Composing Instruments:

Inventing and Performing with Generative Computer-based Instruments

by

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Abstract

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This dissertation describes music composition as an act of composing instruments. The building blocks of such instruments are discussed: the fundamentally interdisciplinary approach, the role of gesture, the role of real-time generative software, the mappings between gesture and generative processes, and the interaction between performer and instrument. A real-time performance instrument that was composed to accompany the opera *Takemitsu: My Way of Life* is described. Key constraints imposed by this project are described, namely: the need for the real-time electronic sound to blend and relate musically to the rest of the music, the need to create a stateless and playable instrument, and the need for an instrument that is robust, adaptable, portable. Design and compositional decisions that address these constraints are proposed and the actual implementation is discussed. As a contrasting example of a composed instrument, a second project is presented: an interactive installation named *...in memory of Leah Deni* created in memory of Leah Deni. This project serves as an example of the same compositional interest in instrument building and interactivity, but applied to an installation setting where the performer is the audience member. Connections between the conceptual and technological aspects of the installation are drawn. Finally, a set of software modules for real-time creative work named *_aLib* is presented. The modules in *_aLib* (a set of abstractions for the Max/MSP environment) were used extensively in the described instruments and will hopefully make a contribution to the real-time computer performance community.

This dissertation is dedicated to Nakhostin and Reza for their never-ending love and support, and to my mentor David Wessel who has been the most influential and inspirational presence in my recent years.

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1 INTRODUCTION

The aim of this document is to not only present the work on a particular piece as is traditionally done through a score by Ph.D. candidates in composition at UC Berkeley, but to also produce a document—with a lot of accompanying software and media—that can serve as a rich resource for research and pedagogy. This dissertation is therefore divided into the following sections: After this introduction, section two is a brief account of my history as a composer and my present day direction. Section three discusses controllers, their central role in my work, and the important issues and considerations surrounding their use in interactive art. Sections four and five are each devoted to a project. Section four is a comprehensive documentation of a composed instrument that was successfully used in multiple performances of the large-scale opera, *Takemitsu: My Way of Life* (Takemitsu 2004), and section five describes an interactive installation titled *...in memory of Leah Deni* that is to be shown at the International Computer Music Conference in Barcelona in September of 2005. The sixth section is the official release and documentation of my library of software tools developed for the Max/MSP real-time programming environment (Zicarelli 2002). The generalized and reusable modules in this package played an extensive role in the realization of the two artistic projects. The software tools as well as the patches for the aforementioned operatic and installation projects are made available to the world for download and reuse. Sections seven, eight and nine conclude this dissertation, make the acknowledgements and the give the bibliography.

2 MOTIVATIONS

My history as a composer began not long before the start of my graduate work at Berkeley. Until my final year of undergraduate studies, my relationship with music was essentially limited to performance. Many years of piano study led to an interest in percussion, jazz and improvisation, which then led to a semester abroad at the Conservatory of Adelaide during my third year of college. After returning to Swarthmore College, I dedicated myself to completing a music major, eventually focusing on composition. At the time of my entrance to Berkeley, I had four modest pieces in my portfolio and was quite enthusiastic about picking up the pencil and formulating musical instructions for others to execute, the beginning and end of what I considered composition to be at that time.

For my first concert at Berkeley I completed my *Movements for String Quartet*, which I had begun the previous year, and began the process of arranging a proper performance. This process—from slaving to produce an executable score, finding musicians, arranging and leading rehearsals, to pulling off the concert and overcoming all manners of bureaucratic logistics—left me feeling cold. I knew immediately that "composition" for me needed to be more holistic, with me closer to and more actively involved in the music, and perhaps even performing on stage.

During the following three and a half years, I dedicated myself to improvisation, performance and instrument building. I performed in every piece that I created, I tried to work with the same group of musicians—a band—and I experimented more and more with alternative contexts for new music, namely musical theater, alternative performance spaces and programs, as well as interdisciplinary projects. These explorations have helped me find an area of creative work that is "composition" for me, an area that I shall call composing instruments. This name has two meanings: First, I refer to instruments that have an internal compositional sense; the software that is written, the controllers that are used and the interaction that is defined **is** the composition. Second, I refer to instruments that themselves compose. For instance, they generate material based on rules, statistics, or algorithms that are selected by the composer or they help organize and explore the musical material. The works presented in this dissertation are two examples of such composed instruments.

3 CONTROLLERS

3.1 Embodiment

Like many researchers and performers, I am a firm believer in the invaluable role of embodiment in music perception, cognition, and most importantly performance. Vijay Iyer gives a impressive overview of the topic in his doctoral dissertation (Iyer 1998). Many critiques of body-less computer music have painted rather stark pictures of the deficiencies of the genre ((Zicarelli 1991), (Ostertag 2002)). These authors have argued that the un-embodied computer music in the classical world generally takes one of two forms: either the music is recorded onto "tape" and played back in performance, or, if the work involves "real-time" activity, then the computer musician is hidden from the stage and the electronic sound is presented in its valued "pure" form. In either case, the computer generated sound is dissociated from its performer's body, it is un-embodied. Outside of large academic or research institutions that support and define the practice of new classical music, computer music performance takes on a slightly different form. There, the same electro-acoustic techniques and tools are employed, but the stage is anything from the main room of a small research center (like CNMAT, CCRMA, La Kitchen, or STEIM), to underground venues and festivals (Placard, Capital Sonor, Public Life), to large scale, highly organized electronic music festivals (Sonar, Ars Electronica, Transmediale). While these performance contexts avoid some of the older pitfalls, they, too, fail to truly embody the musical experience. The familiar and all too telling image is that of an electronic musician isolated behind his laptop screen, at once in the spot light from the LCD's glow and safely hidden in the anonymity and mystery of a computer. Even when a MIDI keyboard or a set of knobs/sliders replace the computer's keyboard, the computer's ways and means remain largely invisible and disconnected from the performer's body. The mouse, knobs, sliders and keys are rarely the most fitting manner of translating a musically rich gesture into control information for a computer. A principal aim of the projects described in this dissertation was to create instruments that allow better involvement of bodily gesture in the music making process. Controllers, mappings and software instruments were sought that allow one to explore and express as intuitively and richly as a sophisticated traditional instrument.

3.2 Mapping

The large array of techniques and philosophies in computer music and the interdisciplinary arts which are classified under the umbrella term "mapping" are particularly relevant to this work. A full-blown technical or philosophical discussion of the topic is beyond the scope of this document. I will, however, discuss two ideas related to mapping which have received a good deal of attention in my work, and are specifically pertinent to the projects described below. First I will discuss various existing categorizations of mapping techniques for using controllers in real-time interactive applications. Second, I discuss the idea of using perceptual spaces to perform interpolations between sets of control data.

I am especially drawn to theories that attempt to differentiate the various mapping approaches by defining characteristic axes. In computer music literature, three fundamental categories are described in numerous articles ((Ryan 1991; Rovan, Wanderley et al. 1997; Hunt, Wanderly et al. 2000)); mapping strategies are described as "one-dimension-to-one-dimension", "one-dimension-to-many-dimensions" and "many-dimensions-to-many-dimensions", where the first and last word refer respectively to the inputs and outputs of the mapping layer[1]. This helpful distinction clarifies the basic function of these mapping layers, namely a need to control many parameters with few inputs.

Another helpful categorization of mapping strategies is the distinction between **generative** mapping layers, e.g. Hidden Markov approaches as in (Visell 2004), or mass-spring models as in (Momeni and Henry 2004), and **explicit** mapping layers, e.g. neural networks as in (Fels and Hinton 1993; Fels and Hinton 1998; Wessel, Drame et al. 1998; Cont 2004) or perceptual spaces (Arfib, Courturier et al. 2002; Momeni and Wessel 2003; Bevilacqua and Muller 2004). In addition to addressing analytical issues of implementation and functionality, this distinction is also thought-provoking in its aesthetic implications; whereas explicit mappings allow the performer to directly and exactly control the instrument, generative mappings relinquish some of this liberty to an algorithm in the mapping layer.

Birnbaum et al. propose a more generalized approach of categorizing and comparing musical artifacts using a 7-dimensional space (Birnbaum, Fiebrink et al. 2005). The 7 dimensions are: goal of interaction, required expertise, musical control, inputs (degrees of freedom), output (feedback modalities), inter-actors, and distribution in space. The authors then go on to define a subjective continuum for each of these dimensions, for example one that ranges from "none" to "extensive" for "required expertise" dimension. Their system is proposed for understanding,

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[1] Different authors have used different terminology for the same line of differentiation. For example, Rovan uses the words "convergent" and "divergent" for "many-to-one" and "one-to-many" whereas Ryan proposes some geometric analogies involving points, lines and curves.

discussing and comparing "musical artifacts", but seems most appropriate for controllers and mapping techniques.

My experience in performance and interactive arts has highlighted yet another axis of differentiation that is worth consideration: modal v. non-modal mapping layers. By modal I refer to controller mappings where the same gesture can produce a variety of different results depending on the instrument's mode or state. The question of "affordance"—the properties of an object that determine and convey how the thing could be used—is also pertinent to the discussion of mapping techniques and their differentiation based on modality. Speaking broadly, non-modal interfaces tend to be more intuitive and less cryptic (Norman 1988); they also tend to have greater affordances than modal-interfaces, because the user's interactions with the interface are always interpreted the same way. On the other hand, modal interfaces allow the user to control more things simultaneously and in a variety of ways. Their state-dependent behavior, however, creates some potential problems, namely mode errors: the performer is required to expend both time and effort to constantly change modes, and performing a gesture in the wrong mode produces a "mistake". Despite these problems, however, real-life situations impose the need for some kind of modal mapping, as hard as one may try to avoid it. There is both the possibility and the need to control more things simultaneously than a non-modal interface allows. In other words, the increasing availability and generality of software and controller hardware as well as the decreasing size of alternative controllers and computer hardware gives more and more importance to modal control. Two noteworthy examples of readily available and quite powerful controllers are the Wacom tablet (Wacom 2004) and the iGesture track pad (Fingerworks 2005).

Techniques that combine the benefits of modal and non-modal mappings are of great interest to my work. Consistency in interface design is also a key issue and a level of consistency must be maintained in the design of interaction with an instrument. I consider perceptual spaces and interpolators as key techniques in providing consistency in modal-mappings. For instance, imagine a mapping scheme with 10 modes where each mode is a different interpolation space for the control of a different process. Even though the mapping scheme is modal, a significant principal is maintained across all of the modes thereby making interaction with the interface more intuitive. The act of switching modes is also worthy of attention because its seamless integration into a modal gesture-mapping scheme can greatly increase an instrument's success. Imagine for instance a sensor-glove interface that modally maps hand gesture information to the input parameters for some software process. Consider now two ways of choosing the mapping mode: first, a series of buttons pressed with the other hand and second, the performance of a specific hand gesture with the same hand. Whereas the former involves two dissociated gestures and a need for coordinating two different actions, the latter combines the two actions. Another advantage of this approach is that one can also predict the initial state of the hand as soon as a particular mode is selected. Advances in gesture analysis evident in software packages like EyesWeb (Musicale 2005) or video-based gesture recognition techniques like (Modler, Myatt et al. 2003) allow for rich possibilities in integrating modal and non-modal mapping techniques. Attention to modality in the mapping layer between gesture and sound has been an important concern in the research and development of this dissertation.

Interpolation as a technique for control has attracted much interest in the computer music community ((Grey 1977; Wessel 1979; Rovan, Wanderley et al. 1997; Arfib, Courturier et al. 2002; Bevilacqua and Muller 2004; Bencina 2005; GRM 2005)). In the instrument descriptions below, there is frequent reference to “interpolation spaces." My interpolation spaces are a technique for mapping low-dimensional controller data to high-dimensional synthesis or transformation parameters. The approach, described in detail in (Momeni and Wessel 2003), is based on creating perceptual maps that organize musical material, processes, parameters, etc. according to their similarities and differences from one another. Objects that are similar are placed near each other on a map, whereas drastically different objects are far apart. Objects can either be placed in maps by hand, or with a variety of automated techniques[2]. In practice, each object on the map represents a list of numbers that may, for example, be the parameters for synthesis or transformation of sound. Each list is associated with a weight function. That height of this function at any point in the space defines the influence of its associated list, in the interpolated mix among all lists for that point. In my implementation, Gaussians were used for the variability they offer with just two parameters, the height and the variance (figure 1).

Navigating this space produces a smoothly varying list of numbers that is a weighed interpolated mix of all of the lists in the space. This map in turn provides an intuitive interface for real-time control of a large number of parameters, using a small number of parameters received from a controller. I created a Max/MSP/Jitter abstraction—available in *_aLib* as ‘ali.jToop’—that performs this type of spatial layout and interpolation (figure 1).

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[2] A few examples are: Multidimensional Scaling, Self-organizing Maps (Kohonen 1997), Fastmap (Faloutsos 1995), Locally Linear Embedding (LLE) (Roweis 2000), Principal Component analysis (PCA) (Moore 1981), Independent Component Analyis (ICA) (Hyvarinen 2000) , Convex Optimization (Kassakian 2005)
Kassakian, P. and D. Wessel (2005). Optimal Positioning in Low-dimensional Control Spaces using Convex Optimization.

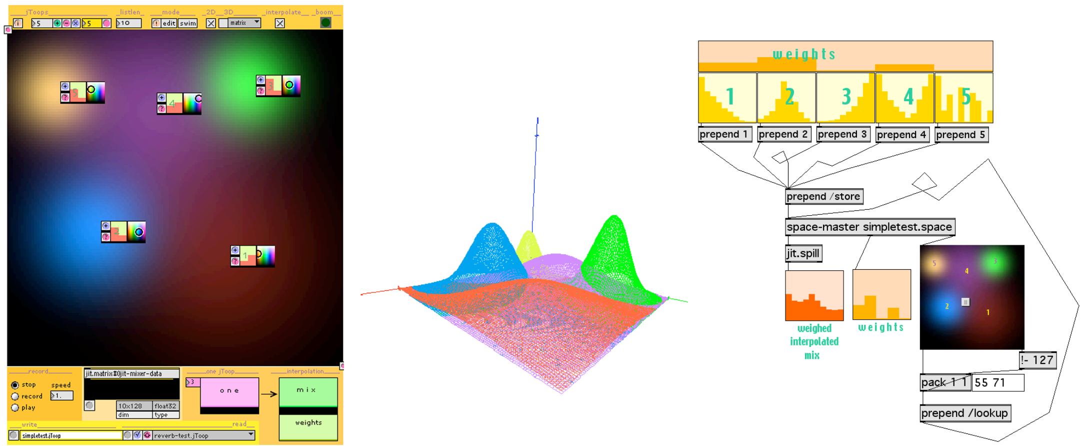

Figure 1. Interpolation Spaces. Left: The interface of the 'ali.jToop' interpolator. Left: The black area with five colored areas is the interpolation space; the brightness of each color represents the degree of influence that point on the interpolated mix. The rectangles associated with each colored area allow one to adjust the shape of each color area. Center: The colors for the map on in the left image are calculated by five corresponding Gaussian functions of varying mean (position of the center in the x-y plane), height and variance. Center: The color of each Gaussian surface corresponds with the color of its 2-dimensional representation on the map in the left image correspond. Right: a snapshot of the helpfile for the 'ali.jToop' interpolater. Note that there is a list of numbers associated with each point in the space (the five numbered set of sliders in the top of the image). Navigating in the interpolation space in the bottom right produces a interpolated mix (red sliders in the bottom) of the five given lists of numbers.

3.3 Mixed sensing (audio + gesture input)

A novel technique that appears underutilized in the literature as well as in the repertoire of new media artists working with controllers is what I call "mixed sensing paradigms." The technique, used in both of the described projects in this dissertation, involves combining two sensing schemes in order to build a richer controller. The technique has a number of advantages: first, the shortcomings of one sensing scheme can be countered with the strength of another, while their strengths can be combined. The example used in both projects below, involves coupling the gesture input from Wacom drawing tablet (Wacom 2004) with the audio input from a contact microphone placed on the tablet. The audio-rate/synchronous input from the contact microphone aids in countering the high latency and timing jitter weakness of the Wacom USB controller. This instrument is described in detail in the section titled Project I.

Other scenarios are easily imaginable, especially by combining video input and analysis with existing gestural controllers.

It is worth noting that the notion of joining a sound-producing source and a technique for its modulation is central to many acoustic instruments where sound is often produced through physical contact and manipulation of the instruments. This intimacy between gesture and sound provides acoustic instruments with a rich space for variation and expressivity. On can apply the same principal to work with alternative controllers: By integrating audio input from contact microphones attached to the controller into the instrument design, one can gains access to control information that describes the physical interaction with the instrument in a most tangible and direct manner. An early example of a similar approach was implemented in a guitar controller developed by Keith McMillan at Zeta Music (McMillan 2005) where analog audio input circuitry captured the amplitude envelop of each string and reproduced it in the synthesized audio, before the slower audio analysis began to give its results. Another related work is the *E-mic* (Hewitt and Stevenson 2003) controller that combined a conventional vocal microphone with a large array of sensors attached to it and to the microphone stand. It is worth noting that in addition to using the audio signal from a controller directly in synthesis, analysis of this audio signal (for amplitude envelopes, spectral content, attack detection, etc.) also enriches the control and mapping systems and allows for more intimate gestural control of the instrument.

The notion of integrating gesture and audio data into one multiplexed stream is central to the development of the Rimas Box Connectivity Processor (Avizienis, Freed et al. 2000), a significant research accomplishment from CNMAT. I hope that in the future, the ability of the Rimas Box to perform data-acquisition from a large variety of inputs devices (microphones, piezo's, analog and digital sensors, and perhaps video in the future) will promote the exploration of mixed-sensing approaches to composing gesture instruments.

3.4 The Double-Edged Sword of Simplicity and Playful Transparency

The more I work with controllers and their integration in making interactive art, the more I notice a romantically bittersweet dialectic at work in my field. The most sensitive and artful success in composing an ensemble of controllers, computers, software and actuators (loud speakers, video projectors, robotics, etc.) can ultimately be experienced like **a game.** In other words, a well-designed controller and mapping scheme renders complicated tasks transparent or even playful. However, this playful quality has the danger of disqualifying sophisticated creative work from being considered "serious art". In my experience it is usually either the audience member or the figure of authority (teacher, conductor, boss, mother) that questions the depth of an interactive work by posing the playfulness/seriousness question; in either case, the situation is not ideal because something about the work has not been fully communicated. The danger of having ones work be considered as **a game** is a disconcerting drawback to attempt at artistic expression using sophisticated technological means.

Many have come to the defense of new media as a serious undertaking and from a great variety of perspectives. There are those who argue for the merits of new media for its redefinition of an artistic language that is based on the interdisciplinary exchange between the involved forces, an idea that is called "transcoding" by Lev Manovich (Manovich 2001). Others take a technophilic stance and revel in the possibilities of technology (e.g. Tanaka and Toeplitz's Global String (Tanaka and Toeplitz 1998), Hajdu's Quintet.net (Hajdu 2005), even to the point of considering it as further evolution as in the bio-robotics work of Australian artist Stelarc (Stelarc 1982)). Another approach is to embrace the potentially toy-like behavior of new media works and integrate it into the works' conception (e.g. Todd Macover's Toy Symphony (Machover Ongoing), Levy Lorenzo's MIDI hamster (Lorenzo 2004), o Eric Singer's Sonic Banana (Singer 2003)). Others defend the computer's potentially childish innocence by posing it against its unique ability to act completely objectively, its ability to "flip a coin"; this objectivity clearly something very attractive for a wide range of artists working with technology. Some have even problematized the defense itself by suggesting that the mere act of defending interactive art against criticism of toy-like behavior unnecessarily dignifies the attack. David Rokeby's essay *Transforming Mirrors* (Rokeby 1996) is an eloquent example of such an argument. I see the situation a bit differently: I am reminded of a simple phrase spoken to me by Francois Pachet—a most imaginative researcher with an admirably high-level view of things: "it should be like a game!" My appreciation of this comment, is not rooted in my faith in the video game industry's latest accomplishments. Rather, I see the potentially toy-like behavior of an instrument as its power of seduction, its "low entry fee" (Wessel and Wright 2002). In the performance context, an instrument's power to seduce its player is central to motivating her—most likely also the instrument's creator—to practice. In the installation context, power of seduction in an interactive object is more than half way to success. But along with this transparency in the interface, there must also be a mystery. This mystery could be in the richness of the material at hand, or a "no-cap on virtuosity" (Wessel and Wright 2002), or an ecstatic sense of agency for the user no matter how simple the interaction. The interactive video game Pain Station (fur 2005) by "art entertainment interfaces" group **fur** (fur 200) is a perfect example: opponents play a simple Atari *Pong* style video game, except with burning, electric shock and strap beating of your opponent as reward; in any case there needs be a depth to the interactivity's composition that not only justifies the game but renders it artful.

Gestural controllers and the mapping between gesture and sound generation play a central role in the two projects described below. The concerns and interests discussed above have been important guiding principals in composing these instruments.

4 Project I: *Takemitsu: My Way Of Life*

4.1 Project Description

Taketmitsu: My Way of Life was a collaborative undertaking by Kent Nagano (musical director and conductor, USA), Peter Mussbach (director, Germany), the Staatsopper Unter den Linden and the Deutsches Symphonie-Orchester of Berlin, Theatre du Chatelet of Paris, a group of about 20 actors and actresses and near 200 additional participants including the orchestra, a chorus, stage crew members, set designers, sound engineers, etc. The project was commissioned by the family of Toru Takemitsu (1930-1996) on the occasion of the 10th anniversary of his death. Taketmitsu, a prolific composer who covered an impressively wide range of genres in his output, had apparently spoken of writing an opera at some point in his life[3]. He died before he could carry out this wish, however, and thus the creation of an opera seemed like an appropriate form of remembrance and hommage. Mr. Nagano, Mr. Mussbach and the Takemitsu family quickly decided that such an opera should comprise of a variety of the composer's music, be multi-lingual—one of Takemitsu's wishes for his never-realized opera—and that it should try to paint a

[3] Most of the information about how the opera came to exist was revealed in emails between Wessel and Nagano plus in conversations with Nagano on-site.

picture of his life, his aims, his interests and his way of working. In addition, the opera's sound designer, Étienne Boultanger, was asked to prepare some electronic compositions that would serve as transition material between the original Takemitsu works performed by the orchestra and small ensembles. Within these criteria, Nagano and Mussbach set out to construct a narrative, a staging concept, and the accompanying music. The final product was titled *Takemitsu: My Way of Life*.

David Wessel was contacted by Kent Nagano after the first performances in Berlin in October 2004. Mr. Nagano was very dissatisfied with these performances: aside from his general dissatisfaction with Mr. Mussbach's decisions in staging and dramaturgy, he found that Boultanger's electronic compositions did not function well in the piece. He felt that the overall pacing of the opera was far too slow, with too many unduly still and lifeless sections. Nagano was familiar with CNMAT's approach to real-time electronics through our collaborations on a number of previous productions[4]. He therefore invited CNMAT to come onboard in order to resolve the shortcomings he has observed by adding real-time electronics. I was promptly contacted by Mr. Wessel to take over the project; the goal was to create a real-time performance instrument that I would play to accompany the already existing instrumental and electronic music in the opera.

[4] David Wessel's *Singularities* (2004), The Ojai Festival (2004), Edmund Campions *Chorail* (2003), Campion-Beethoven *Collaboration* (2003), Ron Smith's *Consolations* (2002), Pierre Boulez's *Dialogue d'Ombre Double* (2001), Kaja Sarijaho's *Noa Noa* (2002), Philippe Manoury's 60th *Parallel* (1998)

Figure 2. Photographs from *Takemitsu: My Way of Life*. Images were taken from the printed program for the Tokyo performances.

4.2 Musical Content of the Opera

Takemitsu's desire to write a multi-genre and multilingual opera played a central role in forming Nagano and Mussbach's collaborative direction. *Takemitsu: My Way of Life* was musically constructed as a collage of original works by Takemitsu, separated by a number of prerecorded electronic works prepared by Boultanger. Table 1 shows the progression of pieces in the opera; the works titled *Komplex1, 2, etc.* are Boultanger's electronic pieces while all others are Takemitsu's orignal compositions.

Title	**Year**	**Instrumentation**	**~ Duration (min)**
Komplex 1	2004	Prerecorded Electronics	14
Requiem	1957	Strings	11
Komplex 2	2004	Prerecorded Electronics	3
November Steps	1967	Biwa, Shakuhachi and Orchestra	19
Komplex 2b + *Water Music*	2004 +1960	Prerecorded Electronics	4
Waltz		Orchestra	8
Komplex 3	2004	Prerecorded Electronics	4
Family Tree	1992	Narrator and Orchestra	20
Komplex 4	2004	Prerecorded Electronics	4
Small Sky		Mixed Chamber Ensemble	5
Munari by Munari	1971	Solo Percussion and Electronics	10
Komplex 5	2004	Prerecorded Electronics	5
Stanza 1	1969	for female voice, piano, guitar, harp and vibraphone	7
Komplex 5a	2004	Prerecorded Electronics	3
Komplex 6	2004	Prerecorded Electronics	3
My Way of Life	1990	Orchestra and Barritone	17
Komplex 7	2004	Prerecorded Electronics	3
		Total Time:	140

Table 1. Musical content and organization of Takemitsu: My Way of Life. Works titled Komplex are prerecorded electronics work prepared by Étienne Boultanger; others are original works by Takemitsu.

Takemitsu's original works ranged from melancholy works with undertones of a romantic language like *Requiem for Strings,* east-west fusion attempts like *November Steps*, and a luscious Ravelian *Watlz*, to idiosyncratic music-theater works like *Family Tree* (featuring the steal drum), cabaret style song as in *Small Sky*, semi-improvised solo percussion and electronics in *Munari by Munari,* the overtly modernist *Stanza* and the almost-Broadway song *My Way of Life,* written as a memorial to Michael Vyner, the artistic director of the London Sinfonietta*.* To stage this great variety of musics, director Mussbach had prepared an experimental dramaturgy that was filled with the bizarre: from the representation of Takemitsu by four women, to the unexpected and unexplained appearance of 6 dwarfs in bear suits along with an 8 foot tall white baby head, Mussbach clearly aimed to perplex the senses and put into question accepted symbols. In a late night conversation with Peter Mussbach and his dramatist Axle Bott, Mussbach relayed that in this project he was above all interested in experimentation, breaking operatic rules and portraying parts of Taketmitsu's character that exposed the dark complexity of his mind.

My job was to not only contribute musically to parts of the opera that Nagano found lacking in richness, but to also work with the theatrical progression and development of the scenes, the transitions among them. I was specifically directed to accompany the sense of tension and release being played out on stage. I contributed during all of the *Komplex* pieces which often served as transition music, by adding harmonic clouds of sound whose color and timbre were derived from already existing musical components of the works. I also controlled the spatialization of these harmonic textures in real-time, creating theatrical movements, accumulations and plays of sound location in the hall. The sections below titled "Migrator" and "Vbap Spatialization" discuss these elements. The solo percussion piece *Munari by Munari* became an intimate duo between the percussionist and my real-time electronics. During this piece, I was continually analyzing the sounds from the percussionist's large palette of acoustic instruments and deriving the harmonic content of what he was playing. I used this harmonic knowledge to create harmonic textures as well as percussive sounds that connected with and complemented what he was playing. To give an example, when the percussionist struck a note on the steel drums, I could extend his gesture by playing a harmonic cloud that started with the color of the steal drums' sound, and evolved into undulating brassy sounds, as it moved from the front of the hall to the back. Or, when the percussionist struck a hand drum, I could analyze the harmonic spectrum and instantaneously create a virtual drum that I could strike by physically striking my controller. The sections titled "Wackres" and "iana-lush" describe these interactive instruments. Finally, I also fulfilled some very specific needs of the show that may be best characterized as theater-sound. These contributions included effects on the voices of an actress, triggering and spatializing sound files at very exact moments in the piece for theatrical purposes, as well as adding sonic tension at key moments in the opera to accompany the staging.

4.3 Aims

Similar to the constraints imposed by a commission for a set acoustic ensemble, this project suggested a set of rather specific aims. The sections below describe these constraints and relate them to specific electro-acoustic techniques that were chosen as ways of meeting these constraints.

4.3.1 Blending In

Perhaps the most fundamental constraint imposed by the context of this project was the requirement to blend in. We were invited to produce electronic sound that was to accompany already-existing music, at times a live orchestra, at times a solo musician and other times already-prepared electronic material. For this reason, I decided that an analysis-resynthesis technique would play a central role in my performance instrument. Specifically, I set out to build a number of sound engines that use data from spectral analyses of the live in order to synthesize musical material that is harmonically connected to the existing material. By performing real-time analysis of the existing music, I sought a complementary harmonic language for the real-time electronics.

Secondly, Wessel and I opted towards harmonic clouds of sounds as a primary musical element. Mr. Wessel's approach to harmony as is displayed in his piece *Antony* (1977) was a particular inspiration. His technique for creating harmonic clouds that "migrate" from one harmonic region was simultaneously rich, malleable and unobtrusive—primarily due to a scarcity of distinct entrances and attack envelopes. The section below titled "Migrator" discusses this synthesis engine

4.3.2 Rehearsal Efficacy

A number of constraints are imposed by large collaborative projects involving many different contributing members (Madden, Smith et al. 2001), the most important of which is highly restricted rehearsal time in the actual performance setting. Since my instrument was to be a part of a much larger production involving a multiplicity of other components including live musicians, actors, lighting, staging, etc., it was imperative that the little rehearsal time that exists be used as effectively as possible. Given the circumstances, there were three practical requirements:

1. The instrument must facilitate jumping to any section of the opera at any moment. Since all the other contributing components of this production were also in need of rehearsing, I needed a **playable** instrument with a rich range of expressive possibilities, any of which could played or combined at any time. In order words, I needed a stateless instrument that could jump to any moment in the entire piece at my will.
2. The instrument must allow me to learn during rehearsals. A robust scheme of remembering desirable outcomes was crucial to the success of the instrument.
3. Also due to limited rehearsal time, as well as the fact that we were brought onto the project so late and thus needed to create our own space in the sound design—both musically and literally—my instrument had to be independent of the existing setup, small and rapidly integratable/adjustable to the existing setup.

4.3.3 Variation and Improvisation

An invaluable advantage in this project was Mr. Nagano's granting of more-or-less complete artistic freedom. Obviously, there were the practical constraints of avoiding undue conflict with the existing theater and music; however, my contribution was left to my own judgment. Naturally, with my history and persuasion in performance and composition as well as my desire to make of this an enjoyable personal musical experience, I opted for a playable instrument that allowed a high level of improvisation and with a rich palette of sound. A conceivable alternative—one that I did not consider for a second—would have been a series of prepared samples that would be triggered at the right time with the computer or a MIDI keyboard. However, I was immediately far more interested in developing a gesture-based computer instrument, that allowed me to play, explore, improve and change things on the fly as I saw fit. This approach is quite consistent with my previous tendencies in computer music as well as CNMAT's[5] overall approach. In defense of this decision, I can retrospectively say that the final performance of this opera in Tokyo was generally viewed as the most successful. I feel that the gradual improvement of my instrument as well as my ability to play it played a significant role in this evolution.

4.3.4 Envelopment, Immersion and Spatial Sound

An aesthetic leaning expressed quite early on by all involved parties—even those generally in disagreement—was a desire for an immersive and enveloping sound experience for the audience. This desire was further supported by the fact that our extremely skillful sound engineer, Etienne Boultanger, as well as his capable team of assistants provided us with a thoughtfully conceived, beautifully implemented and satisfyingly powerful surround sound system, comprised of upwards of twenty hi-quality loud speakers in each hall, the Theatre du Chatelet[6] in Paris and Bunka Kaikan[7] in Tokyo. It was an easy decision to integrate rich sound spatialization as a significant part of my instrument's musical language. Specifically, the instrument was designed to allow independent control of the spatial location of every sound-making module.

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[5] http://cnmat.berkeley.edu/

[6] http://www.chatelet-theatre.com/index.php

[7] http://www.t-bunka.jp/

4.4 The Instrument

The instrument I composed for *Takemitsu: My Way of Life* consists of 5 interconnected components (figure 3): 1) a computer, 2) gestural controllers that allow real-time interaction with the software, 3) specially written software running on the computer within the Max/MSP environment, 4) a multi-channel input/output sound interface, and 5) a surround sound system (including microphones and a mixing console that allowed routing of various audio signals to the sound interface).

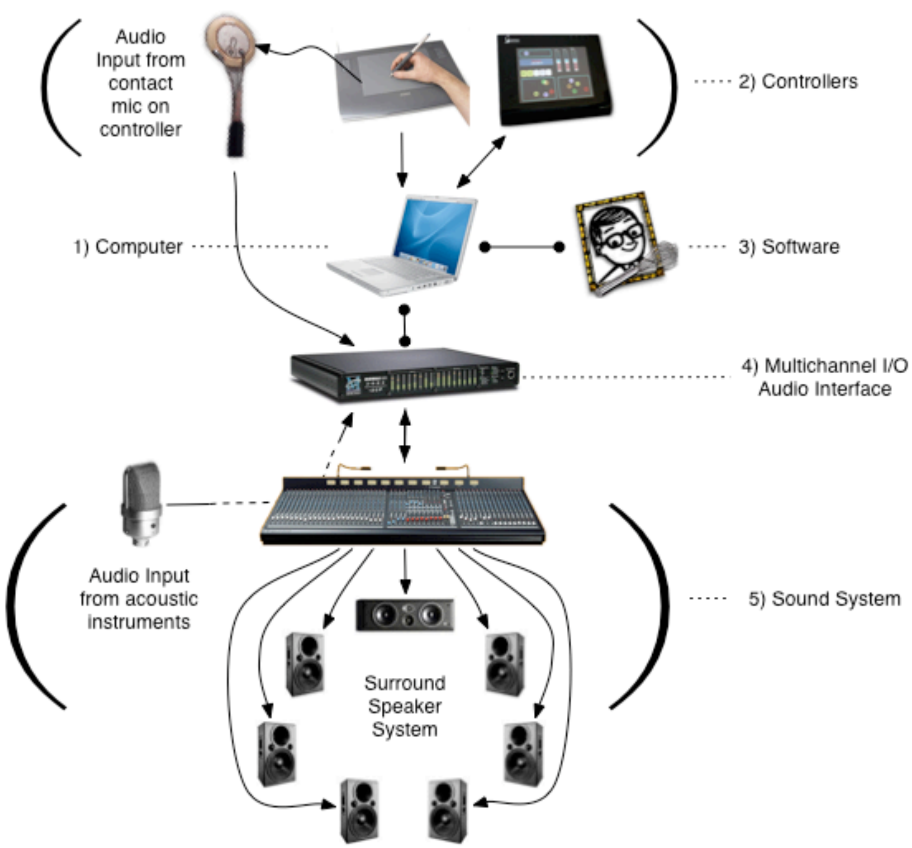

Figure 3. Block diagram of the Takemitsu: My Way of Life instrument. The 5 main components are 1) a computer, 2) gestural controllers (from right to left, JazzMutant Lemur, Wacom drawing tablet and a contact microphone connected to the wacom), 3) software running on the computer, 4) a multichannel audio I/O interface, 5) sound system including console, routing to a surround speaker array and input from microphones on acoustic instruments and actors.

The two most important components of this instrument are the controllers and the software. The computer, the sound interface and the surround system are generic components that can and did change from one performance to the next.

4.4.1 Controllers

My performance setup consisted of a computer, the sound interface, and two interfaces (figure 4). In addition to the computer and the sound interface, two gestural controllers were used to control the audio synthesis in real-time: the JazzMutant Lemur (JazzMutant 2004): a multipoint touch-screen interface and a Wacom drawing tablet.

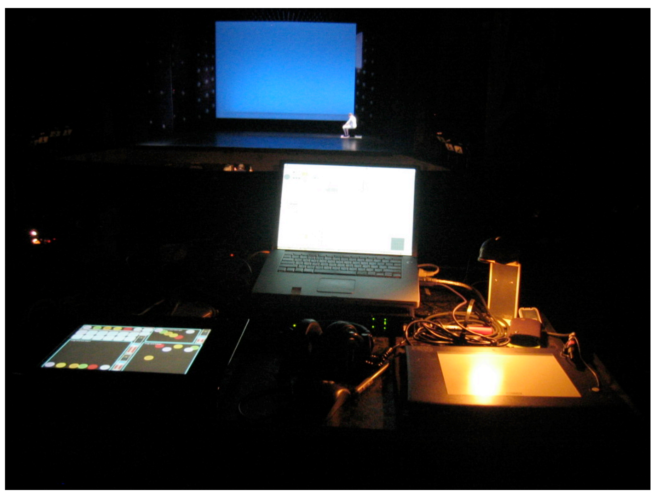

Figure 4. Performance Setup for Takemitsu: My Way of Life. From left to right, Lemur JazzMutant, the stage (blue screen), the computer (white screen), the sound interface (sitting beneath the computer and sporting small green lights), the Wacom tablet (under desk lamp light).

4.4.1.1 JazzMutant Lemur

The first controller was the Lemur by JazzMutant (figure 5). This controller allows one to arrange any combination from a set of interface objects (knobs, switches, 1- and 2-dimensional sliders etc.) on its LCD screen. When these interfaces objects are subsequently manipulated with the fingers, they report their states to the attached computer. A patch in Max/MSP can then recover these values and use them to control sound synthesis. The Lemur is a uniquely powerful controller for a number of reasons: 1) its multipoint sensing capabilities: one can use multiple fingers simultaneously to manipulate multiple graphic interface objects simultaneously, 2) the integration of a visual display into the gestural controller itself, 3) a great ability to manage and simultaneously use multiple arrangements of interface objects, 4) its integration of force-friction-like behavior for themovement of every object. As for its specific usage in the composed instrument, switches and faders were naturally of extreme practical use for real-time control of levels and processes. More interesting, however, was the natural adaptation of the Lemur's 2-dimensional slider, a movable ball in a rectangular space whose (x, y) coordinates are sent to the computer, to the interpolation spaces, and to spatialization coordinates of various sources.

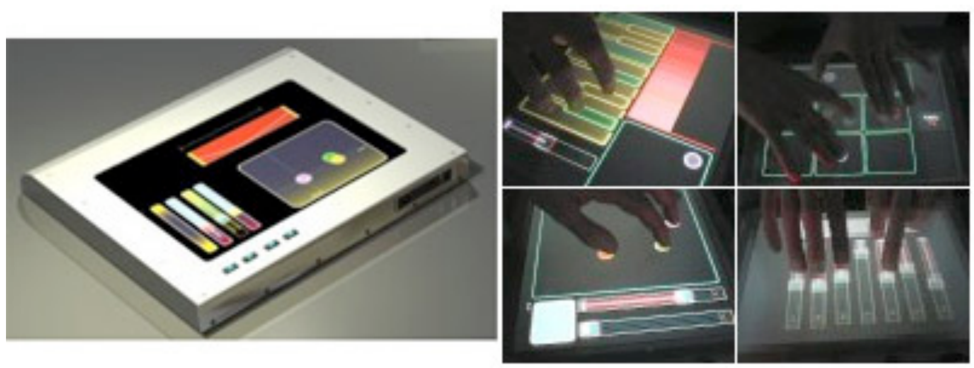

Figure 5. Lemur JazzMutant controller.

4.4.1.2 Wacom Tablet and Pen

The second controller used was a Wacom Inuous 2 drawing pen and tablet (Wacom Technologies 2004) coupled with an attached contact microphone (figure 6). The tablet can sense the (x, y) position of the pen when placed on it, as well as its (x, y) inclination and its tip pressure. In addition to these continuous controls, there are a number of on/off buttons on the pen that can be used to make discrete controls in the software. The addition of the contact microphone to the tablet allowed for combining a rich tactile interface with an impressively multimodal continuous controller (5 continuous controls in all from the pen).

Figure 6. Wacom pen and tablet controller. This interface provides 5 continuous control streams: the x, y position of the pen, the x, y inclination of the pen and the tip pressure. There are also a number of buttons on the pen. A contact microphone was attached to the tablet (right image) to provide additional information about gesture.

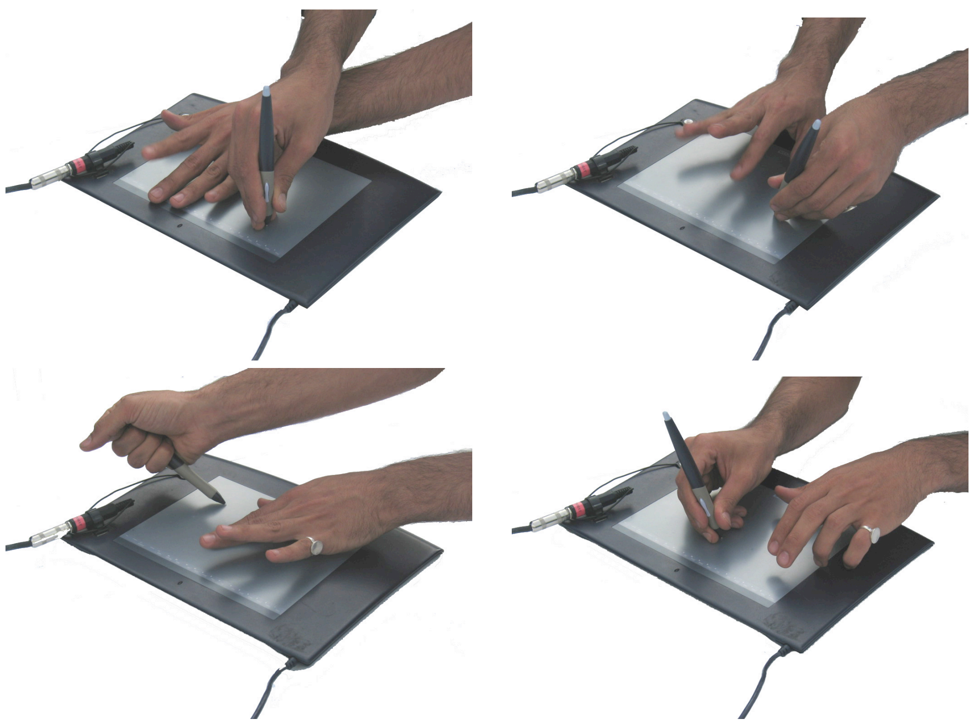

Figure 7. Two-handed playing of the Wacom interface. These photos show the sound excitation/modulation technique described in the above text. The left hand can play the tablet itself like a percussion instrument, while the right hand manipulates the pen in order to modulate the sound. By using the audio input from the contact microphone as an excitation signal in the audio synthesis (e.g. for the Wackres software instrument described below), one gains a great deal of expression. Hitting, scratching, knocking with a metal ring, or rubbing the tablet all produce significantly different audio signals captured by the contact microphone. The resulting synthesis is in turn affected by these variations and can produce a wider range of expressive possibilities.

With the contact microphone providing fast, direct and tangible control over the sound synthesis, playing the Wacom interface quickly became a two-handed activity, where one hand excites and the other modulates the sound (figure 7). As for its application to the instrument at hand, the (x, y) position and (x, y) tilt were generally used to perform interpolations in two different (x, y) parameter spaces (see (Momeni and Wessel 2003) for a discussion of interpolation spaces) while the high-rate audio input of the contact mic was used as amplitude, or excitement of a software synthesizer.

4.4.2 Software

The real-time software that makes this instrument work was created in the Max/MSP programming environment (Zicarelli 2002). The paragraphs below describe the organization of the patch as well as the functions of the main modules. Explicit references are made to Max/MSP abstractions and external objects as well as messages that are sent among the object in the patch. These mentions are placed in quotation marks.

4.4.2.1 Organization

The Max/MSP patch for this instrument consists of a mapping layer for controller input, analysis performed on input audio signal, a number of different synthesis engines, and a spatializer (figure 8). The organization of the concert patch is fundamentally rooted in the OpenSoundControl messaging scheme. The technique involves making the functionality of every part of the patch addressable through an OpenSoundControl (OSC)-style hierarchical message as is described in (Wright, Freed et al. 2001). For example, the gain for the first voice of a synthesizer in the 'migrator' instrument, can be set to the value 98.6 by the following message: '/migrator/1/gain 98.6'. The technique offers a range of advantages. First, the patch becomes self-documenting in a way; every module has a list of its addressable parameters and functionality at the top of the patch, within an 'OSC-route' object[8].

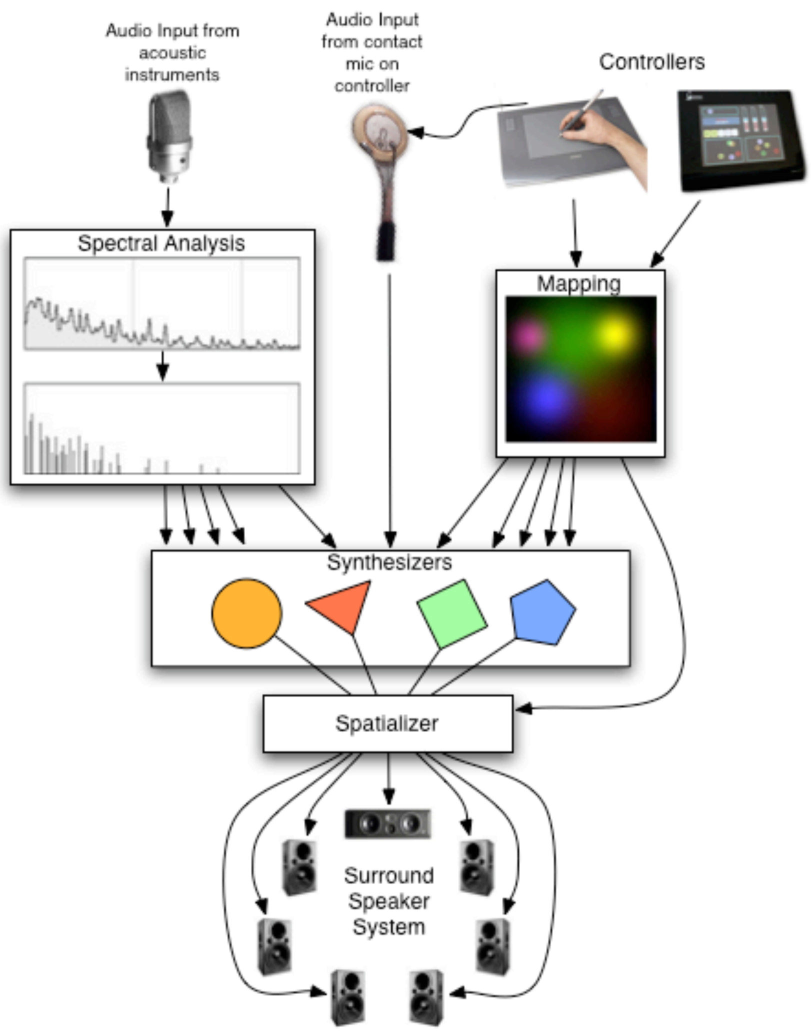

Figure 8. Block diagram of hardware/software organization. White blocks represent software components whereas images represent inputs and outputs.

The graphically hierarchical arrangement of the patch exposes the underlying structure. Also, the patch "OSC name-space" at the top level of the Takemitsu patch shows the complete OSC

[8] Certain patches use the standard 'route' object, but except for the missing '/' character, this does not change the functionality and overall organization of the patch.

name-space for the patch. Using this address scheme, any component of the patch can communicate with any other by using the appropriately addressed OSC message; in this way, one of the synthesizers can ask the analysis engine to perform analysis on the present audio input and to send it the results. Similarly, a controller can be mapped to the spatialization parameters of a source synthesizer. Second, making mappings between controllers that produce OSC messages—like the Lemur, or the Wacom with the 'ali.wacom_X-simple' abstraction in **aLib**—and the synthesis engines in the patch is simply a matter of translating one set of OSC messages to another. This makes adjustments or changes in the mapping scheme or the controller very easy to perform.

4.4.2.2 Analysis/Resynthesis

An important feature of this instrument is its ability to make real-time spectral analysis of the input audio-signal in order to generate musical material that respects the harmonic content of the source. The idea is an extension of the "catch and throw" model of interaction (Wessel and Wright 2001), where the computer instrument performs an acquisition, processes the data, and generates sound based on the data. Whereas in most applications this catch and throw is either quite literal, that is the input signal are recorded and the played back in layers and transformations, or greatly aided by a MIDI input stream that symbolically represents the input signal. Here the input audio signal is never reused verbatim. Rather, information about its spectral content is captured and applied to an independent synthesis scheme (which is in turn transformed for greater variation). The analysis was done using the 'iana~' external object (Todoroff, Daubresse et al. 2001). This object performs spectral analysis and peak-detection of an input signal and provides a list of component frequencies and amplitudes. Different synthesizers in the patch resynthesize the signal in different ways. These resynthesis modules are named 'migrator', 'wackres' and 'Iana-lush' and are discussed below.

4.4.2.3 Migrator

This module performs a probabilistic non-glissing additive synthesis in order to generate harmonic clouds in the style of those used in David Wessel's *Antony* (1977). At the heart of the 'migrator' is a probability distribution for a desired harmony. This distribution represents a harmony as a probability density over a log frequency representation with 10 cent (1/10 semitone) precision. When the 'migrator' is activated, the frequencies of independent oscillators are selected probabilistically based on this distribution. In its connection with the analysis engine, the scaled amplitude of each component was directly used as its probability in the distribution. In this way, stronger components are more likely to be chosen and are therefore stronger in the synthesized signal. An important feature of the 'migrator' is that when moving from one harmony to another one avoids glissandi by independently fading out each oscillator, setting its frequency to a new probabilistically chosen value and then fading it back in. The concert patch allows simultaneous synthesis and control of 8 'migrator's, each with 100 oscillators at its disposal. A number of key improvements were made to the existing 'migrator' patch, as it was used in previous concerts. First, real-time harmonic analysis was integrated into the harmonic control of the 'migrator's; that is, the spectral analysis engine described above could create the harmony probability tables for each 'migrator'. Second, the ability to jump straight to a destination harmony—as opposed to slowly migrating to it—was added. Third, high level controls of the register and density of the harmony were added. This allowed for better orchestration of multiple 'migrator's through control of the octave register of each 'migrator'. It also allowed a manner of "pruning" the harmonies, that is, thinning out a harmony based on the probability of its constituent components. In the pruning process, a test is inserted after the probabilistic frequency selection. The associated probability of the chosen frequency is compared with a variable pruning threshold. If the probability is lower than the threshold, the frequency is blocked and a new frequency is chosen. The pruning threshold thus allows one to variably limit the notes in a harmony to the top components in the spectral analysis.

4.4.2.4 Wackres

A second instrument that utilized real-time analysis for resynthesis was one based on models of resonance synthesized with the 'resonators~' external (Jehan, Freed et al. 1999). Resonance model synthesis involves the excitation of a group of bandpass filters, whose center frequencies are tuned to a desired harmony. In our case, the resonance models were created in real-time from the analysis provided by 'iana~'[9]. Exciting a resonance model requires sending spectrally rich signal through the filter; audio input from the contact microphone on the drawing tablet was used to this purpose, thus offered a range of rather tangible benefits; first, since the contact mic's signal enters through an audio input, the latency in the system was greatly reduced as compared to that of the tablet data received over USB (and thus limited only by the input/output and signal vectors selected for the audio interface). Secondly, great expressivity was gained by the fact that one can hit, touch, scratch, or rub the table in a limitless number of ways,

[9] Whereas additive synthesis models require frequency/amplitude pairs for each component in their bank of oscillators, resonance models require a frequency/amplitude/decay rate triplet. The three parameters define the bandwidth of each bandpass filter, which accounts for how long the filter "rings". Since "iana~" produces sets of frequency/amplitude pairs, it adapts quite naturally to additive synthesis. To be used for resonance synthesis however, the decay-rate parameter for each component must be invented. In this instrument, a simple reasoning was used that higher components lose energy faster. Increasing decay -rates were then chosen for the increasing frequency components, on an experimentally found non-linear scale and within an experimentally found range.

thus producing an excitation signal that is different. For instance, by tapping the tablet with one's fingernails, one can induce greater excitation of the higher components of the resonance model, thus changing the timbre of the synthesized sound. During the performances, I wore a silver ring and used it extensively for timbral variation in what I was playing. As opposed to the harmonic cloud textures produced by the 'migrator', the 'wackres' instrument allowed for more percussive sounds appropriate in certain sections of the work.

Two interpolation spaces were constructed to enrich the control of this instrument. The basic idea in these interpolation spaces is that a 2-dimensional control space is used to interpolate among sets of high-dimensional parameter vectors. The interpolation is a weighted mix of all the parameter vectors, where the weight of each vector is decided by the height of a Gaussian kernel associated with the vector. The center of each Gaussian kernel is the spatial coordinates associated with each parameter vector. In this instrument, an interpolation space with 5 points was constructed to allow the storage of and mixing among 5 different models of resonance. The Wacom pen's x/y location was mapped to the navigation in this interpolation space. Using the buttons on the Wacom pen, an analysis could be made and the resultant resonance model could be placed at the present pen-location in the space, actually the nearest of the 5 points to the present location. Going from one area of the table to another would change the send level of the excitation signal to each resonance model thus resulting in a smooth timbral interpolation.

A second interpolation space was constructed to control numerous model-transformation parameters available with the 'res-transform' external (Jehan, Freed et al. 1999). The technique allows interpolation among predefined model transformation parameters, resulting in real-time control over the timbre as well as the amplitude envelope of the synthesized signal.

4.4.2.5 Iana-lush

A third instrument based on analysis-resynthesis was a two-layered source-transformation instrument based on sinusoidal additive synthesis and granular transformation of the additive synthesis signal. As with the 'migrator', frequencies from analysis by 'iana~' were used to set frequencies for each component in a bank of oscillators. Unlike 'migrator', the amplitude of each component was also directly set by the analysis result[10]. This results in a straightforward, static harmonic drone whose spectral content is decided via analysis. This pure signal, however, was passed through a granular transformation using the 'munger~' external object (Trueman and DuBois 2001). The key to this control, however, was another interpolation space that mapped the x/y tilt of the pen, to all the granulation parameters; as before, navigating this space resulted in interpolation among predefined sets of granulation parameters, allowing very intricate and malleable control over the timbre and texture of the synthesized harmony.

Also similar to the wack-res instrument, the (x,y) position of the pen was mapped to another interpolation space that represented the harmonic material. As before, one of the buttons on the Wacom pen triggered analysis to be performed and the resultant sinusoidal model to be placed somewhere in the interpolation space. Movement in this interpolation space resulted in interpolation among 9 sets of sinusoidal models, spread out on the two-dimensional interpolation map.

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[10] In the "migrator", all the oscillators in the bank have the same amplitude, and the number of oscillators set to a particular frequency dictates the perceived strength of that frequency component.

4.4.2.6 Bamboo

An instrument was developed based on the physical model of bamboo using the 'bamboo~' Max/MSP external (Trueman and DuBois 2001). Using an interpolation space to drive the physical modeling synthesis parameters, a rather rich timbre space was created and played with the Wacom pen/tablet interface. An important feature of this instrument was the mapping of the (x,y) velocity of the pen to the excitation of the physical model. This mapping allowed for natural and intuitive control of the synthesis, in that if the pen didn't move, there was no excitation and thus no sound. Sudden, jerky motion resulted in louder and more aggressive sounds, while subtle, smooth gestures resulted in more reserved sonic textures. Physical models, incidentally, provide an excellent method of synthesis to be controlled by interpolation spaces. They generally have a large number of interrelated parameters that allow for very rich timbral possibilities that can unfortunately be difficult to explore and find. Interpolation spaces allow for an intuitive and efficient way of exploring this parameter space, while providing a simple mechanism for mapping low-dimensional controller data to high-dimensional synthesis parameter input.

4.4.2.7 Spatialized Sampler

A polyphonic sampler whose output was sent to the spatializer, described below, was made to allow on-demand triggering of samples and their real-time spatialization. This sampler served the most functional purpose of all components, that is, it was used to provide "theater sound effects" for certain parts of the opera, where a real-time sampler/spatializer was more effective than sounds cued and read from a compact disc.

4.4.2.8 Vbap Spatialization

A key component of this instrument was the explicit control it allowed over the real-time spatialization of a large number of sources in the concert hall. We generally worked with quite high quality surround sound systems with upwards of 20 loudspeakers, placed in 6 or 7 point surround arrangements. Using the 'vbap_n-to-n' abstraction from *aLib*, many discrete sources were spatially placed in the hall by simple vector-based audio panning with the 'vbap' external object, the help file, 'vbap_n-to-n.help' documents the abstraction. The abstraction dynamically creates inputs, outputs, a signal 'matrix~', and the appropriate control structures for an arbitrary number of sources, spatialized among an arbitrary number of loudspeakers arranged in 2-D or 3-D. Specifically, each 'migrator', each sampler voice, the 'wackres', 'iana-lush' and 'bamboo', as well the output of a reverberation module, were all spatialized separately, thus allowing rather rich spatial activity and interaction among the sources. The 2-dimensional slider interfaces of the Lemur were a natural choice for controlling position in a space of each source. However, even more gratifying was the force-friction modeling of the interface objects in the Lemur. The force-friction behavior models allow the user to choose the "smoothing" and "friction" of each interface objects. By lowering the "friction" of a slider to 0, for instance, one finds a no-energy-loss virtual slider that will continue moving forever. Furthermore, this "friction" parameter can be changed in real-time using another interface object present on the Lemur's LCD screen at the same time. This allowed for exact control of source locations with non-zero friction, as well as continuing trajectories with zero or near-zero friction, that can be set in motion with a short finger gesture. Due to its rich multi-point sensing capabilities, the Lemur also allowed for simultaneous and correlated control of many musical parameters. A most effective example used throughout the opera in making transitions from one section in the piece to another was the simultaneous control of 'migrator' gains and their locations in the room. With four fingers of each hand, I was able to fade out 4 separate 'migrator' voices, while moving all four spatialization locations in the room from the front of the hall to the back. Maestro Nagano's decision to place sub-ensembles of the orchestra in various locations in the hall throughout the opera allowed for many opportunities to make rather direct links between the acoustic and electronic musics by way of rich control of spatialization.

In conclusion, the success of this instrument was due to two factors: the simultaneously intuitive and sophisticated control provided by the Lemur interface. Real-time control of the audio-synthesis, combined with tactile control of the spatialization created a robust and adaptable that was also extremely pleasurable to play. This element of reward was absolutely indispensable in the creative process. The pleasure of playing the instrument was a constant inspiration to improve the instrument and to add more features and possibilities.

The software component of the *Takemitsu: My Way of Life* instrument will be made available on my personal website[11].

[11] http://cnmat.berkeley.edu/~ali

5 Project II: ...*in memory of Leah Deni*

5.1 Project Description

This project is an interactive installation commissioned by the Music Technology Group (MTG)[12] of the Pompeu Fabra University (UPF) of Barcelona. The work will be premiered in September of 2005 during the International Computer Music Conference at MTG/UPF. The work is a collaboration with sculptor Robin Mandel[13] who will be constructing the mechanical components of the installation. The work also has a real-time musical component that is realized with controllers, computers, Max/MSP and a sound system, somewhat similar to the *Takemitsu: My Way of Life* instrument. However, since the performers of this installation will be the general public, it serves as a better example of a composed interaction, in addition to a composed instrument. This section of the dissertation describes the physical presence of the installation, the users' experience with it, as well as its conceptual underpinnings. Rather than presenting detailed explanations of every component of this work, the aim is to further clarify my approach to composition and the wide range of forms that it can take.

This work explores three ideas: a communal musical instrument played by force, a force applied from a distance, and the separation of the performer and the instruments' guts. The user enters the installation space to find a small, dark room out of which extend three wooden arms. When moved about, the wooden arms generate sound from a pair of loud speakers mounted on top of the center room facing the user. They also attempt to seduce simultaneous users into a joint

[12] http://www.iua.upf.es/mtg/eng/

[13] http://www.robinmandel.net

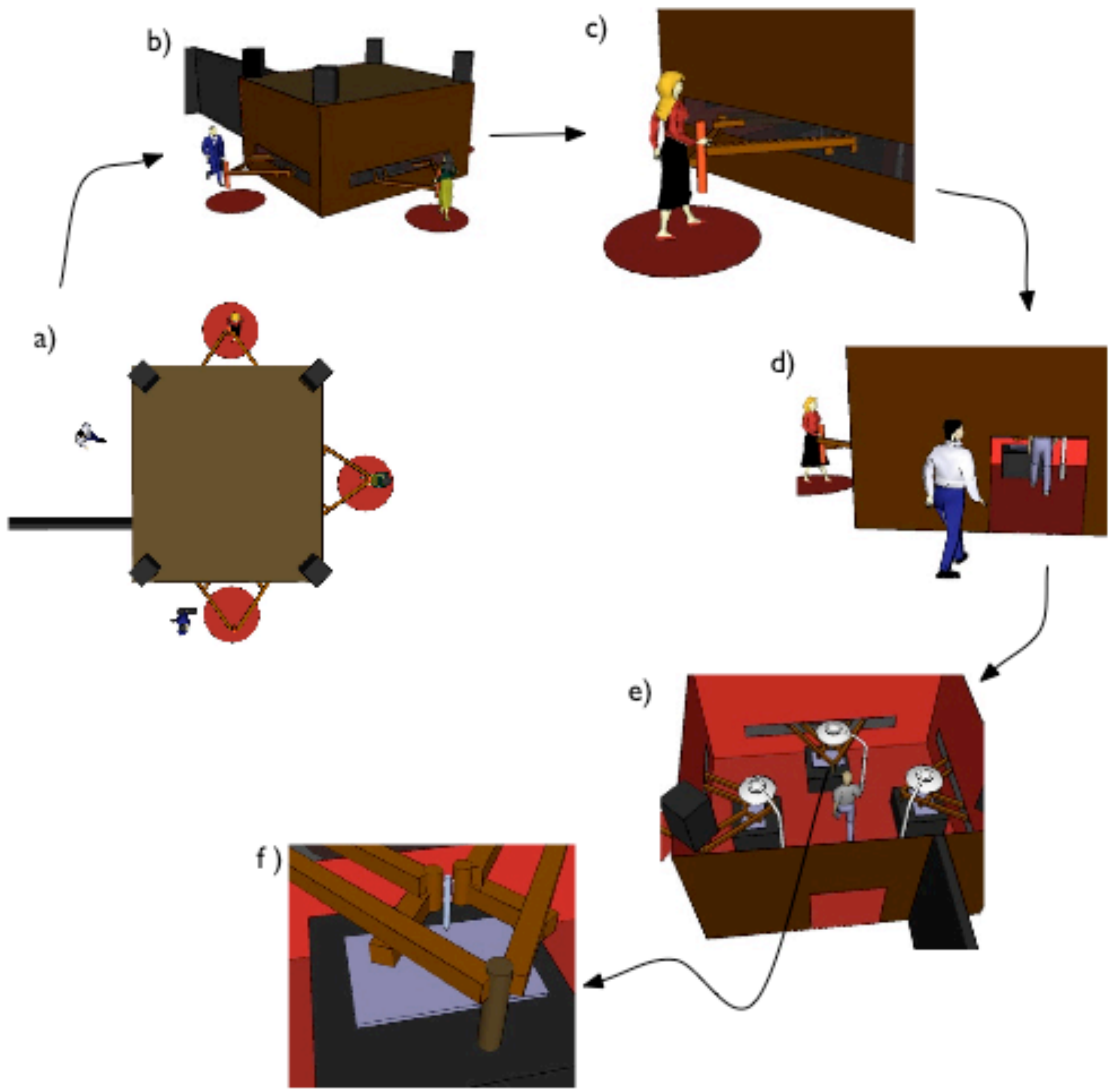

Figure 9. Images from a 3D model of the *...in memory of Leah Deni* installation. a) Overhead view of the installation shows the room, a separated wall extending out to the left, 4 black loudspeakers on the 4 corners of the room's roof, and 3 wooden arms extending out from the inside of the room. Each wooden arm terminates above a playing area designated by red circles. b) Multiple users can approach the arms, grab and move them c) moving the arms makes sound; If left alone, each state stops making sound. Each arm is an instrument and the movement of the arm control the instrument's output. d) The user can then walk around the room and enter through a small opening in the 4th wall. e) A look inside the room reveals the guts of the instrument. For each wooden arm there is a table, a lamp over the table and a large Wacom tablet and pen. f) Each wooden arm is in fact a pantograph that is attached to a Wacom pen moving about on a Wacom tablet. The movements of the arms are translated into similar but much more miniscule movements of the pen on the tablet; the pens movements are sent to a computer

that generates sound. Inside the room, the users hear only an amplification of the acoustic sound of the pen hitting the tablet, as well as the creaks and squeaks of the wooden arms' movements.

musical experience. These arms are in fact pantographs (figure 10), a mechanical device that translates the users' movements to proportional, but much smaller movements, inside the room. Inspired by this tool, Robin constructed a 3D pantograph (figure 11) that attaches the wooden arms outside the room to the guts of the instrument inside the room. After playing the instrument outside the room, the user can then walk around the room and enter through an opening. Entering the dark room reveals the mechanical guts of the instrument. Each pantograph is attached to a Wacom Pen moving about on a large Wacom drawing tablet. Acoustically, inside the room, the users hear an amplification—and slight augmentation—of the sounds produced by movements of the pen on the tablet (subtle

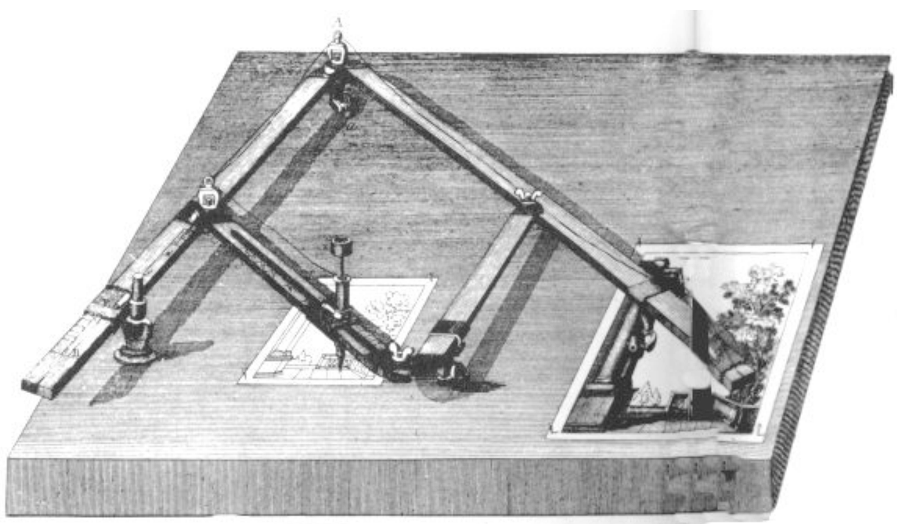

Figure 10. A Pantogrph[14]. A mechanical drawing instrument used to magnify figures.

[14] http://www.daube.ch/docu/graphics/drawing_pantograph2.jpg

scratches, collisions and turns of the pen). Outside, the users play music together, with the aid of real-time software that translates gesture to sound, and ensures compatibility or correspondence among the voices for each pantograph instrument.

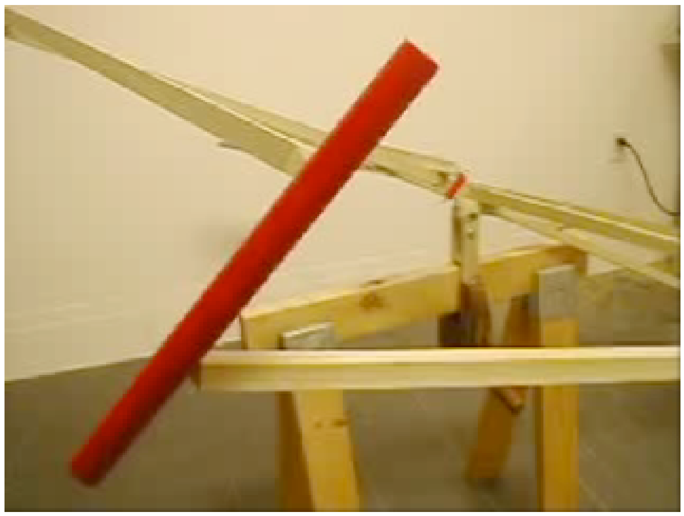

Figure 11. A 3D Pantograph constructed by Robin Mandel. The larger red cylinder corresponds with the handle gripped and manipulated by the user in the installation. The smaller red cylinder corresponds with the Wacom pen, inside the room in the installation.

6 PROJECT III: _*ALIB* TOOLS FOR MAX/MSP

Much of my work at UC Berkeley has made extensive use of the Max/MSP programming environment for creating compositions, interactive instruments, and installations. Max/MSP is a programming language that allows one to create and connect independent modules that perform particular tasks. Like any other programming language, one is bound to use and reuse modules that perform generalized tasks and that can be applied to many different problems. Through the course of my experimentations, studies, performances and teachings with Max/MSP I have developed a large library of generalized modules that can be reused in a many different contexts.

The modules are organized into the 36 categories listed below:

for analysis	for list-SDIF	for resonators
for beats	for lists	for samples
for bpf	for looping	for sampling
for collections	for markov	for SDIF
for compatibility	for MIDI	for seq~
for crap	for mtr	for signals
for data	for OSC	for sinusoids
for envelops	for pattr	for spacialization
for floats	for pitches	for streams
for help	for poly	for symbols
for ints	for prob	for tests
for jit	for processing	for vst

The modules' functionality varies from programming helpers for dealing with Max/MSP data structures e.g. "for coll", "for SDIF", "ali.multibuf", to high level programs that perform interpolations e.g. "ali.jToop" and "list-mixer", Markovian statistics e.g. "ali.markov2" and phase vocoder stretchers e.g. "ali.fstretch~". The documentation for the abstractions in *_aLib* is included with *_aLib* in the form of "help patches". Though a great many of the modules are already documented in this way, further documentation will continue after the submission of this dissertation.

_aLib is available at: http://cnmat.cnmat.berkeley.edu/~ali/share/max/_aLib.zip

7 Conclusions

The two projects described above share an important feature: both are centered on the composition of an instrument that is to be played with bodily gestures. The compositional work is in the ergonomic and mechanical design of the instrument, the representation and organization of the material, the generative real-time software at its heart and the interaction between the performer, software and instrument. Design decisions in the physical form of the instrument as well as its virtual inners are made based on the artistic constraints imposed by each project. The process of creating such instruments is thus a matter of ascertaining the needs of a particular performance context, choosing an appropriate musical language, and designing a manner of playing the instrument that allows intimate control. In the case of the *Takemitsu: My Way of Life* instrument, the solution was a stateless instrument that allowed improvisation using musical material provided by the acoustic instruments. This connection to the existing musical language of the opera was crucial to the success of the instrument. The two gestural controllers used in the instrument were also crucial to the instrument's success for they allowed simultaneous real-time control of many musical processes. In the case of *...in memory of Leah Deni*, the focus was rather on the notions of intuition and exploration. Unlike the previous instrument where the highly modal controller mapping required very precise knowledge of the instruments capabilities and mechanisms, the instrument in this installation was designed to invite performers with no knowledge of the instrument's guts. Interpolation spaces were used extensively in both projects as a primary mapping technique. The advantages of this technique were its ability to allow control of many synthesis parameters with very few inputs from the controller. In the *Takemitsu* instrument, this technique allowed simultaneous control of many complex software processes in order to achieve very particular results at the appropriate time; in addition, this degree of control allowed for a richness and variability in the real-time electronic sound that aided the instrument's success. In the installation, interpolation spaces serve as intuitive and inviting interfaces for exploring unknown musical spaces.

8 Acknowledgements

I would like to thank David Wessel and Edmund Campion for their care and guidance in the past years. I would also like to thank David Bithell, Adrian Freed, Roberto Morales and Matt Wright for their invaluable collaborations, creative efforts and kind words.

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