about it or by playing it in the usual way, preserving its musical heritage.

Visit <http://www-ccrma.stanford.edu/~carrlane/mutha/muthahome.html> for more information.

References:

- Wilkerson, C., Ng, C., and Serafin, S. (2002) *The Mutha Rubboard Controller*. Proceedings of the 2002 Conference on New Instruments for Musical Expression (NIME-02), Dublin, Ireland, May 2002.
- Wilkerson, C., Serafin, S., and Ng, C. (2002) *Physical Model Synthesis and Performance Mappings for Bowl Resonators*. Proceedings of the 2002 International Computer Music Conference. Göteborg, Sweden.

6.5 Audification of Data

6.5.1 Acoustic Remapping of Digital Data

Jonathan Berger (PI), Oded Ben Tal, Ryan Cassidy, Chris Chafe, Ronald Coifman (Yale), Mauro Maggioni (Yale), Shihab Shamma (University of Maryland), Julius Smith, Woon Seung Yeo, Fred Warner (Yale), and Steven Zucker (Yale)

The purpose of this project is to develop methodologies for geometric translation of high dimensional digital data into perceptual spaces . In particular we will translate regions in parameter space to sound, such that the auditory perceptual distance between two points would correspond (approximately) to geometric distance in the parameters.

This project involves the mathematical design of appropriate dimensional reduction and filtering algorithms and design of appropriate sound synthesis and processing strategies to effectively elucidate desired sonified features, patterns or attributes in the data.

The proposed research includes three components of sonification research:

- Develop effective sonification methods for data acquired from hyperspectral imaging, and other natural multisensor data sets.
- Use computational models of auditory perception as well as human subject testing to determine effectiveness bandwidth and metric precision of sonification.
- Develop a general purpose sonification toolbox for sonification research and development

This research is funded by DARPA.

6.5.2 SonART - The Sonification Application Research Toolbox

Oded Ben Tal, Jonathan Berger, Bryan Cook, Michelle Daniels, Gary Scavone, and Perry Cook

The Sonification Application and Research Toolbox (SonART) is an open-source effort whose core code is platform-independent. The primary objective of SonART is to provide a set of methods to map data to sonification parameters along with a set of graphical user interface tools that will provide practical and intuitive utilities for experimentation and auditory display. SonART provides publicly available, well-documented code that is easily adapted to address a broad range of sonification needs. The effort builds upon the Synthesis ToolKit in C++ (STK) (Cook and Scavone, 1999), both of whose authors are part of this research effort.

By classifying sonification methods, the SonART provides researchers with the means of exploring parameter mapping with the same high level control afforded by many data visualization packages. Synthesis and sound processing parameters can be classified by general acoustic or musical properties or by synthesis specific parameters.

Parameter mapping using general acoustic properties or synthesis specific parameters is potentially limited by two factors. First, the finite number of parameters used in a given synthesis method limits the dimensionality of the data to be sonified. Second, the mapping of data to a particular parameter may not be intuitive to the data analyst. One approach to address the difficulty of intuiting the meaning of sonified data involves using sounds resembling those in nature. Synthesis techniques that approximate natural sounds, and physical models that simulate material interactions (such as springs and dampers), may prove useful parameter mapping techniques. Instead of mapping a data dimension to an arbitrary synthesis parameter, a mapping that produces intuitive natural sounds such as vowels (Ben Tal, Berger and Daniels, 2001) may be used. Using this approach, vowel quality or the proximity of a sound to a cardinal vowel can provide an intuitive basis for sonification. While natural sounds may provide more

intuitive and more easily interpreted results, they introduce complications in terms of how parameter mapping methods are organized. Physical models can be used in such a way that the data miner interacts with data by excitation of a sound that impinges upon data points.

6.5.3 SoundWIRE: Sound Waves on the Internet from Real-time Echoes

Chris Chafe, Scott Wilson, Randal J. Leistikow, Gary P. Scavone, Daniel Walling, Nathan Schuett, Christopher Jones, and David Chisholm

New, no compromise, computer applications for audio have been demonstrated using a simplified approach for high quality music and sound streaming over IP networks. Audio is an unforgiving test of networking – if one data packet arrives too late we hear it. Traditionally, compromises of signal quality and interactivity have been necessary to avoid this basic fact. Along with our new professional audio applications we have developed SoundWIRE, a utility which affords an intuitive way of evaluating transaction delay and delay constancy. Its final form is an enhanced “ping” that uses actual sound reflection. A musical tone, such as a guitar pluck, can be created by repeatedly reflecting a digital acoustic signal between two hosts. Using the network delay between these reflections to substitute for a guitar string creates a tone whose stability represents perfectly regular service and whose pitch represents transmission latency. The ear’s ability to discern minute differences makes this an unforgiving test of network reliability.

References:

- Chafe, C. and Walling, D. (2002) *Physical Model Synthesis with Application to Internet Acoustics*. Proceedings of ICASSP, Orlando, Florida.
- Chafe, C. and Leistikow, R. (2001) *Levels of Temporal Resolution in Sonification of Network Performance*. Proceedings of the 2001 International Conference On Auditory Display, Helsinki, Finland.
- Chafe, C., Wilson, S., Leistikow, R., Chisholm, D., and Scavone, G. (2000) *A simplified approach to high quality music and sound over IP*. Proceedings of the 2000 International Conference On Digital Audio Effects, Verona, Italy.

6.6 Techniques and Approaches for Computer-Music Composition

6.6.1 Signal Processing Techniques for Algorithmic Composition

Christopher Burns

This project is oriented towards the development of new tools for algorithmic composition, based on traditional signal processing techniques. While we ordinarily associate filtering and frequency transforms with sampled audio, these methods also possess a number of desirable properties for the generation of higher-level musical materials. These techniques offer meaningful and intuitive relationships between input and output. Additionally, many such tools have “strong parameters,” where a change to a single parameter produces a substantial and observable alteration to the output. Finally, the notion of “frequency,” abstracted to rate of change, analogizes well to music. Harmonic rhythm is the most obvious example, but music in general is multitemporal; operating on a number of different time scales simultaneously, from notes and phrases to sections, movements and complete works.

The first application of these tools was in a work for violin solo titled *Integrities*. In this instance, the time-domain outputs of filters were mapped to musical parameters. Over the course of the piece a number of different filters were used, with particular emphasis on time-variant resonators displaying “classic” behaviors like sweeping filter resonance or bandpass frequency. A variety of different mappings

were also tested over the course of the piece, including inter-event onset times, phrase onset times, phrase durations, and pitch.

Additional work on a companion piece for cello solo concentrates on the sonification of frequency transforms. Spectrograms of speech recordings and other structured audio are the principal data source, and mappings include pitch selection, event duration, and dynamics. The third work in the series, for viola solo, applies filters to various time-domain representations of the musical materials from the violin and cello pieces. The filtered outputs serve as variations of the original music.

6.7 Psychoacoustics and Cognitive Psychology

6.7.1 Setting a Menu to Music: Intonation and Melody in 19th Century Art Songs

Leigh VanHandel

Philosophers, linguists, and musicians have documented the relationship between language and music throughout history. The fields have intersected in the study of speech intonation (the “melody” of an utterance, including such characteristics as pitch, stress, accent, and phrasing); linguists have used musical analogies to explain intonation patterns, and musicians have used linguistic analogies to explain melodic patterns.

This study traces the history of the interaction between speech intonation and musical melody, and will determine whether there is a relationship between speech intonation and musical melody in 19th century French and German art songs. I compare the contours of the spoken languages with the generalized contours of music written to texts in those languages by composers who were native speakers of the language. The musical information is managed using the Humdrum Toolkit, a database system for musical research developed by David Huron.

6.8 Machine Recognition in Music

6.8.1 Automatic Transcription of Polyphonic Piano Music

Randal J. Leistikow

The goal of this project is to develop a system that accepts as input a single-channel or stereo recording of solo piano music and outputs a data file containing the performance parameters necessary to resynthesize an expressively realistic performance of the music. Applications of such a system include the abilities to “resurrect” performances from historic recordings and hear them played live on a modern reproducing piano, release pristine versions of recordings corrupted by noise, process the output data to study aspects of performance practice or playing style, and code piano music extremely efficiently.

6.8.2 Computational Models for Musical Style Identification

Yi-Wen Liu and Craig Sapp

Research is underway to identify musical features which can be used to distinguish between different composers writing in a common style. In the preliminary experiments on Mozart and Haydn’s string quartet movements, probabilities of transition between classes of musical events (such as pitch classes, rhythmic classes, etc.) are computed and compared in the information theoretic sense. It is shown that the classification is 66% “successful” (68/100 in Mozart and 136/212 in Haydn) based only on examining note transition probabilities of the first violin part. A web-paper can be found at <http://www-ccrma.stanford.edu/~jacoblui/254report/>.

As a control for the identification accuracy of computational models, a human-based experiment is being conducted over the web at <http://qq.themefinder.org> where randomly selected MIDI files of string

quartet movements composed by either Mozart or Haydn are played to listeners. The test takers must then choose the composer who they think wrote the musical sample being played. Summary statistics for identifications are viewable in real-time on the experiment's webpage. For example, a prototypical Mozart composition would be K 285, movement 1, where 84% (21/25) correct identifications have been made. A prototypical Haydn quartet movement would be Op. 74, no. 2, movement 3, which so far has 92% (11/12) correct identifications. For all test takers, the average accuracy of distinguishing between Mozart and Haydn string quartets is 56% over 4172 trials. Trained classical musicians with no experience listening to the string quartets of either Mozart or Haydn can identify the correct composers with about 70% accuracy.

Musical data for the experiments has been provided by CCARH which has electronically encoded the scores for nearly all of Mozart and Haydn's string quartets.

6.8.3 Harmonic Visualizations of Tonal Music

Craig Stuart Sapp

Multi-timescale visualization techniques for displaying the output from key-finding algorithms have been developed for harmony analysis in music. The horizontal axis of the key graphs represents time in the score, while the vertical axis represents the duration of an analysis window used to select music for the key-finding algorithm. Each analysis window result is shaded according to the output key's tonic pitch. The resulting diagrams can be used to compare differences between key-finding algorithms at different time scales and to view the harmonic structure and relationships between key regions in a musical composition. Example plots are available on the web at: <http://www-ccrma.stanford.edu/~craig/keyscape>.

Reference:

- Craig Sapp, *Harmonic Visualizations of Tonal Music*. Proceedings of the 2001 International Computer Music Conference, Havana, Cuba, pp. 423-430. Computer Music Association. Available online at <http://www-ccrma.stanford.edu/~craig/papers/01/icmc01-tonal.pdf>.

6.8.4 Themefinder: A Musical Theme Search Engine

Craig Stuart Sapp

Suppose you have a melody stuck in your head, but you don't know the name of it. You can now search a collection of over 36,000 musical themes on the web at <http://www.themefinder.org> in an attempt to identify it. Musical themes can be searched with different levels of exactness, going from a precise sequence of pitch names to basic melodic contours. Wildcards similar to those used in regular expressions are supported in most types of searches. Themefinder is useful for research purposes as well. It has been used to identify melodies suitable for musical performance experiments and has also been used to identify common starting pitch patterns in music. *Themefinder* is a collaboration between the Center for Computer Assisted Research in the Humanities at Stanford University and the Cognitive and Systematic Musicology Laboratory at Ohio State University. *Themefinder* uses the Humdrum data format for encoding and manipulating music for search and display on the website.

6.8.5 Audio Content-Based Retrieval Methods and Automatic Style Classification

Unjung Nam

The rapid proliferation of user accessible digital music data poses significant challenges to the tasks of searching and retrieving music from massive data sets. Signal analysis methods to derive high level musical information such as pitch and instrumentation could be used to formulate classification methods that may prove useful in efficient and flexible content retrieval. My research evaluates some current

approaches to content-based music retrieval methods and proposes a model that attempts to distinguish among three classes of music (jazz, popular, and classical) by analysis and extraction of features in the frequency and time domains.

6.9 Historical Aspects of Computer Music

6.9.1 New Realizations of Electroacoustic Works

Christopher Burns

There are a number of reasons to create new realizations of favorite electroacoustic works. First and foremost are the reasons for performing any interesting piece of music. Performance creates the opportunity to share the work with new audiences, and encourages close study of the work by the performer. This engagement is especially important for indeterminate or otherwise flexible works which require the performer to make decisions traditionally considered compositional. Additionally, many electroacoustic works will eventually require rescue from technological obsolescence. New realizations, using new technologies, can extend the performing lifespan of a piece with complex technical requirements. Finally, the process of realization admits the possibility of an evolving, performing tradition for a particular work, with new solutions and interpretations enriching the music's sense of possibility.

Two recent realizations by the author are useful case studies in the creation of new performing versions of electroacoustic music. Although very different works, Alvin Lucier's *I am sitting in a room* and Karlheinz Stockhausen's *Mikrophonie I* present some similar challenges in realization. Both works have relatively open, flexible scores which encourage experimentation and variation. They also have well-established performing traditions, centered on the composer as authoritative interpreter, which have minimized the flexibility suggested by the variations and alternatives possible in Lucier and Stockhausen's music.

Our experiences realizing and performing *I am sitting in a room* and *Mikrophonie I* suggests that the interpretive aspects of a realization are not established in a single moment, but are the product of a series of small decisions and practical solutions - as is the case with most musical performances. Every question must be met with an appropriate balance of textual fidelity, musical effectiveness, and pragmatism.

Continuing work on this project focusses on the creation and performance of additional realizations: recently completed works include *Rozart Mix* by John Cage, *Poème Symphonique* by György Ligeti, *Study #21 (Canon X)* for player piano by Conlon Nancarrow, and *Still and Moving Lines of Silence in Families of Hyperbolas* by Alvin Lucier.

6.9.2 Compositional Process and Documentation in Computer Music

Christopher Burns

As more and more composers produce electronic records, musicians and scholars will have to come to grips with these new forms of documentation. In some ways the new forms will be preferable: electronic records can be very revealing about a composer's technical intentions. What a composer can scribble on paper in a cryptic shorthand has to be spelled out in detail to make software work; composers' code and other electronic records may prove more useful than paper sketches when working methods are complex. However, these sketches are only comprehensible if the reader is initiated into the programming language, and only fastidious and self-conscious composers are likely to preserve their mistakes, false starts, and reconsiderations, through multiple versions of their code.

This project considered the sketches and other creative intermediates from Fernando Lopez-Lezcano's *iICEsCcRrEeAaMm* for four-channel tape, and Christopher Jones' *Matragn* for clarinet and CD. The sketches for *iICEsCcRrEeAaMm* were entirely in electronic form, and consisted principally of software "instruments" and "score" written in the Common Lisp Music language. In particular, repeated revisions of the composer's "grani" granular synthesis instrument and the "dlocsig" spatialization instrument are suggestive of the ways in which compositional desires influenced the software development.

In *Matragn*, the creative work was more focused on pencil sketches, with the programming work coming last. Most of the precompositional work documented in the sketches is borne out in the finished piece. There are a number of revisions and rethinking of the pitch scheme in the sketches; this seems to have been an area of concern to the composer, and an area for experimentation. The draft of the clarinet part included impressionistic hieroglyphs suggesting possibilities for the sounds on CD. However, comparisons of these graphic sketches with the finished CLM code provide evidence of revisions and rethinking in the electronic part.

Computer music sketch materials enable us to learn about the composers' creative process, and may in some instances be useful in an analysis of the completed works. It is important to remember, however, that there are a wide variety of working methods, technologies, and records, and some of them are much less genial to examination after the fact. Finally, documentation plays an important role in the creation of musical canons: one of the reasons that Karlheinz Stockhausen's work *Kontakte* is discussed, performed, and taught is that the composer published his exhaustive studio diaries made while creating the tape part. Sketches, electronic or otherwise, play a role in the lifespan of the music itself.

6.10 Computer Assisted Music and Acoustics Research

6.10.1 The Center for Computer Assisted Research in the Humanities (CCARH)

The Center for Computer Assisted Research in the Humanities (CCARH), located in the Braun Music Center, Stanford University, is concerned with the development of data resources and software applications for music research and allied areas of humanities study.

Its address is:

Braun #129
Stanford University
Stanford, CA 94305-3076
tel. (650) 725-9240
fax (650) 725-9290
Web: <http://www.ccarh.org/>

CCARH staffs a two-quarter graduate course sequence, cross-listed with Computer Science:

Music 253 Introduction to Musical Information <http://www.ccarh.org/courses/253/>
Music 254 Seminar in Music Representation <http://www.ccarh.org/courses/254/>

This course sequence is team-taught by Eleanor Selfridge-Field and Walter B. Hewlett. The current teaching assistant is Craig Sapp.

CCARH maintains a lab for applications in music notation, analysis, and sound sequencing. It also maintains some CD-ROM titles related to music research. See <http://www.ccarh.org/software/> and <http://www.ccarh.org/lab/> for more information.

CCARH supports a variety of research projects in data development, access, and query, such as *Musedata* and *Themefinder*.

Publications and Performing Materials:

- *Beyond MIDI: The Handbook of Musical Codes*, ed. Eleanor Selfridge-Field (MIT Press, 1997).
 - Comprehensive coverage of codes used in sound, notation, analysis, and interchange of musical data.
 - Updates at <http://www.ccarh.org/publications/books/beyondmidi/>
- *Computing in Musicology*, ed. Walter B. Hewlett and Eleanor Selfridge-Field. Vols. 1-10 (CCARH): <http://www.ccarh.org/publications/books/cm/>

- *A Base-40 Number-line Representation of Musical Pitch Notation*, Walter B. Hewlett.
<http://www.ccarh.org/publications/reprints/base40/>
- *Musical Information in Musicology and Desktop Publishing*, Eleanor Selfridge-Field and Eddmund Correia, Jr. <http://www.ccarh.org/publications/reprints/ieee/>
- *Melodic Similarity* (= CM 11) (MIT Press, 1998):
<http://www.ccarh.org/publications/books/cm/vol/11/>
- CM 12: covering XML, NIFF, virtual editions, image reconstruction et al. (in progress)
- Operas and oratorios by G. F. Handel: contact ccarh@ccrma.stanford.edu
- Parts: Vivaldi Op. 8 (including "The Four Seasons"):
<http://www.ccarh.org/publications/scores/vivaldi/op8/>
- Scores and parts: Bach cantatas (in progress)

6.10.2 The Musical Acoustics Research Library

Gary P. Scavone and Max V. Mathews

The Musical Acoustics Research Library (MARL) is a collection of independent archives or libraries assembled by distinguished groups or individuals in the field of musical acoustics research. MARL is directed by representatives of each member collection, in conjunction with the Center for Computer Research in Music and Acoustics (CCRMA) at Stanford University, which maintains the contents of each library. Currently, MARL is comprised of the Catgut Acoustical Society Library, the Arthur H. Benade Archive, the John Backus Archive, and the John W. Coltman Archive.

Background and History:

The Musical Acoustics Research Library (MARL) has its origin in the vast acoustics research collection of the Catgut Acoustical Society (CAS). These files were assembled over many years by CAS and housed in the home of its founder Carleen M. Hutchins. In the late 1980s, CAS began an effort to establish an appropriate long-term residence for the collection, such that it could serve as a valuable reference source for the musical acoustics community at large. In 1992, the Center for Computer Research in Music and Acoustics (CCRMA) at Stanford University was selected as the repository for this library.

In conjunction with the establishment of the Catgut Acoustical Society Library, CCRMA and CAS encouraged the idea of having the personal archives of Arthur Benade and John Backus at the same site. Both were world leaders in the study of wind instrument acoustics. The personal files of John Backus were acquired in 1995. An agreement for the establishment of the Arthur H. Benade Archive at CCRMA was reached in 1997. In autumn 1996, representatives of CAS and CCRMA, together with Virginia Benade, established the Musical Acoustics Research Library at CCRMA in order to provide a single point of reference for the various collections. The most recent addition to MARL, the John W. Coltman Archive, was founded in April 1998. The archives of three of the most prominent wind instrument acousticians of our time, together with the extensive string instrument resources of the Catgut Acoustical Society Library, position MARL as a primary musical acoustics reference source in the world.

Organizational activities of MARL are directed by Gary P. Scavone, with faculty representation by Max V. Mathews and Chris Chafe, the director of CCRMA. MARL is a collective and each member/group representative is encouraged to take part in policy decisions. CCRMA, as an equal partner in MARL, is committed to helping establish the library as an important resource of musical acoustics knowledge for the entire global acoustics research community. A World Wide Web (WWW) site has been created for MARL, which will serve as the primary means for disseminating information to the public about the various collections.

Activities:

The primary ongoing activities of MARL are centered on the development of a uniform databasing system to record the sub-collection catalogue information, as well as the creation of World Wide Web (WWW) pages for the dissemination of the library contents to the global musical acoustics community. The MARL WWW pages currently provide Internet access to overviews of the materials available at CCRMA. When requests for particular documents are received, those documents are being scanned and converted to Portable Document Format (PDF) files using Adobe Capture software and subsequently linked to appropriate locations within the MARL WWW pages. The files at CCRMA are also available for on-site perusal by appointment.

MARL activity is coordinated at CCRMA by Gary P. Scavone and organizational decisions are made by agreement among the representatives of each member collection. Activities are ongoing for the addition of new collections to MARL.

6.10.3 Web-Based Infrastructure for Research and Teaching

Julius Smith

The Web is extremely attractive as a basis for supplementary educational infrastructure. Advantages of Web-based tutorials include:

- Links to related documents anywhere on the Web.
- Live demos (Java applets, sound examples).
- Searchable by topic.

On the negative side, excessive use of hypertext links can be distracting, and following links can even derail and disorient the learner. Good design practices can help minimize this problem, e.g.,

- Links always point to a supporting *definition* or *tutorial*. In other words, the student can be advised to click on a link only if the underlined term is not well understood.
- At any time it is easy to *print* the current document in a form optimized for printing. (Alternatively, a book containing the current material can be ordered.)
- A *local search* facility supports navigation-by-topic in a relatively confined scope.

Signal Processing “Knowledge Webs”:

The above design goals have been pursued in the development of a *knowledge web* regarding digital signal processing for music applications.¹ Based on our experience to date, online knowledge webs are best suited for (1) online reference and (2) self-paced study. It is apparent that an effective self-paced curriculum could be developed on the basis of online knowledge webs, particularly with the addition of interactive problem sets.

Web Publishing is On the Way:

Full utilization of the Web in online publishing is barely beginning. However, research has already shown that publications available on the Web tend to be cited more often than publications requiring a trip to the library. Much of what technology does for society is making repetitive tasks faster and more convenient; the far greater convenience of online search and retrieval is indisputable. It can be expected that paper-bound publications will be replaced, one way or another, by online versions.

¹<http://www-ccrma.stanford.edu/~jos/pubs.html>

Web Publishing Tools:

There are several impediments for authors attempting to get their writings onto the Web and *well linked* to supporting materials. One problem is the lack of tools for managing interlinked online documents. To address this issue, tools² for conveniently managing online documents generated from L^AT_EX are being developed. Presently, publications may be generated automatically to the Web in HTML, PDF, and compressed PostScript formats. The footer of every HTML page includes a full bibliographic citation and hyperlinks for downloading either of the two hardcopy formats for printing. Thanks to latex2html, every page also contains “navigation links” (‘next’, ‘previous’, ‘up’, ‘contents’, ‘index’, and the like), which serve to orient the reader. These features are especially useful when a page is reached via a remote hyperlink, such as from a Web search engine.

Databases for Automatic Linking:

When writing an online document, it is useful to draw upon a collection of *links* to related materials, so that the document will be well connected on the Web. Toward such a link collection, the beginnings of a “global index”³ of online reference materials pertaining to digital signal processing in music and audio is under development. In addition to its use in automatic link installation, the global index functions on its own as a kind of hypertext *glossary* for web-resident content in signal processing applied to music and audio.

The Open Dictionary:

Most of links in the global index also appear in the Open Dictionary,⁴ a website allowing researchers and educators in related fields to organize their respective links into a global hierarchical encyclopedia. The Open Dictionary is also designed to serve as a basis for automatic link installation, among other functions.

Open Dictionary content is currently dominated by CCRMA Web links. As more “linkable” educational content appears on the Web, the percentage of CCRMA content should decrease, as no one institution can be expected to keep up with the entire world. One project of particular note is the well funded MIT OpenCourseWare (MITOCW) project,⁵ in which all MIT courseware is to be placed on the Web for free public access. The second largest source of “definition links” in the Open Dictionary is presently Eric Weisstein’s Math World⁶ and Treasure Troves⁷ of math, physics, astronomy, and music. Due to the excellent “linkability” of Weisstein’s online encyclopedias, Math-World and Treasure-Trove definitions blend seamlessly with CCRMA definitions. Longer term, we expect to be linking to best-of-category online tutorials all over the world, as they slowly (so far) come into existence.

Concept Home Pages:

In general, the best link targets tend to be “Concept Home Pages” (CHP), i.e., Web destinations devoted to a *single topic*. Like any good “hub” on the Web, a CHP attempts to efficiently route all types of visitors to all types of content on the given topic. The topic is covered exhaustively in a top-down way, leveraging links to other CHPs as much as possible. The *Digital Audio Resampling Home Page*⁸ is a prototype CHP devoted to sampling-rate conversion. It presently consists of

- A link to a general definition and introduction
- Links to available open-source software
- An in-depth tutorial
- Links to related websites

²<http://www-ccrma.stanford.edu/~jos/webpub/>

³<http://www-ccrma.stanford.edu/~jos/JOSGlobalIndex.html>

⁴<http://www-ccrma.stanford.edu/~jos/od/>

⁵<http://web.mit.edu/newsoffice/nr/2001/ocw.html>

⁶<http://mathworld.wolfram.com>

⁷<http://www.treasure-troves.com>

⁸<http://www-ccrma.stanford.edu/~jos/resample/>

Concept home pages are under development for other topics which support CCRMA teaching and research. However, the great majority of current links are generated automatically from online document index files. While a cross-document index link can function well as a pointer to supporting material, it is not usually sufficiently comprehensive to be considered a concept home-page. The CHP can provide a much better initial orientation to the topic, unlike a subsection of some remote document. Nevertheless, index links are serving quite well as placeholders for now.

7 Recordings

Recordings of works realized at CCRMA include the following:

- *Arctic Contrasts*, Min Ensemble. Matthew Burtner, "Sikuigvik". Euridice Records (EUCD#012), 2000.
- *II SBCM (II Brazilian Symposium on Computers and Music)*, – digital compact disk containing Celso Aguiar – "Piece of Mind", DISC MFG., INC., BHS1046, Brazil, 1996.
- Matthew Burtner. *Portals of Distortion: Music for Saxophones, Computers, and Stones*. Innova Records (Innova 526), 1999.
- *Cache*, Compilation of winners of the Young and Emerging Sound Artists competition sponsored by the CEC and SOCAN. Michael Gurevich, "Soft White". Canadian Electroacoustic Community, 2000.
- *Center for Computer Research in Music and Acoustics*, CDCM, Computer Music Series, Vol 8. Works of Chafe, Schindler, Jaffe, Berger, and Morrill. Digitally mastered CD, CRC2091, Centaur Records, 1991.
- Chris Chafe. *Arco Logic*, Solo composer album. Centaur Records, Inc. (CRC2514), 2001.
- Chris Chafe. *Arcology*, Performer/Composer album. Centaur Records, Inc. (CRC2515), 2002.
- Chris Chafe. *Extrasensory Perceptions*, with Greg Niemeyer, 2002.
- *John Chowning*, – Phoné, Turenas, Stria, and Sabelithe. Digital compact disk, WER2012-50 Wergo, Germany, 1988, Harmonia Mundi, Distributors.
- *Current Directions in Computer Music - Sound Examples*. Digital compact disk to accompany the book *Current Directions in Computer Music*, J. R. Pierce and M. V. Mathews, editors, MIT Press, Cambridge, MA, 1989.
- *Computer Music @ CCRMA vol. I*. Works of Aguiar, Norton, Lopez-Lezcano, Hopkins, Hind, and Roy. Produced by Celso Aguiar and Marco Trevisani at CCRMA, Stanford University, 1997.
- *Computer Music @ CCRMA vol. II*. Works of Trevisani, Landa, Soley, Edwards, Dong, and Brummer. Produced by Celso Aguiar and Marco Trevisani at CCRMA, Stanford University, 1997.
- *Computer Music from CCRMA, vol. I*. Digitally mastered cassette with works by Moorer, Schloss, Schottstaedt, Chafe, Jaffe, Berger, and Chowning. Produced by Jan Mattox for CCRMA, 1982.
- *Computer Music from CCRMA, vol. II*. Digitally mastered cassette with works by various composers, 1984 (out of print).
- *Computer Music Journal Volume CD*, – digital compact disk to accompany the 20th Anniversary Issue includes Chowning – "Turenas", MIT Press, Cambridge, MA, 1996.
- *The Digital Domain*. Elektra/Asylum Records 9 60303-2, 1983. Works by Jaffe (Finale to "Silicon Valley Breakdown"), McNabb ("Love in the Asylum"), Schloss ("Towers of Hanoi"), Mattox ("Shaman"), Rush, Moorer ("Lions are Growing"), and others.
- *Dinosaur Music*. Digital compact disk. Jaffe – "Silicon Valley Breakdown," Chafe – "In A Word," Schottstaedt – "Water Music I & II," and "Dinosaur Music," WER2016-50, Wergo, Germany, 1988, Harmonia Mundi, Distributors.
- Janet Dunbar. *Spirit Journey* Original electroacoustic and computer music with spoken and sung poetry and guitar and synthesizer improvisation. Amberlight Productions (JD10SJ), 1999.

- *Electroacoustic Music II*. Music by Berger, Child, Dashow, Duesenberry, Shapiro (Jonathan Berger: "An Island of Tears"), Neuma 450-73-[J].
- *Intercambio Exchange*. Digital compact disk containing computer music from Buenos Aires and California. Works of Cetta, Chafe, Dobrian, Willey, Losa, Krupowicz, Calzon, Lopez-Lezcano, Pozzati, Jaffe, Labor, Cerana, Linan, Lyon and Viera. Produced by CCRMA, LIPM, and CRCA, 1994.
- David Jaffe. *The Seven Wonders of the Ancient World*, – digital compact disk available in September, Well-Tempered Productions, 1996.
- David Jaffe. *XXIst Century Mandolin - acoustic and computer music for the mandolin*. WTP5164, Well Tempered Productions, 1994, Allegro Records, Distributors.
- Michael McNabb. *Computer Music*. Digitally mastered LP. McNabb – "Dreamsong," "Love in the Asylum," "Orbital View," (LP out of print) - CD now available as WER-2020-2, Wergo, Germany, 1994, Harmonia Mundi, Distributors.
- Michael McNabb. *Invisible Cities*. Digital compact disk, WER-2015-50, Wergo, Germany, 1988, Harmonia Mundi, Distributors.
- *Musica Maximalista - Maximal Music Vol. 2*, – digital compact disk containing Celso Aguiar – "Piece of Mind", CD MM-002, Studio PANorama, Brazil, 1996.
- *Musica Maximalista - Maximal Music Vol. 3*, – digital compact disk containing Celso Aguiar – "All blue, I write with a blue pencil, on a blue sky", CD MM-003, Studio PANorama, Brazil, 1997. CD of the II International Electroacoustic Music Competition of So Paulo.
- *Musica Nova 2000 Final Protocol CD*. Matthew Burtner, "Fern", First Prize, Musica Nova 2000 Electroacoustic Music Competition. Society for Electroacoustic Music of Czech Republic, Ministry of Culture, Czech Music Council, 2000.
- *New Music for Orchestra*. VMM 3024, Vienna Modern Masters, 1994. Works by Jaffe ("Whoop For Your Life!") and others.
- *Night Chains*. (Composers Recordings Inc - Emergency Music Series, CRI CD681). Jeffrey Krieger, electronic cello (Jonathan Berger: "The Lead Plates of the Rom Press").
- *The Science of Musical Sound - Musical Examples*. Cassette tape produced by Jan Mattox for CCRMA to accompany the book *The Science of Musical Sound*, J. R. Pierce, Scientific American, 1985.
- *Unknown Public (04): Musical Machinery*, – digital compact disk containing Nicky Hind – "Rain", Unknown Public, UPCD04, United Kingdom, 1994.
- *The Virtuoso in the Computer Age-V*. Music for Mathews/Boie Radio-Drum and Radio Baton, CDCM Vol. 15. CRC 2190 Centaur, 1994. Works by Jaffe ("Terra Non Firma"), Jaffe/Schloss ("Wildlife"), Radunskaya ("A wild and reckless place"), Austin ("Mathews Epsiode"), and Appleton ("Pacific Rimbombo").

For availability of a particular recording on the list, please contact the composer.

8 Publications

The following is a list of publications since 1996 by people from CCRMA. An extensive list of publications since 1970 is available online at www-ccrma.stanford.edu/Overview/publications.html. A printed list of CCRMA publications from 1970 – 1995 is available from CCRMA as Stanford University Department of Music Technical Report STAN-M-103. Stanford University Department of Music Technical Reports are available from CCRMA. Publications with notated prices are also available from CCRMA.

- Ben-Tal, O., Berger, J., and Daniels, M. (2001*a*). De natura sonoris: Sonification of complex data. In *Mathematics and Simulation with Biological, Economical and Musioacoustical Applications; Mathematics and Computers in Science and Engineering*, p. 330. WSEAS Press. Edited by Attellis, Klurv and Mastorakis.
- Ben-Tal, O., Berger, J., and Daniels, M. (2001*b*). Sonification in science and art. In *Proceedings of the 2001 ESCOM Conference, Liege, Belgium*.
- Bensa, J., Bilbao, S., Kronlan-Martinet, R., and Smith III, J. O. (2002). From the physics of piano strings to digital waveguides. In *Proceedings of the 2002 International Computer Music Conference, Sweden*.
- Berger, J. (1996). Modeling the degree of realized expectation in functional tonal music: A study of perceptual and cognitive modeling using neural networks. In ICMC (1996).
- Berger, J. (1998). Connected to what? *JOURNAL of the College Music Society*. Plenary ADDRESS, 1997.
- Berger, J. (1999*a*). The ghost of johannes brahms. In *Proceedings of the TED IX (CD-ROM disk 1)*, Monterey, CA.
- Berger, J. (1999*b*). Modeling composition, performance and listening. In *Music at the Crossroads: Technology and Composition Pedagogy*, Rubin Academy of Music, Jerusalem. Plenary ADDRESS. Proceedings published in *Art in Time*, Vol. 4, Issue 1, pg. 53, 1999.
- Berger, J. (2001*a*). *Musical Expectations*. Cambridge, MA: MIT Press.
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