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Musical Muscle Memory and the Haptic Display of Performance Nuance

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Abstract

We have begun exploring extraction and editing of nuances of a performance through the sense of touch. Expressive variations in MIDI piano recordings were obtained, limiting the initial study to timing and velocity information. A force-feedback interface displays in real time an analysis of the performer's musical conception and can be used to graft aspects of one performance onto another.

1 Introduction

A challenging analysis problem has haunted one of the authors for years, usually mentioned in terms of how synthesis could benefit from a deeper understanding of performance. Posed as conjecture, it's to imagine if two string quartets were to perform the same piece on different nights: the first night's performance is competent, and the audience is happy enough about it. The second night the performance is simply stunning, transcendent, and the audience leaves ecstatic. Part of the problem poses the question of imagining the differences in terms of quantities which would be acoustically-measurable differences between the performances. A second, possibly more difficult part of the problem, is in comprehending such a wealth of detail so that the analysis is imageable and useful.

A second interest motivating this study is to further exploit the sense of touch in music editing tasks. Beyond automated mixer controls, digital editing involves only display to the eye and ear. However, in the physical creation of music, sounding events are registered by the hand and ear [Chafe, 1993] [Gillespie, 1995]. Present digital technology can be adapted to incorporate the kinesthetic (muscular), tactile, and vibro-tactile (cutaneous) senses, modalities well-suited for data that depicts time and motion.

Performances of the same music can have vastly different feelings even when constrained by a fully-notated score. For simplicity, a short piano excerpt was chosen for this study and independent renditions were compared in terms of event timings and key velocities. As listeners, we are acutely sensitive to these differences, but it is more likely that we are only aware of their aggregate effect, for instance, the feeling that one passage was played more forcefully than another. What are the note-level differences, how are they structured, and are such structures the basis for the affect?

The hope that differences of affect can be characterized and displayed leads to the further possibility of manipulating recorded or synthesized performances. A computer-controlled force-feedback interface was programmed to display aspects of performance and manipulate them in real time. Haptic display has the advantage of communicating directly to the motor senses, the same that are involved in musical performance. The word "haptic" is employed to describe devices that engage both the kinesthetic and tactile senses. In our work, the quantities displayed to the observer are ideally a replay or recasting of human motor commands which might have created or accompanied a performance. The end-result is a prototype system that allows the observer to feel musical *feeling* through the real-time display of parameters analyzed from performance. Because the controller permits direct interaction with its display, the performance can be edited in an intuitive manner.

2 Method

An excerpt from the opening of Beethoven's Piano Sonata, Opus 109, was recorded by two excellent pianists using a Yamaha Disklavier grand piano, Figure 1. Recorded data was transferred into standard MIDI file format and analyzed in several steps (with the Stella programming environment, a Lisp package for symbolic musical manipulation [Taube, 1993]). First, the two performances were

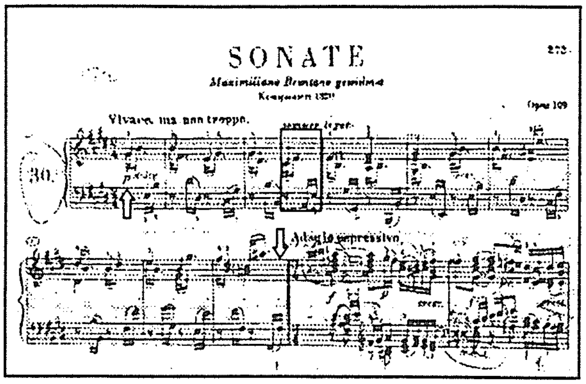

Figure 1: *Two performances of the opening of Beethoven's Piano Sonata, Opus 109, were recorded by Yamaha Disklavier. Note timings and key velocity data were transferred to standard MIDI files.*

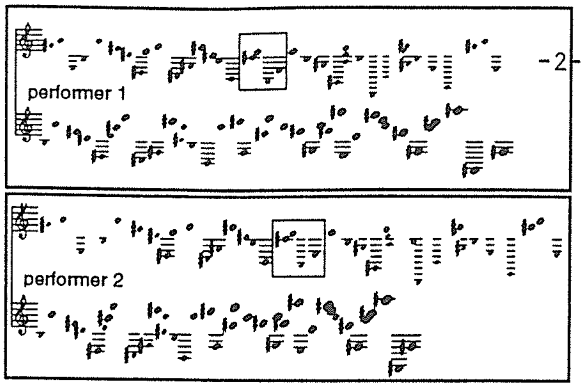

Figure 2: *Distinct short-term shapes are found in raw data displayed from the first 77 notes (marked by arrows in Figure 1). Note placement is proportional to time and size is proportional to key velocity.*

matched up in terms of detected pitches. Our performers were not supervised in any way and were free to submit what they wished. Approximately 2% of the notes did not match up for a variety of reasons, including wrong notes and order differences in chords. Since our project is ultimately directed at acoustically recorded performances, and we expect an even greater error rate in the transcription process, this level of mismatch was acceptable [Chafe and Jaffe, 1986]. A matching algorithm was applied, working from the beginning of the data and pairing equivalent pitches between the two performances. Discrepancies were eliminated and the resulting data set of matched pitches provided the basis for initial experimentation.

2.1 The Moose

Performance data was transferred to a program written in C++ commanding a MIDI synthesizer and the moose, a two-dimensional haptic display device. The moose is essentially a powered mouse-like pointing device. It consists of a puck or manipulandum in the center coupled to two linear voice-coil motors through two perpendicularly oriented flexures. The double flexures conveniently decouple the 2-axis motion of the puck into two single-axis motions at the linear motors. The puck's motion is restricted to an area in the horizontal plane approximately 3 inches on a side.

The moose was designed as part of a larger project based at CSLI, Stanford, to investigate the possibility of using haptic technology to display elements of graphical user interfaces such as window edges, buttons, etc. to blind computer users [O'Modhrain, 1995]. The prototype display has proven the feasibility of the approach, and will continue to be developed alongside our exploration into the use of haptics as a component of a digital music editing systems.

2.2 First Results

Restricting the data to the first eight and a half measures of the Beethoven focused initial analysis on a passage consisting only of running sixteenth-note rhythms. For further simplification, pedal information and durations were ignored. The collected note onsets and key velocities show short-term shapes superimposed on longer-term phrasings. The moose was programmed to directly display key velocity data in the form of an elastic wall. The observer presses the puck to a virtual wall whose stiffness depends on the MIDI velocity being sent to a piano synthesizer. While the performance is sounding, the wall portrays a strong sense of note-to-note variation. As can be seen in Figure 2, some of the note-to-note instantaneous changes are quite abrupt, and a modification was made to display a small mixture of instantaneous key velocity plus a moving average of key velocity whose window is centered on the current note. A rather satisfactory sensation of dynamic phrasing results.

The next refinement consisted of combining onset timings with velocity data to establish an abstract *effort* parameter. Effort, in this sense, represents the directions a conductor might impart to an orchestra. High effort corresponds to faster & louder, low effort to relaxed & softer. However, *ritardando* & *crescendo* can also elicit strong effort, as in the end of the passage studied. A formula to represent these relationships was devised (based on the simplification that the score excerpt only consists of sixteenth notes, which are nominally 125 msec):

$$effort = nv * (1/r + C * r^2)$$

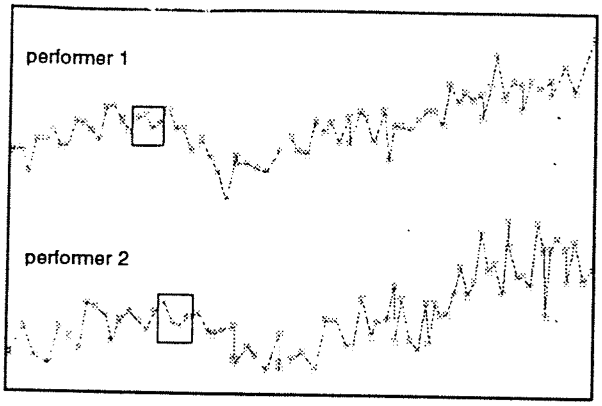

Figure 3: Effort *vs. time is compared for the same passage as Figure 2. The effort quantity is derived from note onset timings and key velocity. Total duration has been normalized for ease of comparison.*

nv is normalized velocity scaled from 0.0 to 1.0 from the recorded range of velocities, r represents the time interval from the onset of the previous note, and C is a coefficent to bring the nominal rhythm value into range.

Figure 3 shows a graph of effort derived for the same passage as Figure 2. Multi-measure swells correspond to long-term phrasing. Short-term shapes can be seen in note groupings of 2 - 6 notes at a time. The two performances have the keenest difference on this short-term time-scale. Groupings are sometimes similar but shapes are distinct. For example at note 17, a four-note groupin appears (marked by boxes in the figures). Through the effect of a single note, the shape differs between the two performances.

2.3 Manipulations and Muscle Memory

The moose displays the two time scales as separate sensations: a background long-term motion and superimposed, faster foreground shapes. In the background, long-term changes are displayed by averaging the effort parameter with a moving window and causing the virtual wall position to change smoothly. In the foreground, instantaneous effort values affect the wall's compliancy, with higher effort values causing a stiffer spring, Figure 4. The observer quickly trains on differences between the two performances.

A third performance can be created as a product of the first two through linear interpolation of onset rhythms and velocities. The wall's length is used as the interpolation control. At the wall ends, the observer experiences one performance or the other and, in between, an interpolated version. Sliding along the wall in real time allows grafting of one performance to the other.

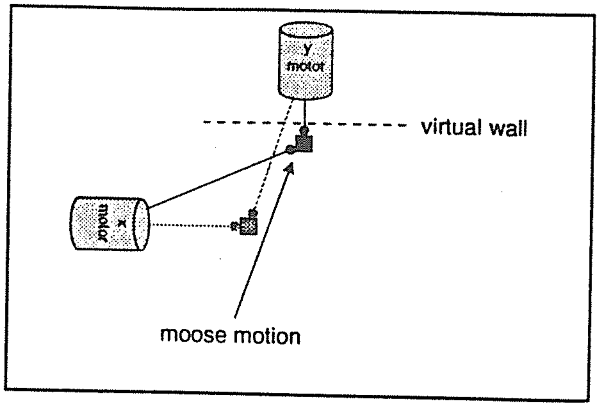

Figure 4: *The moose, a powered mouse, consists of two linear voice-coil motors controlling the location of a puck. Virtual objects and surfaces are displayed by force-feedback. The performance analysis is displayed by changes to a virtual wall's location and compliance in real time while the music is played.*

The prototype system suggests that in-real-time experiences through haptic devices such as the virtual wall can be coupled with sound to offer a rich display for performance analysis and editing. Imaging and memory of patterns is enhanced by appealing to muscle memory. One way to imagine this is to contrast the method with an out-of-time graphical display, such as in Figure 3, or a static haptic display which would project Figure 3 onto a touchable surface. Spatial displays excel for side-by-side pattern discrimination, and performance shapes, such as those briefly discussed, are easily found. Animated spatial displays increase dimensionality, often to include time. The force-feedback system is used to go the other way, to reduce the data into one simplified, intuitive, musical dimension such as the effort parameter. The observer is able to experience, vicariously, the performer's own feeling of effort during performance.

3 Summary: Haptics and Sound

Haptic perception *of the signal* has been lost through changes in music-making technology. The mechanical musical world consists of direct manipulation of sound-producing mechanisms and a sense of their vibration. The analog world replaced this with the feel of various specific control devices or the feel of motion of the recording medium. The digital world has reduced this further to a few general purpose controllers and displays, eg. mouse, keyboard, CRT.

This study has already shown us that there are indeed parameters within music which can be manipulated to allow a performer, composer or music editor to traverse the space between two totally different interpretations of the same piece. We have demonstrated that we can make these parameters apparent to the kinesthetic and vibrotactile senses, those same senses which, in live performance, complete the musician's feed-back loop. With a few simple haptic interface tools we can bring back to the editing process some of its former intuitiveness and flexibility [O'Modhrain, 1995].

Specifcally, what we have lost in the transition to mouse-based digital music editing environments is the close contact which sound engineers once enjoyed with their media. We can design new haptic controls and program their "feel" by making them more or less resistant to being moved. A shuttle wheel detent is, for example, easily mediated by motors. And a detent could represent variously manipulator or signal state.

Unique physical operations on sound persist today as metaphors in digital audio editing tools. For example, records are scratched back and forth, tapes are slowed and sped up. The musical arts themselves are strongly influenced by such technologies which often form a basis for new genres of technologically-influenced music. We look forward to enjoying the artistic output inspired by the programmable, multi-modal, and physically coupled interfaces of the future which will feature haptic components.

The authors gratefully acknowledge contributions to the project from our colleagues George Barth, Brent Gillespie, Craig Sapp, and Frederick Weldy. The Archimedes Project at Stanford University's Center for Study of Language and Information provides ongoing support for development of haptic access to graphical user interfaces.

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CCRMA Studio Report

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1.0 The place and the people

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. CCRMA is located on the Stanford University campus in a building that was refurbished in 1986 to meet its unique needs. The facility includes a large quadraphonic experimental space with adjoining control room/studio, an all-digital recording studio with adjoining control room, a MIDI-based small systems studio, several work areas with workstations, synthesizers and speakers, a seminar room, an in-house reference library, classrooms and offices.

For a detailed tour and more information feel free to visit us in the World Wide Web:

- **http://ccrma-www.stanford.edu/**

The CCRMA community consists of administrative and technical staff, faculty, research associates, graduate research assistants, graduate and undergraduate students, visiting scholars and composers, and industrial associates. Departments actively represented at CCRMA include Music, Electrical Engineering, Mechanical Engineering, Computer Science, and Psychology. CCRMA has developed close ties with the Center for Computer Assisted Research in the Humanities (CCARH), recently affiliated with the Department of Music.

Staff & Faculty: **Chris Chafe**-Associate Professor of Music, Director; **Johannes Goebel**-Technical Director; **Fernando Lopez-Lezcano**-System Administrator/Lecturer; **Heidi Kugler**-Secretary; **Jay Kadis**-Audio Engineer/Lecturer; **Max Mathews**-Professor of Music (Research); **Jonathan Berger**-Associate Professor of Music; **Julius Smith**-Associate Professor of Music and Electrical Engineering; **John Chowning**-Professor of Music, Emeritus; **Leland Smith**-Professor of Music, Emeritus; **John Pierce**-Visiting Professor of Music, Emeritus; **Earl Schubert**-Professor of Speech and Hearing, Emeritus; **Jonathan Harvey**-Professor of Music; **David Soley**-Assistant Professor of Music; **Eleanor Selfridge-Field**-Consulting Professor of Music; **Walter Hewlett**-Consulting Professor of Music; **Marcia Bauman**-Research Associate, IDEAMA Archive; **William Schottstaedt**-Research Associate.

2.0 The activities

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

3.0 The research

This array of research summaries will give you an idea of the current crop of research at CCRMA and who's doing it:

Computer Music Hardware and Software: "PadMaster, an Interactive Performance Environment. Algorithms and Alternative Controllers", "A Dynamic Spatial Sound Movement Toolkit" **Fernando Lopez Lezcano**; "ATS: Analysis/Transformation/Synthesis; A Lisp Interface for SMS (Spectral Modeling Synthesis; and CLM (Common Lisp Music)" **Juan Carlos Pampin**; "SynthBuilder---A Graphical SynthPatch Development Environment" **Nick Porcaro** and **Pat Scandalis**; "Franken Hardware: On Scalability for Real-Time Software Synthesis and Audio Processing" **Bill Putnam** and **Timothy Stilson**; "Common Lisp Music and Common Music Notation" **William Schottstaedt**; "Music Synthesis and Digital Audio Effects for UltraSparc Processor" **William Putnam**, **Tim Stilson**, and **Julius Smith;**"Rapid Prototyping for DSP, Sound Synthesis, and Effects" **Julius Smith;** "SynthScript - A Sound Synthesis Description Format" **Pat Scandalis, David Jaffe, Nick Porcaro**, and **Julius Smith**; "The CCRMA Music Kit and DSP Tools Distribution" **David Jaffe** and **Julius Smith**; "Capella: A Graphical Interface for Algorithmic Composition" **Heinrich Taube** and **Tobias Kunze**.

Physical Modeling and Digital Signal Processing: "Physical Modeling of Brasses" **David Berners**; "Adding Pulsed Noise to Wind Instrument Physical Models" **Chris Chafe**; "Synthesis of the Singing Voice Using Physically Parameterized Model of the Human Vocal Tract" **Perry Cook**; "Synthesis of Transients in Classical Guitar Sounds", "The "Flutar" a New Instrument for Live Performance" **Cem Duruoz**; "Spectral Operators for Timbral Design" **Jose Eduardo Fornari**; "Voice Gender Transformation with a Modified Vocoder" **Yoon Kim**; "Processing of Critically Sampled Audio Subband Data" **Scott Levine**; "Feedback Delay Networks" **Davide Rocchesso**; "Acoustical Research on Reed Driven Woodwind Instruments for the Purpose of Efficient Synthesis Models" **Gary Scavone**; "FFT-Based DSP and Spectral Modeling Synthesis", "Digital Waveguide Modeling of Acoustic Systems" **Julius Smith**; "A Passive Nonlinear Filter for Physical Models" **John Pierce** and **Scott Van Duyne**; "The Digital Waveguide Mesh" **Scott Van Duyne** and **Julius Smith**; "The Wave Digital Hammer" **Scott Van Duyne** and **Julius Smith**; "The Commuted Waveguide Piano" **Scott Van Duyne** and **Julius Smith**.

Controllers for Computers and Musical Instruments: "Real-time Controllers for Physical Models" **Chris Chafe** and **Perry Cook**; "Ongoing Work in Brass Instrument Synthesizer Controllers" **Perry Cook** and **Dexter Morrill**; "The Touchback Keyboard" **Brent Gillespie**; "The Computer-Extended Ensemble" **David Jaffe**; "Haptic User Interfaces for the Blind" **Sile O'Modhrain** and **Brent Gillespie**; "The Radio Baton Progress" **Max Mathews**; "Optimal Signal Processing for Acoustical Systems" **Bill Putnam**; "Signal Processing Algorithm Design Stressing Efficiency and Simplicity of Control" **Timothy Stilson**.

Psychoacoustics and Cognitive Psychology: "Distance of Sound in Reverberant Fields" **Jan Chomyszyn**; "Embedded Pitch Spaces an The Question of Chroma: An Experimental Approach" **Enrique Moreno**; "Pitch Perception" **John Pierce**; "Psychological Representation of English Vowel Sounds" **Roger Shepard**, **Perry Cook**, and **Daniel Levitin**; "Applying Psychoacoustic Phenomena to the Coordination of Large Speaker Arrays" **Steven Trautmann**.

Computer Music and Humanities: "The International Digital Electroacoustic Music Archive" **Max V. Mathews** and **Marcia L. Bauman**; "The Catgut Musical Acoustics Research Library" **Max Mathews** and **Gary Scavone**; "Impact of MIDI on Electroacoustic Art Music in the mid-1980s" **Alex Igoudin**; "The Chorister-Chorister Interaction: an Ethnography" **Paul von Hippel**.

4.0 The music

Some of the recent (during this past year) compositional works realized at CCRMA:

Michael Alcorn (Visiting Composer / Ireland) -*Double Escapement* (for piano and tape); **alt.music.out**-*Wonderment in Eb* - live jazz/electroacoustic fusion involving 7 performers, several NeXTs, drums and vocals; **Chris Chafe** (CCRMA Director)-*Push Pull*, for Celletto and live electronics; **Cem Duruoz** (MA Graduate Student)-*Cycles*, interactive piece for classical guitar, NeXT (physically modeled SynthBuilder Flute), and Mac (sequencer); **Michael Edwards** (DMA Student) and **Marco Trevisani**-*segmentation fault beta1.0*, for prepared piano and computer; **Doug Fulton** (PhD Graduate Student)-*Holding Betty under Water* for computer generated tape; **David Jaffe** (Visiting Composer / Researcher) - 5th and 6th movements of *The Seven Wonders of the Ancient World*, for Mathews/Boie Radio Drum-controlled Disklavier and an ensemble of plucked string and percussion instruments; **Nicky Hind** (DMA Graduate Student)-*Awakening*, computer-generated sound installation for the 18-th century garden; **Jun Kim**- Reverberation, for two sopranos, percussion and computer processed sounds on tape**;** **Peer Landa** (Visiting Composer / Norway)-*Downcast* for tape using original C-based software; **Lukas Ligeti** (Visiting Composer / Austria)-*New Music for Electronic Percussion*, performed and processed live, inspired by African drum music; **Fernando Lopez Lezcano** (System Administrator / Lecturer)- *Three Dreams*, tape piece using CLM, performance involves pre-programmed four channel spatialization; *Espresso Machine II* and *With Room to Grow*, in which PadMaster splits the Radio Drum surface into programmable virtual pads, grouped in sets or "scenes"; **Jonathan Norton** (PhD Graduate Student)-*Vicissitudes*, computer music for a documentary about a striving African-American community; **Fiammetta Pasi** (Visiting Composer / Italy)-*Collage*, for stereo tape; **Juan Pampin** (PhD Graduate Student)-*Transcription #1*, for computer controlled Disklavier; **Jorge Sad** (Visiting Composer /Argentina)-*VOX*, *VOXII*, for computer originated tape; **Marco Trevisani** (Visiting Composer / Italy) *Frammenti e Variazioni su Aura*, a Bruno Maderna inspired tape composition.

Recent awards won by CCRMA composers:

Celso Aguiar, for *Piece of Mind*, "Premio Sao Paulo '95", Brazil; **Chris Chafe**, National Endowment for the Arts Composer's Fellowship 1994-95, Green Faculty Fellowship 1995-96; **Kui Dong**, for *Flying Apples*, First Prize, 1994 Alea III International Composition Prize; 1995 Djerassi Foundation for Art, 1995 ASCAP Grants to Young Composers; **David Jaffe** for *The Seven Wonders of the Ancient World*, Collaborative Composer Fellowship, National Endowment for the Arts; **Juan Pampin**, for *Apocalypse was postponed due to lack of interest*, Award, 22e Concours International de Musique Electroacoustique, 1995, Bourges, France; **Jorge Sad**, for *Vox II*, Juan Carlos Paz Electroacoustic Music Prize, 1995, National Foundation for the Arts, Argentina.

SEE—A Structured Event Editor: Visualizing Compositional Data in Common Music

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Abstract

Highly structured music composition systems such as Common Music raise the need for data visualization tools which are general and flexible enough to adapt seamlessly to the—at times very unique—criteria composers employ when working with musical data. The SEE visualization tool consists of an abstracting program layer to allow for the construction of custom musical predicates out of a possibly heterogenous set of data and a separate program module which controls their mapping onto a wide variety of display parameters. The current version is being developed on a SGI workstation using the X11 windowing system and the OpenGL and OpenInventor graphics standards, but portability is highly desired and upcoming ports will most probably start out with the Apple Macintosh platform.

1 Introduction

Among the vast variety of ways in which music has been put in relation to the visual senses, only a few have been researched or otherwise developed to a noticeable extent. Today, sound and graphics interconnect most prominently in the audiovisual domain, that is in multimedia applications and—more recently—in the area of data sonification, but also in the more arcane areas of music visualization and graphical user interface design as well as in art. These domains, however, are not unrelated: sonification of data may be taken as an inverse process of music visualization and music visualization itself leads seamlessly to music data *manipulation* as in some GUI-designs: it may form half of a genuine music authoring environment. Musical data visualization could, it seems, profit on the other hand from the extensive computer graphics technology and visualization experience scientific data visualization projects today rely upon. In contrast to scientific visualization applications, however, music visualization does not typically deal with an enourmous amount of "flat" data such as data masses acquired by satellite photos, surveys or oceanographic sonic measurements: musical datasets are most often comparably small—but generally include heterogenous and not necessarily commensurable datatypes such as, for instance, notes and rests. They also tend to call for interpretation processes that *evolve* over time to model the changing belief contexts that characterize musical hearing. In short, music visualization differs from data visualization in that it deals with our understanding of music. And musical data, unlike scientific data, may be arbitrarily changed according to the aestethic criteria we decide to apply.

2 Visualization Today

Although a number of promising approaches to signal visualization to faciliate the process of sound (re)creation exist, research in visualization of compositional data is rare and focuses on musicology as opposed to creative applications. More recent examples include the analysis of features of music by Bartók and Webern in the graphical plane by A. Brinkman and M. Mesiti [2] and J.-P. Boon's interesting examination of significant differences between three-dimensional phase portraits of selected three-part compositions by Bach, Mozart, and Schumann [1]. The majority of musicological analysis toolkits, however, doesn't go beyond a symbolic representation of their results (cf., for instance [3]).

Alternative approaches to signal visualization leading to graphical representations of higher-order features of sound data that approximate complexer musical predicates in a raw manner have been presented previously by J. Pressing et al. and B. Mont-Reynaud [8, 7] as well as, most recently, by B. Feiten and G. Behles [5].

Finally, I. Choi et al. [4] and Y. Horry [6] document some specific research into the application of musical concepts using graphical controllers to generate both MIDI and digital sound output.

Graphical user interfaces for compositional oriented software today has begun to venture into the domain of 3D, with more and less success and not