

Interconnected Musical Networks - Bringing Expression and Thoughtfulness to Collaborative Group Playing

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Abstract

Music today is more ubiquitous, accessible, and democratized than ever. Thanks to technologies such as high-end home studios, audio compression, and digital distribution, music now surrounds us in everyday life, almost every piece of music is a few minutes of download away, and almost any western musician, novice or expert, can compose, perform and distribute their music directly to their listeners from their home studios. But at the same time these technologies lead to some concerning social effects on the culture of consuming and creating music. Although music is available for more people, in more locations, and for longer periods of time, most listeners experience it in an incidental, unengaged, or utilitarian manner. On the creation side, home studios promote private and isolated practice of music making where hardly any musical instruments or even musicians are needed, and where the value of live group interaction is marginal. My thesis work attempts to use technology to address these same concerning effects that it had created

by developing tools and applications that would address two main challenges:

1. Facilitating engaged and thoughtful as well as intuitive and expressive musical experiences for novices and children
2. Enhancing the inherent social attributes of music making by connecting to and intensifying the roots of music as a collaborative social ritual.

My approach for addressing the first challenge is to study and model music cognition and education theories and to design algorithms that would bridge between the thoughtful and the expressive, allowing novices and children an access to meaningful and engaging musical experiences. In order to address the latter challenge I have decided to employ the digital network – a promising candidate for bringing a unique added value to the musical experience of collaborative group playing. I have chosen to address both challenges by embedding cognitive and educational concepts in newly designed interconnect instruments and applications, which led to the development of a number of such Interconnected Musical Networks (IMNs) – live performance systems that allow players to influence, share, and shape each other’s music in real-time.

In my thesis I discuss the concepts, motivations, and aesthetics of IMNs and review a number of historical and current technological landmarks that led the way to the development of the field. I then suggest a comprehensive theoretical framework for artistic interdependency, based on which I developed a set of instruments and activities in an effort to turn IMNs into an expressive and intuitive art form that provides meaningful learning experiences, engaging collaborative interactions, and worthy music.

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Introduction

Common wisdom says that the computer has enriched and advanced the art form of music. Research in computer music has brought new palettes of sounds to the hands of composers and new ways for performers to control these sounds. Algorithmic techniques let composers write music in ways never possible before and computerized analysis methods allow for machines to retrieve meaningful information from raw audio. This may be true. But after more than half a century of computer music research it seems that we should ask ourselves a number of possibly naïve but necessary questions: how does the product of state-of-the-art synthesis, sampling or physical modeling techniques compare with the richness and subtleties of acoustic sound? Can electronic controllers provide the expressiveness and finesse of playing traditional instruments? Can computer-based analysis and information retrieval techniques extract basic aspects of musical “common sense”? Is there anything to be said about the aesthetics of algorithmic music in comparison to music that was written with traditional means? And most importantly, has the computer truly contributed to the expressive, emotional, and sensual core of the musical experience? A genuine reflection on these questions may suggest that although tremendous progress has been made, there is still quite a lot of work ahead of us before the computer truly becomes as important and long lasting a contribution to the musical experience as it can be.

Composer Luciano Berio, who passed away this year, addressed the gap between the promises and the realities of computer music in an interview held in 1983 with musicologist Roassan Damlonte. Berio stresses:

“Very quickly it became clear that ‘the unlimited possibilities of electronic music’ is a meaningless statement (I don’t think I have ever used it, not even at the peak of excitement of the turbulent 50’s) because these possibilities mostly addressed the acoustic and

manipulative domains of music and not the ideological realm, which quickly deteriorated to give place to tedious (although often tempting) electro acoustic litter. And like me, many of the musicians who were aware of their surroundings, quickly reached the conclusion that it is easy and superfluous to produce new sounds that are not the product of musical thinking, just like it is easy today to develop and 'improve' electronic music technologies when they are disconnected from a deep and realistic musical context. With or without new tools and technologies, electronic music as a means for musical thinking reached a dead end. Moreover, the new tools detached it even further from the global and comprehensive *idée* of music making which is perceived not only by its technical, historical, and expressive terms, but in contemporary and social terms as well." (Berio 1983.)

Twenty years later, it is clear to me that Berio was wrong when asserting that electronic music reached a dead end. In my view, technology during this time has often, and still does, serve as an important "means for musical thinking." But, like Berio, I do see the difficulties in routing the excitement from technology to meaningful and "ideological" domains. I believe that one of the causes for these difficulties is the focus many musicians and researchers put on imitation, reproduction, and analysis of the old rather than innovation and exploration of the new. On one hand, it is clear that research in areas such as reproduction of acoustic sound and traditional instruments, or modeling musical "common-sense" and compositional processes can lead to valuable and interesting results. But I also believe that researchers in these areas should make sure that they are creating this link between the technical/theoretical realm and the musical/ideological one, if their work is to have a meaningful effect on music practice.

Pioneers such as Varèse and Cage have addressed, in words as well as in their music, the problematic side of using technology for reproduction and imitation. Edgar Varèse, maybe the first to identify technology as a promising source for the creation of new sounds, was clear about the exact manner in which he would like pursue this goal: “I need an entirely new medium of expression: a sound producing machine, not a sound reproducing one” (Manning 1985, p.14) and “I refuse to submit to sounds that have already been heard.” (p. 48.) John Cage went beyond rejection of the old to pure disregard of it in his famous saying: “We need not destroy the past. It is gone.” Berio, specific and harsh in his own way, pointed to the roots of the problem, in his opinion: “At times it seems that musical creativity is being replaced by music applicable scientific creativity, and that musical thinking retreats to the level of the dull opinions voiced by a Bell-lab electronics engineer or a Stanford University computer scientist.” (Berio 1983).

Inspired by these thinkers, my personal approach for the use of technology in music is to identify and investigate research areas where new technological innovations would touch the expressive and creative core of music making. I am interested in using the computer to design musical experiences that could never have materialized by traditional means and to bring these experiences outside the lab and into the world. I believe that if the important questions are asked, and the right challenges are posed, digital technology can make a much more significant contribution to music culture than it previously has. My research interests stem from examining social and cultural effects of recent technological innovations on the way we create, perform and listen to music, which has led me to explore new ways for introducing musical expression, creativity and thoughtfulness to novices and children. Recent technological advancements such as high-end home recording, music compression, and digital distribution have substantially changed the way in which we create, perform, and listen to music in everyday life. Thanks to these innovations, music today is more accessible, ubiquitous and democratized than ever: accessible, since almost any piece of music is a few minutes of download away from the listener;

ubiquitous, in the sense that music surrounds us in everyday life, from elevators and malls to cars and buildings, and even urban streets where some cities mundanely play music for the benefit of their citizens. By the “democratization” of music I refer to the affordable high-end home recording, mixing, mastering, and distribution tools that allow for almost any interested musician, novice or expert, to compose, perform and distribute their music directly to their listeners without a dependency on the old oligarchy of the artistic elite or the music business corporations.

But at the same time these technologies can also be seen as contributing to some disconcerting social effects on the culture of consuming and creating music. Although music is available for more people, in more locations, and for longer periods of time, most listeners experience it in an incidental and unengaged manner, usually as a background for other activities (see Figure 1). Other times, music is used in a utilitarian manner, such as in shopping malls where it is used to encourage listeners to shop, aerobic classes, where it powers up workout sessions (see Figure 2), or airplane flights, where it is used to relax travelers (DeNora 2000). These activities, unfortunately, tend to lack the rich and thoughtful aspects of concentrated listening and active creation of music, and cannot provide the alert and engaged experience that makes music the deep and worthwhile experience that it can be.

Other technological developments have led to problematic effects on the composition and performance side of music. High quality affordable tools such as digital audio workstations, sequencers, synthesizers, and samplers opened the way for novices to compose, perform, record, and master their music by themselves in their own bedrooms. But the negative consequences of this proliferation in home studios, in my eyes, is its promotion of private and isolated practice of music making, where hardly any musical instrument is needed (timbres can be generated or sampled digitally, (sequencers and digital audio workstations provide hundreds of asynchronous recording tracks and hundreds of redo levels so no live multiplayer performance is actually required). This is unfortunate since



Figure 1. Elevator music – ubiquitous music



Figure 2 Aerobics class – utilitarian music

music has always been a collective social ritual which functioned as a cohesive force for building and maintaining communities. It is particularly unfortunate for me personally since one of the main reasons that drew me into music in the first place was its collaborative and social aspects – the experience of playing and collaborating with other players in a group.

In an effort to address some of the problematic social effects of new technologies on music creation and consumption and in order to better address the question of whether technology has truly contributed to the expressive, creative, and ideological core of the musical experience, I have attempted to use technology to correct the same concerning effects that it has created. This has led me to identify the two main research goals for my research work:

- To develop tools and applications that would promote engaged and thoughtful as well as intuitive and expressive musical experiences for novices, children, and the general public.
- To enhance the inherent social attributes of music making by connecting to and intensifying the roots of music as a collaborative group ritual.

My approach for addressing the first challenge was to study and to model music cognition and education theories and to design algorithms that would bridge between the thoughtful and the expressive, allowing novices and children an access to meaningful and engaging musical experiences. In order to address the latter challenge I have decided to employ the digital network, which is a promising candidate for bringing a unique added value to the musical experience of collaborative group playing. I have chosen to address both challenges by embedding cognitive and educational concepts in newly designed interconnected instruments and applications, which led me to focus on the field of Interconnected Musical Networks – live performance systems that allow players to influence, share, and shape each other's music in real-time. Informed by social and biological systems,

these networks are designed to allow a group of performers to interdependently collaborate in creating dynamic and evolving musical compositions. In the first chapter of my thesis, I present the basic concepts, aesthetics, history, and current research in the field of Interconnected Musical Networks (IMNs), and a comprehensive theory of music interdependency that I developed. Based on this theory In the second chapter I define my research goals which center on bringing together novices and experts, musical process and product, expression and thoughtfulness This leads to a presentation of a set of interdisciplinary fields of study in Chapter 3 – Music Perception, Music Education and Human-Computer Interaction – which informs my research hypothesis and assessment criteria as described in Chapter 4. The three projects that constitute my research work are presented in Chapter 5, followed by an assessment and evaluation sections in Chapter 6. I end the thesis with a description of a set of transitional projects that I am currently working on (Chapter 7) and suggestions for future work in the field (Chapter 8).

1 Interconnected Musical Networks

1.1 Concepts and aesthetics

Music performance is an interdependent art form. Musicians' real-time gestures are constantly influenced by the music they hear, which is reciprocally influenced by their own actions. This interdependency is true not only in group playing but for soloists as well, for example, a violinist who listens to the music she is plays and constantly modifies her actions with correlation to the auditory feedback stream. In group playing, however, the interdependent effect bears unique social consequences. Rudolf Rasch (1978) shows how group synchronization has a direct influence on individual players' isochronization. Comparing onset times of ensemble performance, played to a multi-track recorder in an anechoic chamber. Rasch found a number of different social tendencies such as the formulation of leaders and followers (in milliseconds) or the effect of group synchronization on individual players' dynamics and timing. Other models of group performance show different manifestations of interdependency. Standard Jazz improvisation (see Figure 3) features interdependent routines such as call and response, propagating motifs, supporting and contrasting dialogs, and a higher level of leader/follower dynamics. Milt Hinton, the double bass Jazz player, stressed the importance of interdependently sharing and collaboration in his playing: "I was pretty young when I realized that music involved more than playing an instrument, it's really about cohesiveness and sharing...I've always believed you don't truly know something yourself until you can take it from your mind and put it in someone else's." (Hinton 2001.)

Non-western music too demonstrates its own variations of group interdependency, such as in the case of Gamelan music (see Figure 4) which is based on the concept of heterophony – the simultaneous performances of melodic variations on the same tune (countermelodies) or Persian art music, where instrumentalists are expected to vary the singers'



Figure 3. Acoustic group interdependency in Jazz: call-and-response routines, propagating motifs, leaders and followers.

improvised lines in real time. An interesting example for a unique interdependent non-western musical experience is described by William Benzon (2001), a cognitive scientist and a musician, who discusses his experience playing Ghanaian bells in a group of four: “melodies would emerge that no one was playing... it arose from cohesions in the shifting patterns of tone played by the ensemble... Occasionally, something quite remarkable would happen. When we were really locked together in animated playing, we could hear relatively high-pitched tones that no one was playing...” Benzon, who studies how the brain functions in musical experiences such as in group playing, use this examples to strengthen his definition of music as “a medium though which individual brains are coupled together in shared activity.”

But although the acoustic interdependent models provide an infrastructure for a variety of approaches for interconnections among players, they do not allow for actual manipulation and control of each other’s explicit musical voice. Only by constructing electronic (or mechanical) communication channels among players can participants take an active role in determining and influencing, not only their own musical output, but also their peers’. For example, consider a player who while controlling the pitch of his own instrument also continuously manipulates his peer’s instrument timbre. This manipulation will probably lead the second player to modify her play gestures in accordance with the new timbre that she received from her peer. Her modified gestures can then be captured and transmitted to a third player and influence his music playing in a reciprocal loop. Another example is a network that allows players to share their musical motifs with other members in the group. By sending a motif to a co-player who can transform it and send it back to the group, participants can combine their musical ideas and tendencies into a constantly evolving collaborative musical product.



Figure 4. Acoustic group interdependency in Gamelan music - heterophony and counter melodies.

1.1.1 The biological metaphors

The shape of the composition in IMNs grows from the topology of the network and its interconnections with the performers. Such a process-driven environment, which responds to input from individuals in a reciprocal loop, can be likened to a musical “ecosystem.” In this metaphor, the network serves as a habitat that supports its inhabitants (players) through a topology of interconnections and mutual responses which can, when successful, lead to new breeds of musical life forms. Such IMN ecosystems differ from other closed process based musical networks in the significant role they provide to the real-time input from a society of live performers. An examination of such systems calls for disciplines such as system dynamics, which looks at complex interdependent natural and social systems and tries to explain them by using computerized simulations. Another biological metaphor that can help illustrating the experience of participating in IMNs is that of “gene mixing,” which is derived from the penetrative quality of diffusing and influencing each other’s music. The network, therefore, can be seen as a (pro)creative environment that allows a group of musician “parents” to give birth to their musical crossbred offspring. The members of “The League of Automatic Music Composers” – a computer-music-network group – describe how a coherent and vital musical entity can emerge from interdependency and feedback in one of their compositions: “There are moments of tuned correspondence where the voices seemed to listen to each other; at other times they appear to be independent. There are also instances of odd grandeur...when the elements of the network are not connected the music sounds like three completely independent processes, but when they are interconnected the music seems to present a “mindlike” aspect.” (Bischoff, Gold, and Horton 1978) Analogical examples from the visual arts which can elucidate this metaphor from a different perspective are Karl Sims’s Genetic Images (1993) and Galapagos (1997) Installations (see Figure 5). In these interactive works, viewers can “evolve” still photographs or 3D animated forms by selecting the ones that they find

“most aesthetically interesting” from a pool of constantly generated graphics artifacts. The selected visual “organisms” mix their genes with each other, mutate and reproduce. Sims explains: “An analogy can be made between these images and biological organisms. They are both synthesized from ‘genetic’ descriptions and are both subjected to the forces of evolution. An organism is grown from the coded instructions of its DNA. Similarly, these images are generated from instructions in the form of computer coded mathematical equations...and random operations... (producing) results that can not be produced in any other way.” (Sims 2003)

1.1.2 Coherency vs. immersion

But achieving such a life-like effect requires the maintenance of a delicate balance. On one hand, the low-level scheme of the network should be kept comprehensible and intelligible so that players and audiences are able to participate and follow the music in a meaningful and coherent manner. On the other hand, one of the exciting promises of IMNs is to provide participants with an interconnected immersive whole which can grow to be bigger than its parts, where low-level rationalization of rules and algorithms is counterproductive to the social and artistic experience. An effective IMN would, therefore, be able to help facilitate interdependent connections so that the group members would smoothly transfer between the two perception modes – the analytical low-level coherency and the more abstract and high-level immersion. Such interdependent dynamics, which is not possible with any acoustic means, would let participants complement and enrich each other without losing control of their personal contributions. The network can allow, for example, for a soloist to guide his collaborators with a simple interdependent touch towards a musical idea that he is interested in, to change a supporting voice into a contrasting one so a desired musical idea will become clearer, to shape a peer’s accompaniment line so it would lead towards a new direction when the current one is exhausted, to send a motif to another player who would manipulate it and send his variation back to the group, to have a musical



Figure 5. Visual “gene mixing” – images from Genetic Images and Galapagos by Karl Sims

response accentuated by the player who sent the original call, to plant a musical “seed” that would be picked up by the group in various manners, etc.

1.1.3 Music as a social ritual

A fundamental aesthetic concept in IMNs is the computer’s role as a supporter and enhancer of live musical interaction with its surprise, immediacy, and flexibility. The system should be able to enrich the interpersonal interactions through its control and manipulation algorithms and to stir the musical output into unpredictable directions, leading to an experience that is based on evolving and dynamic social contexts. An effective IMN would therefore promote the interpersonal connections by encouraging participants to respond and react to these evolving musical behaviors in a social manner of mutual influence and response. This unique form of live performance can, therefore, enhance the inherent social attributes of music making that are usually obscured in many other forms of music technology practices. Home studios, sequencers, sound generators and other technological innovations can lead to a private and isolated practice of music making. IMNs, on the other hand, bear the promise of bringing back music performance to its social context and to its ritual roots. Interconnected performance, as opposed to common utilizations of technology in music, can provide a direct connection to the roots of music as exciting and immersive social ritual.

1.2 Historical landmarks

The concept of IMNs can be seen as a descendent of the tension that emerged in the midst of the 20th century between the radicalization of musical structure and composer's control, practiced mainly by "avant-garde" and "post-serialist" composers such as Stockhausen and Boulez on one hand, and the escape from structure towards "Process Music" as was explored mostly by American experimentalists such as Cage and Reich. As opposed to the European movements that emphasized the composer's control over almost every aspect of the composition, process music came from the belief that music can be a procedural and emergent art form and that there are many ways of handling form other than constructing structures in different sizes. In such procedural process-based music, the composer sacrifices certain aspects of direct control in order to create an evolving context by allowing rules (in closed systems) and performers (in open ones) to determine and shape the nature of music. John Cage addressed this tension referring to his own experience: "I was to move from structure to process, from music as an object having parts to music without beginning, middle or end, music as weather." (Cage 1961) The use of technology in IMNs pushes the tension between Structure and Process music further into an experience where predetermined rules and instructions combined with improvised interdependent group interactions leads to evolving musical behaviors, giving a new meaning to Cage's exploration of unpredictability, chance determination processes, accidents, and contextual music emergent. In particular I see three major technological innovations which helped making such interconnected musical behaviors possible. These are the transistor radio, the personal computer, and the Internet. When these technologies became widespread and commercially available they inspired musicians who were looking for new ways to expand the vocabulary of socio-musical expression. I will base my historical review on these three technological milestones, starting with John Cage and his early 1950s' experimentations with the transistor radio as a musical instrument that provides crude interdependent musical

interactions. I continue with the League of Automatic Music Composers and their offspring group “The Hub,” which utilized the personal computer to create the first programmable digital IMN, and end with an overview of recent Internet music research, which focuses on scaling musical networks up to a large number of participants with a variety of musical backgrounds, while providing a wide range of interconnectivity models.

1.2.1 John Cage and the transistor radio – technology for interdependency

John Cage (see Figure 6) was one of the first to take notice of the expressive potential that lies in using technology to enhance acoustic group interdependency by treating the then recently invented commercial transistor radio as a musical instrument that can be used to provide a sonic medium for interdependent procedures, rules, and processes. Cage’s compositions for transistor radios allowed, for the first time, for an external entity (audio streams from a set of radio stations) to generate and support evolving and dynamic musical contexts, providing a first crude glimpse at the concept of decentralized “musical ecosystems.” Cage’s 1951 “Imaginary Landscape No. 4” for twelve radios played by twenty-four performers can be possibly considered the first electronic IMN. The composition score indicates the exact tuning and volume settings for each performer but with no foreknowledge of what might be broadcast at any specific time, or whether a station even exists at any given dial setting. Inspired by the Chinese book of oracles, the I Ching, Cage demonstrated his fascination with chance operation, allowing players to control only partial aspects of the composition, while technology, chance, and performers determined the actual audible content. The role of Cage as a composer was narrowed down to setting the high-level blueprint of dial setting instructions. The interdependency in the piece was manifested in two planes: First, there were the interdependent interactions between the players and the network of radio stations that provided unknown and dynamic music content. But the system also supported intra-player interdependencies since for every frequency-dial player there was a

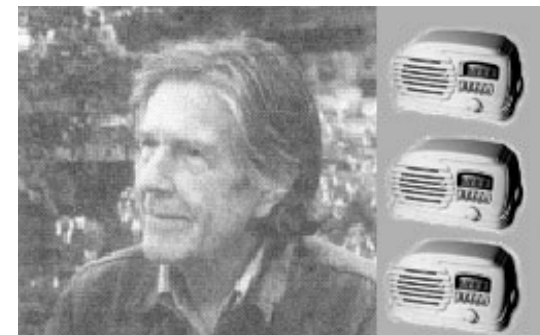


Figure 6. John Cage – interconnected transistor radios.

volume-dial player who could manipulate the final output gain, controlling a full continuum from complete muting to maximum volume boosting. The volume-dial player, therefore, had a significant impact on her peer's musical output, as she could control anything from rendering his actions inaudible, through blending them smoothly in the mix, to boosting them up as a screaming solo. "Imaginary Landscape No. 4", therefore, can be seen as a synchrotrons anarchic decentralized network which provides very simple algorithmic control (basic volume manipulation) and no control over the musical content. Cage continued to experiment with interconnected compositions for radio broadcast in *Speech* (1955) for five radios and a news reader and *Music Walk* (1958) for one or more pianists, radios and phonographs. Addressing the biological metaphor, he referred to these compositions, stating that his goal was "to affirm this life, not to bring order out of chaos... but simply to wake up to the very life we're living, which is so excellent once one let it... act of its own accord" (Cage 1961). The explorations of the transistor radio as an infrastructure for interdependency opened the door for further experimentation with interdependency, which were not necessarily based on external sound production. In "Cartridge Music" (1960), for example, Cage made his first attempt at an IMN that is focused on tactile generation of sounds and intra-player amplification-based interdependencies. Here, players were instructed to pluck small objects (such as toothpicks or pins) that have been put into a gramophone cartridge, and to hit larger objects (such as chairs) that were amplified with contact microphones. The simple intra-player interdependency was generated due to other players who controlled the amplifiers' volume knob, leading, again, to a wide range of output from muting to soloing. On "Cartridge Music" Cage remarked: "I had been concerned with composition which was indeterminate of its performance; but, in this instance, performance is made indeterminate of itself."

1.2.2 The League, the Hub and the personal computer – the digital advantage

Although revolutionary, the level of interdependency in Cage's early experiments were constrained by the crude nature of the technology, where in effect, the only possible direct interpersonal connections were limited to coarse gain manipulations. More elaborate attempts at analog interdependencies were made by composers such as Stockhausen, who in "Mikrophonie II" (1965), for example, routed the sound from four choruses and a Hammond organ to modulate each other's spectra through a single ring modulator. The analog synthesizer too, provided an infrastructure for bands such as Emerson Lake and Palmer and Tangerine Dream to interdependently manipulate multiple sound parameters, or to experimentalists such as David Rosenboom to use biofeedback methods for interconnecting a group of players to generate synthesized sounds (Rosenboom 1976). But the next big breakthrough in technology for detailed and controllable interdependent networks has been achieved thanks to the second technological milestone – the commercialization of the personal computer. One of the first commercial computers which were used for creating fine-tuned and configurable network topologies was the 1976 Commodore KIM-1. The League of Automatic Music Composers (see Figure 7), a group of musicians from Oakland, California, was one of the first to use a number of such KIM-1s to write interdependent computer compositions. By networking their computers, each composition could send and receive data from the other compositions, and for the first time create programmable and detailed musical interconnections. The League named their new genre of musical performance "Network Computer Music." In their 1978 performance in Berkeley, California, for example, the group set up a 3-node synchronous decentralized democracy-oriented network, mapping frequencies from one computer to generate notes in another, or mapping intervals from one composition to control rests and rhythmic patterns in another. The League continued to work until 1986 when it evolved into an offspring group, "The Hub," which employed



Figure 7. "The League of Automatic Music Composers" introducing electronic group interdependency.

more accurate communication schemes by using the MIDI protocol and central control, using a central computer to facilitate the interaction. The group also experimented with more hierarchical systems, such as in Waxlips (1991), where a “lead player” sent cues to initiate new sections and to jump-start processes by “spraying” the network with requests for note messages, etc. The Hub also expanded their explorations to other areas such as remote collaboration and audience participation. These, however, were less successful, according to group members’ testimony. In their first 1985 remote networking effort, the group was divided into two sites and communicated via phone lines. The experiment was ineffectual mainly because of technical problems that impaired the flow of the performance. Another less than perfect remote experiment was HubRenga (1989) in which the general public was able to interdependently participate in the composition through the Internet. Scot Gresham-Lancaster, a Hub member reflects: “The varying range of taste and innate talent made for a pastiche that lacked fitness and cohesion, and despite the best intentions of the contributors, the results were mixed” (Gresham-Lancaster 1998). Regarding their last remote interaction effort in 1990, using IP based OpenSoundControl for Max, Gresham-Lancaster reasons: “the technology was so complex that we were unable to reach a satisfactory point of expressivity.” The League’s and The Hub’s Network Computer Music contributed significantly to the field of IMNs by introducing the computer as a versatile and resourceful partner for interconnected group interaction. They were, however, less successful in supporting large scale systems for novices and wide ranged general public, challenges that were more successfully addressed by the Internet.

1.2.3 The Internet – various levels of interconnectivity

In recent years there has been an increasing interest in Internet based musical systems for multiplayer interaction and collaboration. The different approaches that have been taken by composers and researchers vary in the musical activities they offer, the network topology, the number of participants, the musical skills that are required, etc. In this section,

however, I will map the field of Internet IMNs based on what I see as the central innovative concept of the medium – the level of interconnectivity among players and the role of the computer in enhancing the interdependent social relations. Based on these criteria I have identified four different approaches and named them “The Server,” The Bridge, ”The Shaper,” and “The Construction Kit.” They are explained below.

The Server approach - This simple approach uses the network merely as a means to send musical data to disconnected participants and does not take advantage of the opportunity to interconnect and communicate between players. Participants in such a server/client configuration cannot listen to, or interact with their peers and the musical activities are limited to the communication between each player and the central system. Therefore it is difficult to define this approach in terms of motivations, social philosophy or topology. A typical example for the Server approach is the Sound Pool web application, which is part of the interactive piece “Cathedral” by William Duckworth (De Ritis 1998, Duckworth 1999). Here, a Beatnik based java applet allows individual players to trigger sounds by “accidentally or randomly” clicking on hidden nodes on the screen. The interaction occurs independently in each player’s browser so that “each user can create his or her own unique experience.” Since there are no connections between participants, the system can support any number of users. In particular, the application addresses “passive audience” and tries to “bring the audience closer to the actual creation and performance of music.” The original sounds in the piece were composed by Duckworth but users can contribute their own sounds to be mixed in. Still, participants can only listen to their own creation, which significantly limits the sense of collaboration.

The Bridge approach - The motivation behind the Bridge approach is to connect distanced players so that they could play and improvise as if they were in the same space. Unlike the Server approach, musical collaboration can occur in such networks since participants can listen and respond to each other while playing. However, the role of the network in this

approach is not to enhance and enrich collaboration, but to provide a technical solution for imitating traditional group collaboration. Aspects of bandwidth, simultaneity, synchronization, impact on host computer, and scalability are some of the challenges that are usually addressed in this approach. A characteristic example of the Bridge approach is the “Distribute Musical Rehearsal” project (Konstantas 1997), which focused on remote conducting. With the help of video streaming and a 3D sound system, an ensemble of six players in Geneva was connected to a conductor in Bonn in an effort to rehearse “Dèrive” by Pierre Boulez. The system aimed at “giving the impression to the participants that they are physically in the same room,” and the main challenges were minimizing transmission delay and accurately reproducing the sound space by using multiple microphones and a dummy head. The TransMIDI system (Gang 1997) addresses a similar challenge but instead of sending audio, the system uses the more efficient MIDI protocol that helps minimizing latencies. By using “Transis” group communication system, TransMIDI also allows for easy arrangement of multicast groups so that a “conductor” player can determine exactly what each participant hears at any time. Here, too, the system is aimed at bridging the distance between remote participants, allowing them to play, improvise, and listen to music in a way similar to a traditional jam session.

The Shaper approach - In the Shaper approach the network’s central system takes a more active musical role by algorithmically generating musical materials and allowing participants to collaboratively modify and shape these materials. Although players in Shaper networks can continuously listen and respond to the music that is modified by all participants, the approach does not support direct algorithmic interdependencies between players and therefore can be seen as synchronous and centralized. One of the first attempts at this approach was the Palette (Yu 1996) which allowed online players to control aspects such as “style,” “coherency” and “energy” of MIDI events that were generated based on input from other online players. The Palette was performed as part of Tod Machover’s Brain Opera. Another example of the Shaper

approach can be demonstrated by the Pazellian application (Pazel 2000), a web-based application that uses “Smart Harmony” – an algorithmic mechanism that annotates each note with harmonic information and determines a set of harmonic constraints for the composition. Here, players can control parameters such as pitch range, volume, and instrumentation as well as manipulate multiple individual parameters for all voices in the composition. Players can hear and respond to the musical output that is generated by all the participants, but cannot directly communicate with any specific player. The “Variations for WWW” project (Yamagishi 1998) takes a similar approach. In this system, a Max patch is connected to the web via the W protocol so that remote users can manipulate parameters in an algorithmically generated theme. The Max patch sends MIDI commands to a MIDI synthesizer, which transmits the audio output back to the participants via a Real Networks audio encoder. The system’s interconnectivity is derived from its ability to play the combined manipulation of all users back to the participants, who can modify their musical contribution in response. Here, too, the focus is not on generating original material but on modify existing musical content.

The Construction Kit approach - This approach offers higher levels of interconnectivity among participants, who are usually skilled musicians, by allowing them to contribute their music to multiple-user composition sessions, manipulate and shape their and other players’ music, and take part in a collective creation. Interaction in such networks is usually centralized and sequential as participants submit their pre-composed tracks to a central hub and manipulate their peers’ material off-line. Faust Music On Line (Jorda 1999) is a representative example of this approach (see Figure 8). Here, a web-based synthesis engine allows players to create musical tracks and construct them into a composition, which then can be downloaded by other participants. If the downloaded composition is not complete (i.e., it still has empty tracks) a participant can generate new tracks locally, add them to the composition, edit them and upload the full piece back to the web. Participants can also reprocess and distort any of the previous tracks in the composition by using a variety of synthesis

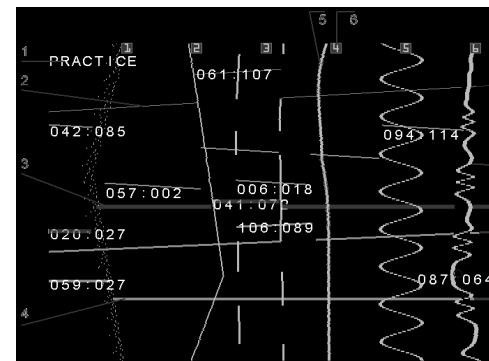


Figure 8. The Construction Kit approach for Internet music collaboration as demonstrated by Sergi Jorda’s “Faust Music On Line.”

generators and modifiers. A commercial paraphrase of this idea is the Rocket Network (2001). The WebDrum application (Burk 2000) demonstrates a slightly different take on the Construction Kit approach by basing the application on a traditional drum pattern editor where users turn on or off notes on a grid. Synthesized drum sounds are used in order to avoid downloading large audio sample files. Web users can play and listen to others participants' edits and to add their instrument sounds to their own pallets. The ISX project (Helmuth 2000) combines between the Construction Kit and the Shaper approach by allowing users to algorithmically change their peers' sounds, as well as to create new tracks from scratch and construct them into a collaborative composition. The project uses Internet2 as a wideband platform that can support the exchange of large audio files.

The Construction Kit approach provides a high level of interconnectivity by allowing participants to combine their musical materials into compositions and to modify each other's music. However, the central system in this approach usually plays the role of a static infrastructure as its function is not influenced by the dynamic contributions from participants. Moreover, due to difficulties in controlling Internet latencies, this composition-oriented approach cannot really address the live performance challenges of full real-time IMNs.

1.3 Collaborative instruments for novices

The historical review highlights a number of deficiencies which hindered the popularity of IMNs and prevented them from becoming a significant form of artistic expression that could address wide audiences. The field's main drawback seems to stem from the focus that composers and designers put on creating complex interconnections between participants and the lack of clear gestural cues, which made it almost impossible for audiences, and even performers, to follow the musical and social interaction. As a result, many of these networks posed high entrance barriers for players, requiring them to be skilled and experienced in order to partake in a meaningful experience. Moreover, participants and audiences in such interaction had to concentrate on low-level topological aspects of the network, which hindered the system's coherency and compromised the expressive and social aspects of the experience. In live performances such as in the case of the League, or the Hub, participants and audiences tended to lose track of the correlation between what was heard and what was seen. In Internet based systems the problem was more acute as participants usually do not see each other at all. Although most of those on-line systems utilize graphical user interface to convey the interaction, this can not replace the personal unmediated connection with instruments in a physical space.

In an effort to address these drawbacks many current interconnected collaborative musical designers try to cater to novices and wide audiences by simplifying and restricting the interaction and by utilizing physical instruments and gestures in an attempt to facilitate expressive and more conveyable interaction. In this section I will review recent trends and research directions in collaborative musical networks for novices and will present and discuss a number of representative systems. I categorized these systems into two groups - small scale systems (supporting up to 10 players) and large scale systems. These two groups substantially differ in

the challenges they impose and the solutions that designers are using to address these challenges.

1.3.1 Small scale systems

Small scale collaborative systems usually support 4-8 players in close proximity, which allows for detailed and subtle interpersonal interactions that are not possible with large scale systems. One such collaborative system was developed by Dominic Robson (2002) as a set of “sound toys” titled Play! It includes instruments such as digital bullroarers (spun instruments with embedded potentiometers) and latex rubber controllers that are designed for novice group collaboration. Robson’s toys allow different players to control musical aspects in different tracks of a synchronized music piece (often of the electronic dance variety.) With these instruments, players can manipulate aspects such as rhythm and timbre of prerecorded tracks or remix pre-composed chunks of music which “were all designed to work musically together in that they were all in the same tempo and key.” Interaction with the toys is usually in a simple one-to-one manner while “the simplicity of the interaction of hitting an object to get a sound playing is overcome by the multiplicity of objects.” But just adding more participants in an effort to create interesting collaborative musical behaviors does not seem to suffice. In an effort to maintain understandability and simplicity of operation, the system gave up on facilitating meaningful social or musical interconnections among the players. Moreover, in spite of the large gestures promoted by the instruments and the simple and direct mappings, the designer testifies that it was difficult to realize who was controlling what in the piece.

Toshio Iwai’s Composition on the Table (1998) is a more elaborate example for an effective small scale collaborative novice system (see Figure 9). The piece is comprised of four tables with various controllers such as switches, dials, turn-tables and sliding boards that players can manipulate to control sound and projected image. In one of the applications, a grid is projected on the table and players can direct



Figure 9. Toshio Iwai’s “Composition on the Table”

animated objects by setting arrows at each node on the grid. When an object hits a node, a MIDI note is played so that interlocking loops and rhythms can be generated by the participants. The system can be operated by one player, but its size and multiple controllers make it easy for a number of players to collaborate. The experience promotes collaboration when players follow each other's gestures and try to predict the objects movement, and therefore the music that will be generated. The simplicity of the system, however, comes at a price as players do not have the ability to create their own musical material, but rather can only navigate and explore a piece that had already been composed. Moreover, the system does not make good its potential to create interconnections and interdependencies among players, which could have allowed for more intimate and social collaborative experiences.

Chris Brown's "Talking Drum," a local area network music installation (Brown 1999), is a collaborative system that attempts to address more skilled novices as well as professionals by promoting thoughtful and intricate musical collaborations. Here, four computerized stations are installed in a large room or outdoors. Computer players (using MIDI instruments or computer mice) as well as acoustic instrument performers (playing to a microphone and an electronic pitch follower) interact with a piece of software that uses a genetic algorithm to create rhythmic units. The software responds to various aspects of users' playing (such as timing, loudness, density and pitch) by changing parameters in the algorithms, so that the pre-programmed rhythmic units are shaped by the players. The motivation behind this work is "to create a participatory context for the presentation of computer music... toward a situation in which audience and performers share the same acoustic space and interact in a multifocal way." The central system in this network (which runs on one of the four stations) coordinates timing and synchronization between stations. Brown's system uses more complicated algorithmic approach to generate more interesting and richer musical results; however, here too, the system does not facilitate interconnections among the players. Moreover, the richer interaction comes on account of being less accessible to novices.

Another interesting approach for a gestural musical collaborative performance is taken by Sensorband (Bongers 1998), a group of three musicians: Edwin van der Heide, Zbiniew Karkowski, and Atau Tanaka. The group has built the “Soundnet” – a giant web, measuring 11 x 11 meters, strung with thick shipping ropes (see Figure 10). The trio performs on the instrument by climbing it, as a set of stretch sensors at the end of the ropes measure the movements and send the data to control digital signal processing of natural recorded sounds. The instrument was built in an effort to “focus attention on the human (physical) side of human-machine interaction,” and was purposely made too large for one person to master thoroughly. Bongers explicates: “The ropes create a physical network of interdependent connections, so that no single sensor can be moved in a predictable way that is independent of the others. It is a multi-user instrument where each performer is at the mercy of the others’ actions. In this way, the conflict of control versus uncontrollability becomes a central conceptual focus of Soundnet.” However, where the system gains in interesting interdependencies among its players, it usually fails in being coherent, addressing novices (even its expert players find it difficult to master), and in conveying the interaction to the audience.

1.3.2 Large Scale Systems

Large scale systems are designed for dozens and even hundreds of participants. Here, the details and intricacies of individuals’ input and interconnections are usually hidden by the mass. Such systems, therefore, should be able to derive and represent the large scale interaction patterns of the group in a meaningful manner. One of the earliest attempts at creating a large scale collaborative musical system for novices was The Brain Opera (Machover 1996). In this project (see Figure 11) audience members were able to experiment with a number of new instruments such as the “Rhythm Tree,” which included dozens of drum pads wired to trigger percussive sounds and word fragments, the “Gesture Wall” which captured visitors’ body movement and mapped them to music, the “Singing Tree” which manipulated MIDI-based accompaniment correlated



Figure 10. Sensorband - SoundNet



Figure 11. Tod Machover's Brain Opera

to the “pureness” of participants’ singing, and “Harmonic Driving” which allowed players to navigate in a song, choosing between different harmonies using a video game controller. The physical and intuitive operation of these instruments allowed for almost any visitor, from children to senior citizens, to partake in an expressive interaction with the electronic sound. However, the instruments were designed to facilitate a social or collaborative experience. When dozens of unprepared and unskilled visitors were simultaneously playing the instruments, the result was often cacophonous as no connections or synchronizations were established between the instruments. Nonetheless, the Brain Opera is one of the first promising efforts to create a large-scale improvisational interaction for large groups of novices, and has led the way for later collaborative systems to improve upon.

A completely different approach for large scale musical group participation is Golan Levin’s Dialtones: Telesymphony (see Figure 12). Unlike the improvisational nature of the Rhythm Tree, the musical material in Dialtones is pre-composed and generated by orchestrating the dialing and ringing of audience members’ mobile phones. The composer downloads ring tones into participants’ cell phones, registers their number, and sets the participants in grid of 10x20. During the concert, performers call the participants’ cell phones in an orchestrated manner, and players are asked to raise their cell phones when being called. A projected grid helps audience and performers to follow the activity which lead to a coherent musical outcome. But in order to support this coherency, players in Dialtones are stripped of any meaningful musical contribution and are essentially used as a grid of speakers for the composers’ musical ideas. If the network creates any interconnections between cell phones, it is the composer, and not the participants, who has the control over these interconnections. In that sense, Dialtones demonstrates the difficulty in creating a coherent musical outcome while still allowing a large group of players to meaningfully participate in the musical activity.



Figure 12. Golan Levin’s Dialtone Music

A much more player-oriented approach for addressing this challenge was taken in Mark Feldmeier's Large Group Musical Interaction Using Disposable Wireless Motion Sensors project. Here, the designers developed a set of low-cost wireless motion sensors that allow for a large group of participants (up to hundreds) to control and influence the music to which they are dancing. The system doesn't identify each performer but measures and react to the characteristics of the group in general. Algorithms based on temporal and frequency analysis of the data were used for detecting group behavior and to map it to the generated musical material. Aspects such as tempo, layers, rhythmic complexity, timbre and register were controlled and manipulated based on the level of activity of the group. Results showed that the group was much more active and synchronized when controlling the music as opposed to a non-interactive control group. The system was successful in promoting social interaction and synchronization among participants since it focused on overall group output. However, players could not control detailed musical elements and got "disinterested after all the various voices and the musical mappings had been exhausted" (Feldmeier 2002). Here, too, similarly to other large-scale systems that provide active roles to large group of novice performers, such as the Interactive Dance Club (Ulyate et al. 2002), players are not able to generate their own musical creation, but just interact with pre-composed materials.

1.4 A theory of musical interdependency

Informed by the historical review and the current-work survey that I have presented in the previous chapters, I here suggest a number of fundamental principles for the definition and design of interdependent musical interactions. I believe that these principles can also be extended to define other forms of artistic group interdependency. This theoretical effort is aimed at mapping the field, identifying the principal aspects that should be taken into account when designing IMNs, and suggesting a number of principles that would lead to the development of successful IMNs. My investigation is based on a number of anchoring questions: “*Why*” – what are the goals and motivations for designing and participating in IMNs? “*How*” – what are the different social perspectives, architectures, and network topologies that can be used to address these different goals and motivations? “*What*” – what are the musical parameters and interdependent algorithms that can be utilized in the network, filling the architectural form with musical content? As part of this analysis I will address the pros and cons of the variety of approaches that can be taken and will suggest a scheme for maintaining well-balanced systems that maximize pros over cons.

1.4.1 Goals and motivations

My definition for IMNs – live performance systems that allow players to influence, share, and shape each other’s music in real-time – suggests that the network should be interdependent and dynamic, and facilitate social interactions. The motivations for designing and participating in such interactions, however, can stem from different sources, which I generally classify into two categories – *Process* centered networks and *Product* centered networks. The focus in process centered IMNs is on players’ experience, whether it is social, creative or educational (see Figure 13). For designers of such networks, the musical outcome of the interaction is less important than the process that participants go through while creating this outcome. The music in such systems would therefore tend to be less

coherent and structured than in product centered systems. Different networks can emphasize different aspects of the process. Some networks would focus on facilitating elaborate social dynamics between players, others would emphasize the expressive and creative process for individual players, while others would center on providing a rich learning experience. In all of these examples, the interaction in process centered systems can be further classified into two additional subcategories – exploratory and goal-oriented interactions. Exploratory IMNs do not impose specific directions or goals for the participants. Such systems are driven by abstract motivations such as the investigation of novel ways to play in a group, the creation of unexplored musical crossbred offspring, the “elevation” of participants toward an immersive “flow” oriented learning experience, etc. The interaction and the musical outcome in Exploratory networks is likely to be less structured and directional than in goal-oriented systems although the musical experience would tend to be deeper and more meaningful as exploratory networks are less likely to be driven by extra-musical goals. Goal-oriented interactions, on the other hand, are designed to encourage players to achieve specific objectives, musical or non-musical, by offering rewards or game-like activities. Such games can be designed to reward participants for their social skills, musical creativity, or for their learning achievements and can be based on encouraging collaboration or competition. Goal-oriented systems are therefore more likely to capture and engage players for longer sessions, providing a higher “fun” factor. They are, however, less likely to provide meaningful musical experience or rich learning activities if the challenges and rewards become more important than the musical content.

The different varieties of process centered networks are fundamentally different than Product centered systems where the most valued goal for the interaction is its outcome, whether it is the music or the performance (see Figure 14). For designers of product centered systems, players’ experience is relevant only in regard to the final outcome of the system. Composers and designers of such systems would be more interested in aspects such as artistic vision, compositional structure, and performance construction.

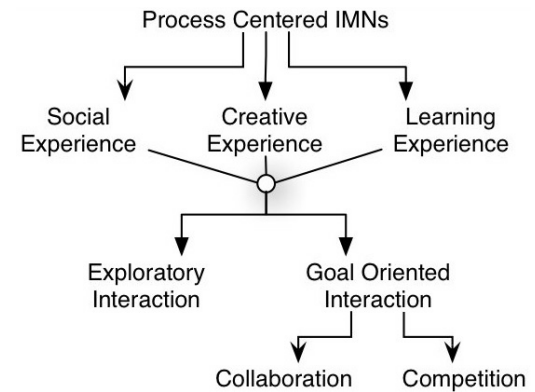


Figure 13. Motivations for Process centered IMNs

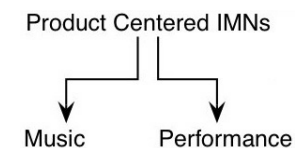


Figure 14. Motivations for Product centered IMNs

Players in such networks, on the other hand, will be expected to try and realize the artistic vision of the composer. It can be claimed that the main target of product centered systems is the audience rather than the performers.

It is important to note that most IMNs combine social, creative, educational and musical aspects in different levels and balances. Some designers try to combine process and product, games and explorations, goal-originated activities with abstract interactions. Creating such balances, however, is extremely difficult as many of these motivations are contradictory in nature. For example, it is extremely difficult to create an IMN that would allow players to create worthy music as they are trying to win a game. When learning and collaboration are part of the motivational mix, chances are that none of these goals would be successfully achieved. In general, exploratory networks are likely to provide meaningful experience for participants but will find it difficult to maintain the level of interest and engagement of players over time. Goal specific systems, on the other hand, are more likely to engage participants over time and to produce more structured and less improvised musical output. The risk in such systems, however, is that participants would focus on extra-musical challenges which might lead to less meaningful musical experiences.

1.4.2 Social organization and perspectives

Since all IMNs facilitate social interactions, designers should decide early on in the process what their social philosophy is and how their network would be governed. The main axes at play here are the level of central control desired and the level equality provided to the different participants in the interaction. Centralized systems (see Figure 15) would usually be governed by a computerized hub responsible for receiving input from the participants, based on which the musical output will be generated. In decentralized systems (see Figure 16) players would usually communicate directly with each other through instruments that have computational power of their own. Under the centralized and decentralized systems

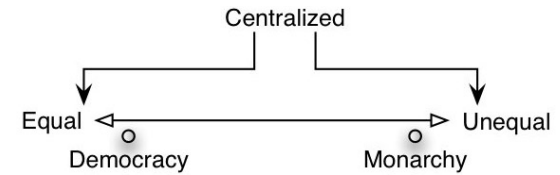


Figure 15. Decentralized Social Perspectives

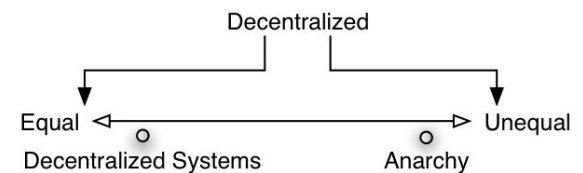


Figure 16. Decentralized Social Perspectives

umbrella we can find a variety of approaches that are based on the levels of equality provided to participants in terms of their musical role. State governmental metaphors may be appropriate. For example, a “monarchic” system can serve as an example for a centralized unequal social approach. Here, a leader (a person or the computer) controls and conducts the interaction. This “monarch” can provide temporary freedom to other players when desired, change and manipulate the interconnections gates between players, or take control over the interaction in general. While providing a “composed” and structured interdependent experience, the monarchy approach usually fails in providing a true collaborative voice due to the leader’s dominancy. Such systems would also rarely facilitate a true dynamic experience as the dominant leader is likely to have idiosyncratic preferences and tendencies that would hamper the elements of chance and surprise. A “monarchic” system, therefore, would be more effective in addressing a product centered motivation than a Process centered one. Democratic IMNs, on the other hand, may be more effective when the process is emphasized. Here, the centralized system provides an equal, or close to equal, role for all players in defining the musical output. In goal-oriented democratic systems, participants would have to collaborate or synchronize their actions in order to create a noticeable and significant musical effect. Often in such systems, only the collaborative act of the majority will define the final musical result. Different participants in “democratic” networks may have different roles and responsibilities (such as controlling the harmony, melody or rhythm) while some players may temporarily receive a leading role from their peers or from the system. Democratic systems are more likely to facilitate more agreeable social experience for participants than the monarchic systems, but they also bear the risk of creating directionless musical textures without a clear purpose or structure since forming a decisive majority in real time is not a trivial task. The classification of participants to different roles might also create confusion and imbalances in regards to players’ level of contribution.

In decentralized systems, on the other hand, interaction occurs directly between participants without central control that governs the experience.

One extreme example for a decentralized unequal IMN would be the “anarchic” network which would provide minimum central control and maximum freedom for players to generate and manipulate their musical material. However, such systems can hardly be considered IMN since they usually violate some of the medium’s basic definitions such as interdependency, coherency, and dynamism. As a result, the musical output of anarchic systems, especially when children and novices are involved, is likely to be incoherent and cacophonous. A much more equal (and interesting) decentralized approach is designing rule-based decentralized systems where high-level musical patterns emerge from the interaction between many participants who follow identical simple rules (see Resnick 1999). Such decentralized systems can comply with all the important aspects of successful IMNs as they are based on interdependency and social dynamic behaviors, while their low-level simplicity can help keep the interaction simple and the music coherent. The high-level emerging patterns, if they occur, can lead to interesting musical structures that would lead to interesting musical outcomes. It is important to note, though, that it is not trivial to design such simple rules that lead to interesting high-level musical patterns. Some of my personal attempts at creating decentralized IMNs have led in the past to directionless and monotonous texture-oriented pieces (Weinberg 1999.)

1.4.3 Architectures and topologies

In this section I discuss the technical aspects of the network topologies and controllers that would best serve the social approaches discussed above. Here, too, the main categorization is to centralized and decentralized topologies, which correspond to the respective social approaches. In centralized networks, players are likely to interact through instruments and controllers that do not have computational influence on the group interaction. Data from the players would be sent to a central hub that would analyze it and generate the music outcome algorithmically. In decentralized architectures, players interact directly with each other using instruments that have computational power that is applied to determining

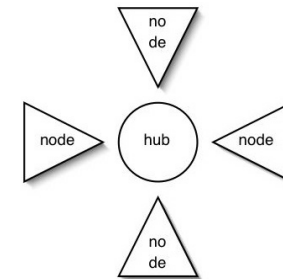


Figure 17. Synchronous Centralized interaction – “Flower” topology

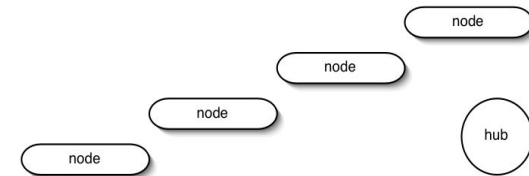


Figure 18. Synchronous Centralized interaction - “Wheelbarrow” topology

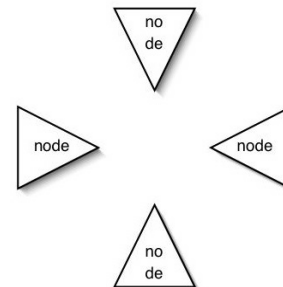


Figure 19. Synchronous Decentralized interaction – “Star” topology

the group interaction (see the Musical Fireflies project, Chapter 5.2). Centralized and decentralized topologies can be classified into two additional categories – Synchronous (or real-time) and Sequential (or non-real-time). In synchronous networks, players modify and manipulate their peers’ music while they play it. In sequential systems, players generate their musical material with no outside influence and only then “submit” it to further transformations and development by their peers. At its simplest form, a centralized synchronous network can be depicted as having a “Flower” topology (see Figure 17). The different input nodes of the network, representing the players, are constantly connected to a computerized hub which is responsible for creating the interconnections between the nodes. A centralized sequential network can be depicted as having a “Wheelbarrow” topology (see Figure 18.) Here the inputs nodes, or players, are separated from each other in time, and each new input stage is building upon the last one. Figures 19 and 20 represent the decentralized versions of the flower and wheelbarrow topologies. I entitled them “Star” and “Stairs,” respectively. In general, it can be claimed that synchronous networks bear the promise of creating a constantly evolving immersive whole that may be bigger than its parts. On the other hand this approach also bears the risk for individual players to lose the sense of coherency and causality. In sequential systems, on the other hand, the interdependent interactions occur in ordered manner by actions such as turn-takings. This approach is simpler to follow for the individual player but bears the risk of compromising the group collaboration as not all players are constantly involved in music making.

These generic depictions of synchronous, sequential, centralized, and decentralized interactions do not represent the connections among the nodes in the network. In order to demonstrate this aspect of the topology let’s look at a number of examples: Figure 21 depicts simple one-way flower architecture. Here, the data is sent synchronously from the players to the hub, which is responsible for generating the musical output based on algorithmic treatment of players’ input. The interdependent aspects in this simple network are derived only from the players, who listen to the

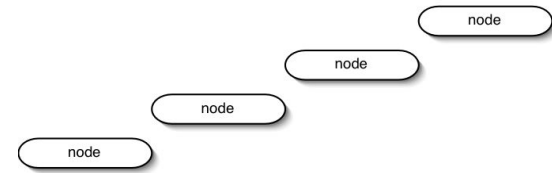


Figure 20. Sequential Decentralized interaction – “Stairs” Topology

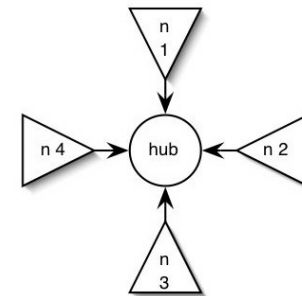


Figure 21. Symmetric one-way “Flower”

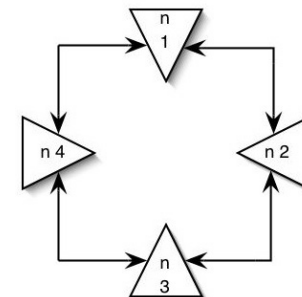


Figure 22. Symmetric interdependent “Star”

musical output from the hub and change their actions accordingly. A higher level of interdependency is presented in Figure 22 which depicts a decentralized star topology where players are connected directly to each other and can interdependently manipulate each other’s musical outcome. Both Figures 21 and 22 depict symmetric topologies, where all nodes are connected to the hub or to each other. Such architecture would correspond to an “equal” social approach. Figure 23, on the other hand, presents an asymmetric (unequal) network architecture where connections are possible only in specific directions, and in between specific nodes. Figure 23 also introduces the concept of weighted gates, which control the level of influence at each intersection in the network. Normally, gates would be open, providing a full level of influence to the respective algorithm and/or musical content that passes through them. The gates, however, can also be partly (or fully) shut, allowing only a partial level of functionality at each particular intersection. The gates can have different weights as default values (depicted as numbers next to some intersections in Figure 23) but can also be changed and manipulated in real time based on players’ input. This asymmetric weighted interconnected Flower topology is common in democratic networks, as it provides different roles and levels of importance to the different players. It was used in the Squeezables project (see Chapter 5.1). An extreme version of such topology can lead to a monarchic network where one player can control all the weighted gates in the systems and therefore has full power in conducting the experience.

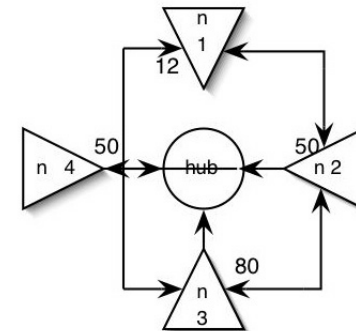


Figure 23. Asymmetric weighted interconnected “Flower”

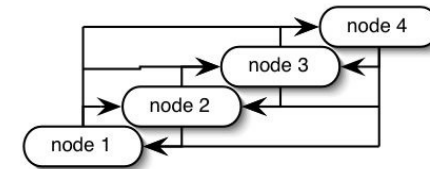


Figure 24. Symmetric one-level “Stairs”

Sequential networks have similar levels of interconnected complexities. In the simplest architecture each node is only connected to the next one so that every player can manipulate the musical product of the previous player (see Figure 24). The arrows between steps are bidirectional – the outgoing arrow represents the musical output that is sent to the next node, and the incoming arrow represents the algorithmic manipulation that is applied to it. More elaborate Sequential topologies allow players to transform not only the previous player’s musical output but also the musical product of the other participants in the different nodes of the network. This manipulation can be done directly between players, or

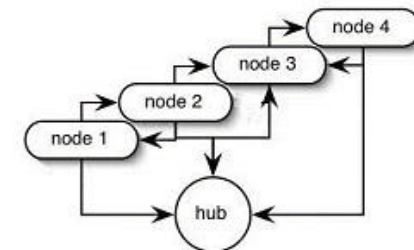


Figure 26. Symmetric multi-level “Wheelbarrow”

through a central hub. Such a symmetric multi-level Wheelbarrow topology is depicted in Figure 26. Just like synchronous networks, asymmetric sequential networks facilitate interdependency only in specific directions and provide idiosyncratic roles to the different players. Here too, weighted gates can be assigned to different intersections (see Fig 27). In practice, most elaborated IMNs will combine synchronous and sequential elements in different balances. In such hybrid networks (such as the Beatbug network, see Chapter 5.3) part of the interaction will be sequential where players have autonomous control over their own music before sharing it with the group, while other parts of the interaction will be synchronous, as players will be able to influence their peers' musical output in real-time. In addition, some parts of the interaction can work in a centralized manner and others in decentralized way. In general, these Hybrid systems can be depicted in two manners: "Stairs of Flowers," where synchronous interactions are ordered sequentially in time (see Figure 28), and "Flowers of Stairs," where a set of sequential interactions are synchronously connected to the system's hub (see Figure 29). Here too, a weight system can be assigned and controlled in real-time to provide more dynamic levels of influence.

1.4.4 Musical parameters

The motivations, social perspectives, network topologies and architectures are all important steps towards setting up the framework for an IMN project. But up until now we haven't addressed the actual musical parameters and transformation algorithms that would fill such frameworks with musical content. Decisions have to be made regarding the musical parameters that will be generated, controlled and manipulated, autonomously or interdependently, by the participants. This aspect of the design bears a subjective aesthetic core. Different composers/designers may have different ideas, tastes, or artistic interests when determining the precise parameters for control. The musical content and transformation decisions are closely related to all other design aspects discussed before. For example, the system can simultaneously provide all players with a full

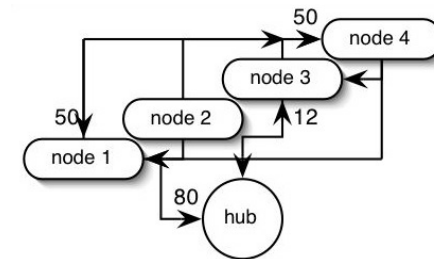


Figure 27. Asymmetric multi-level weighted "Wheelbarrow"

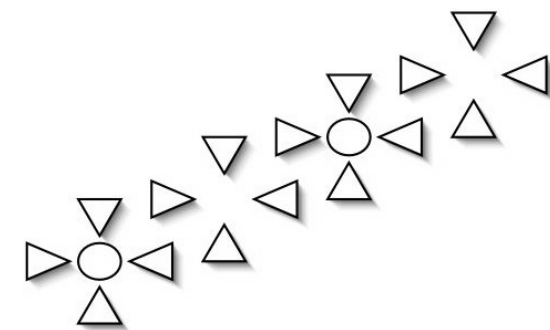


Figure 28. Hybrid generic "Stairs of Flowers."

gamut of pitches, timing values, and polyphony to generate and manipulate. Such a network would have an abstract, anarchic Flower topology. On the other extreme, the system can limit the possibilities for input and manipulation by allowing players to choose from a limited bank of presets in an effort to achieve a specific task (see the section on novice and expert systems below). In general terms, any musical parameter, i.e., pitch, rhythm, timbre, or dynamics, is a candidate for autonomous as well as interdependent generation or transformation. However, there are some rules-of-thumb that I would recommend to follow in an effort to create a coherent and meaningful interaction. For example, allowing players to influence and control parameters such as pitch or melodic contour of their peer's melody, may lead to an incoherent experience for the peer who may feel that she has no control over the most basic aspects of the music she tries to create. Such mappings may draw the systems into an anarchic domain, even if the architecture supports other social perspectives. On the other hand, granting a player full autonomous control over his pitch content while allowing other players to control ornamental aspects such as timbre or dynamics may lead to more coherent experience for the melody player, while interdependently enriching his playing experience as he tries to accommodate his playing to the new timbres and dynamics. Another helpful aspect for maintaining the interaction coherency is preserving the nature of the musical material as it was originally created. In sequential networks in particular, it is easy to allow co-players to modify their peers' music beyond recognition. This can lead the original players to feel disconnected from the music they created, as their detailed idiosyncratic contribution might be eliminated. The interdependent transformation algorithms, therefore, should focus on modifying surface elements and to maintain reversibility, so that the original musical output would be able to be perceived and retrieved from the modified material. Setting up and adjusting the musical parameters for autonomous and interdependent control is one of the most important (as well as time-consuming) aspects of the design process. In the following sections, where I describe my thesis work in more detail I will address my specific design choices for each of the different networks that I developed.

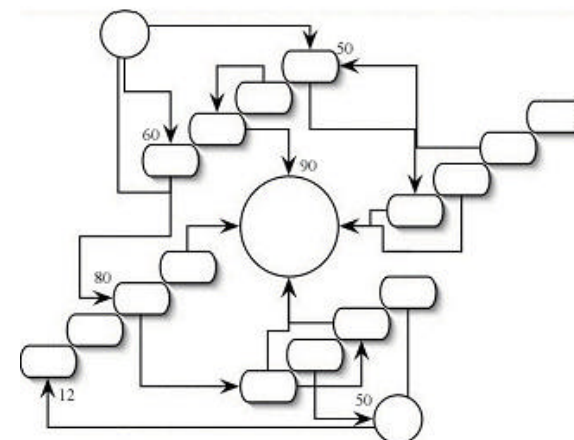


Figure 29. Hybrid interconnected “Flower of Stairs.” Some of the intersection gates are weighted.

2 Research goals

Informed by the theoretical framework and design principles, I have set to investigate and compare the earlier “high-art” IMNs described in Chapter 1.2 and the more recent attempts at collaborative musical experiences for novices presented in Chapter 1.3. My investigation revealed a vast gap in intent, implementation, design considerations, and results. Expert networks such as in the case of Cage, Stockhausen, the League and the Hub, as well as the professional Internet systems aim mainly at skilled musicians and educated audiences. As such, they tend to use technology for creating complex interdependent topologies, and they require prior skills and knowledge and value the final musical outcome. Gestural systems for novices, on the other hand, usually utilize technology to simplify and constrain the interaction for the untrained. Their main goal is creating compelling experiences for participants rather than listeners, and they are designed mainly for short interactions in public spaces. The learning curve for participating in novice networks is smooth, which usually comes at the cost of the long term depth of the interaction. (see Table 1 for a comparison between novice and expert Systems.)

Expert and novice IMNs have their respective pros and cons. The complex interdependent connections in the expert systems usually provide deeper and more thoughtful musical experiences but might require participants and audiences to use previous musical training and knowledge and to concentrate on low-level analytical elements in order to follow the interaction. Such interdependent complexity might also hinder the system’s coherency and prevent performers and audiences from focusing on the social and collaborative aspects of the network. Since the composition is the motivating force in expert systems, their design does not necessarily emphasize the conveyance of the interaction to audiences, and in many cases not even to the performers themselves who may find it difficult to follow. Moreover the music that is usually written for such systems has not historically resonated well with wide audiences and the

general public. As a result, these systems have never crossed out of the high-art academic music realm and have not grown from an academic exercise into a viable new and exciting musical art form.

Table 1. Comparison between novice and expert IMN systems

Novice IMN systems	Expert IMN systems
Emphasize the process and the experience – collaboration, creation, or learning. Aimed mainly at performers.	Emphasize the final product – musical composition or stage performance. Aimed mainly at audiences.
Technology’s main use is to simplify interaction for players by constraining musical possibilities	Technology’s main use is to create complex and rich interdependent topologies.
Low floor / low ceiling learning – fast and easy learning curve but low long-term depth value	High floor/high ceiling learning – pre-required skills and knowledge, richer longer term learning value
Designed for short interactions (seconds to minutes) in public places.	Designed for long interactions (minutes to hours) in concerts hall or on-line.
When the system leads to a coherent musical product, the music tends to be of the popular variety.	Historically, musical product tended to be of the high-art music variety. Little accessibility to wide audiences.

Most novice systems, on the other hand, by trying to cater to the untrained and unskilled, often fail to capture the unique interdependent promise of the IMN experience. In many of these systems, players cannot truly contribute meaningfully and creatively to the composition, but rather they are only allowed to manipulate and control pre-composed material. When players are provided with more control over the music, the result is often a short and cacophonous multiplayer game with sound. The novice systems also rarely create interesting interdependent connections among players.

Large scale systems in particular are more likely to fail in facilitating the thoughtful collaborative interactions that draw participants into long and fulfilling interactions. Moreover, the musical composition, not being the center of attention in such systems, rarely demonstrates structured and coherent results which can have long term value.

My belief is that novices and children, if given the right tools, can be much more expressive and creative musically than they are currently given credit for. I believe that novices can appreciate and benefit from the concentrated, engaged and thoughtful side of collaborative music experiences and that with the right kind of support, they would also create worthy high-quality music. I also believe that expert systems can gain from the unmediated expression and simplicity that characterize novice systems. Therefore I have decided to try and address the challenge of bridging the gaps between the novice and the expert systems by creating new hybrid networked interactions that would combine intuitive and expressive collaborative experience, high learning value, as well as worthy music. Addressing the differences between the novice and expert systems as presented in Table 1, I have come up with four general goals for such interconnected musical networks:

- Provide a compelling social and collaborative experience for participants as well as a coherent and worthy music for listeners and spectators – worthy process as well as worthy product.
- Use software and hardware solutions to address the cognitive abilities and educational needs of children and novices without compromising the depth of the musical experience.
- Create pedagogy for the networks that will be based on a low floor / high ceiling principle for intuitive as well as deep learning experiences.

- Provide scalable interactions that would be effective both in short demonstrations or public spaces such as museums and more extensive experiences such as in long term workshops, rehearsals, and concerts.

The main risk in this “bridging” approach is that it might lead to hybrid mediocre networks that fail to capture the thoughtfulness affiliated with expert systems on one hand, as well as the unmediated expressiveness affiliated with the novice systems, on the other. In an effort to avoid this pit, and to address the social, pedagogical and technological challenges that I have mentioned above, I decided to investigate three main research areas – music perception, music education, and human computer interaction – which I believed would be instrumental for the development of effective hybrid IMNs. My investigation into these fields is described in detail below.

3 Fields of study

The interdisciplinary approach I take looks at cognitive, educational and computer interaction aspects. In music perception I studied cognitive theories and focused on novices' musical perception in an effort to design algorithms that would provide novices with intuitive and expressive access to rich musical concepts. In music education I investigated a number of learning theories and education programs in an effort to facilitate a low floor / high ceiling pedagogy for IMNs. In the field of computer human interaction I focused on theories and principles for the design of musical controllers as well as design principles for computer mediated group interaction in an effort to create coherent, conveyable, and scalable networks. In this chapter I discuss in detail theories and concepts from these fields of study which were instrumental for the development of my hypothesis and assessment criteria.

3.1 Music perception

There is a growing body of research which indicates that novices perceive music differently than experts. David Smith (1997) surveys a number of these studies and demonstrates how a significant number of musical percepts which are regarded as fundamental and obvious by expert musicians are not shared as such by novices. For example, he shows that novices cannot perceive octave equivalence; they do not identify or categorize intervals, diatonic hierarchy or transposition, and do not follow structure and shape in the same way that experts do. Smith and Marla (1990) also conducted a quantitative study showing that while experts' aesthetics center on syntactic musical aspects, novices' aesthetics stem more from referential, sensual and emotional sources. Related fMRI studies strengthen Smith's hypothesis, showing that there is a difference in brain activity between skilled and novice artists when involved in creating art work (Solso 2001). Other studies, on the other hand, show the existence of "high-level musical percepts," also known as "surface musical percepts"

(Dibben 1999). These are composite musical elements such as rhythmic stability, melodic contour, or harmonic tension, which have been proved to be universally perceived by novices and experts, children and adults. For example, various psychoacoustics studies show the perceptual significance of melody contour (Schmuckler, 1999). In one case, it has been shown that novices' ability to retain melodic contour of a semi-known melody is much better than their ability to retaining the specific pitches (Sloboda 1987.) Trehub et al. (1984) even demonstrated that contour can be perceived by infants as young as one year old, strengthening the assumption that this percept is well ingrained in human cognition.

These studies may suggest that by embedding algorithms for controlling contour in IMNs we can provide intuitive and meaningful musical interaction for the untrained. Such interaction bears the promise of bridging between the expressive manner in which novices relate to melodic curves and the more analytical manner in which experts perceive the lower-level relationships between pitches and intervals. More importantly, by providing novices with the power to create and phrase melodies by manipulating their contours (regardless of their exact pitches and intervals) we offer a unique creative experience that is usually reserved only for experts and that can serve as an entry point for further investigations into more advanced concepts such as harmony and counterpoint.

Another example for a high-level musical percept that can serve as an intuitive and expressive bridge for deeper musical investigations is stability. It has been shown, for example, that the cognitive perception of structural stability is influenced by musical parameters such as tempo, interval size, register, dissonance, and rhythmic variation (Dibben 1999). Here, too, an algorithm that would allow players to manipulate these parameters (and therefore control stability) would provide players with an intuitive and meaningful high-level musical experience that could lead to deeper musical understanding.

Music perception studies look at cognitive processes that take place in our brain when we listen to music. I suggest that findings from such studies can also be used in the opposite creative direction when implemented in systems for music making. Such systems can allow untrained players to make music based on the way they perceive it. The more quantitative a perceptual theory is, the easier it should be to use the musical parameters it addresses to design algorithms for high-level control. An example for such a theory and a perceptual study that supports it is Fred Lerdahl & Carol Krumhansl's Quantitative Theory of Tonal Music (2003) which is based on Lerdahl and Jackendoff's generative theory of tonal music (1985). The theory, which is loosely based on Schenkerian analysis, defines four mathematical models to describe human perception of tension and release in tonal music. The models are:

1. A representation of hierarchical structure
2. A model of tonal pitch space
3. A treatment of surface (psychoacoustic) dissonance
4. A model of voice leading (melodic) attractions

The theory defines a set of formulas and algorithms for calculating how we perceive hierarchies and attractions between notes, chords and larger structural elements in tonal music. For example, one such formula shows that the distance between a major G triad chord to a major C triad chord in the scale of C is smaller than the distance between a major C triad and its minor version c. The formula actually calculates a specific value for each distance – in our case the first distance is defined as 5 and the latter 7. Similarly, based on a pitch anchoring strength model, the theory calculates the level of attraction between pitches. For example the attraction value between b and the c in the scale of C is calculated as 2 while d is less attracted to c in the same scale (only 0.5).

These formulas, although making sense in an intuitive level, seem to be based on arbitrary constants and algorithmic relationships. One may ask, for example, why was $1/n^2$ chosen (and not $1/n$ or $1/n^3$) to define the weight of the distance between notes to their attraction level. In their new study Lerdahl and Krumhansl address this question by reinforcing the theory with empirical cognitive experiments. The study shows a strong correlation between how people perceive tension and release in a number of given musical pieces and the tension and release values that were calculated by the theoretical formulas. The researchers claim that more studies are needed before deciding whether there is a need to modify constants and variables in the theory.

As the generative theory of tonal music utilizes precise values and relationships and provide some empirical reinforcements, I suggest that it should be possible to embed similar formulas for hierarchies and attractions in new digital musical instruments and applications in an effort to allow players to control high-level contours of attraction, tension, and release, melodically and harmonically. The computer in such scenarios will generate the actual musical material based on look-up tables that are informed by the formulas. Such an approach bears the promise of providing untrained and unskilled players with an expressive access to control musical concepts that are meaningful and intuitive to them.

3.2 Music education

With many musical education systems, such as Dalcroze, Orff-Schulwerk and Suzuki, educators find it difficult to combine theory and technique with the expressive and emotional aspects of playing and creating music. The Orff-Schulwerk method (Warner 1991), for example, focuses on traditional folklore by using poems, rhymes, games, songs, and dances as examples and basic materials. Similarly to the Dalcroze Eurhythmics approach (Dalcroze 2003) it focuses on gaining a practical experience in music through body movements but does not provide a link between these



Figure 30. Dalcroze eurhythmics - teaching of music through the use of body movement

expressive activities and deeper theorization (see Figure 30). Other more instrument-oriented programs, such as the Suzuki system (see Figure 31), demonstrate the difficulty in bridging expression and thoughtfulness from another perspective. The Suzuki system (Suzuki 1969) has been successful in showing that a large number of individuals can learn to play musical instruments remarkably well, even at early ages. However, the system demands a long technical learning process, which shadows the expressive and creative aspects of playing. This may explain why the method is not especially successful in producing great concert-player musicians who are skillful and expressive.

The different approaches taken by popular music education systems demonstrate how difficult it is to bridge expression and creativity on one hand and technique and theory on the other. It seems that music is an especially problematic medium in that regard due to its abstract nature and its time dependency. Visual art, on the other hand, is usually easier for children to use as a creative medium. An untrained child with a paper and a pencil is more likely to have a longer and more meaningful experience if asked to be creative in free drawing than an untrained child who is given a piano and asked to create music. Whether drawing abstract or concrete paintings, the visual art challenge is supported by stronger references and connections to the world known to the child, who will probably find it easier to modify and manipulate tangible artifacts than illusive aural stimuli.

Jeanne Bamberger (1982) addressed this difficulty and related it to the gap between what she calls “figural” and “formal” in music learning modes. Bamberger claims that preteens are inclined to process music in a figural manner, in which they tend to focus on the “know-how,” addressing intuitive aspects such as the global features of melodic fragments, the “felt” features of contour, rhythm grouping, etc. The know-how approach is based on intuition and creation, irrespective of any theoretical knowledge about music. Most instrument education programs, however, require children in their early teens to abruptly change their learning style



Figure 31. Shinichi Suzuki

to what Bamberger defines as the formal mode, in which musical notation, theory and analysis are abruptly introduced. As a result of this “know-that” approach certain important musical aspects that came naturally in the figural mode may be hidden, at least temporarily, when children try to superimpose formal knowledge upon figural intuitions. If this “crisis” is not acknowledged and the gap between the different modes is not negotiated, Bamberger stresses this can lead players to give up on music altogether.

A related “learning-gap” is presented by Howard Gardner, who in his book *The Unschooled Mind* (1991) describes three different kinds of learners:

- The Intuitive Learner – also referred to as the natural, naïve, or universal learner. The young child who is superbly equipped to learn languages, the physical world, and the world of other people.
- The Traditional Student (or the scholastic learner). Usually at school from seven to twenty years old. Trying to master literacy, concepts and other disciplinary forms.
- The Disciplinary Expert – an individual of any age who has mastered the concepts and skills of a discipline or domain and can apply such knowledge appropriately in new situations.

Gardner believes that one of the main goals of any educational system should be to help learners to bridge the conceptual gap between these learning approaches. He suggests two different models that can serve as starting points for creating such a bridge – the traditional apprenticeship model where the apprentice learns through participating in the master’s work, and activities in children museums, where children get hands on access to educational material.

My approach for addressing this conflict is informed by Seymour Papert’s Constructionist Learning theory (1980) – an educational philosophy that is based on the notion that learning is most effective when students construct

personally meaningful artifacts. The theory is informed by Piaget's constructivism (1972), which asserts that learning is an active process of knowledge construction and not passive absorption. It emphasizes the critical role of interaction with the world for learning and cognitive development. Piaget demonstrates how processes such as the development of spatial locomotion, definition of the self, and abstract representation are connected to and enhanced by interacting with concrete elements in the world. Papert extended this theory, showing how students can construct their knowledge and obtain powerful theoretical ideas through intuitive and emotional connections with personally meaningful artifacts that they construct themselves. Papert emphasizes the ability of the computer to provide such personal and meaningful learning experiences to a wide variety of learners – "Because it (the computer) can take on a thousand forms and can serve a thousand functions, it can appeal to a thousand tastes" (1993).

Other researchers have elaborated on Papert's ideas, investigating how embedding technology in physical objects can enhance children's and adults' learning and everyday experiences. The "Programmable Brick," for example, is a tiny computer embedded inside a LEGO construction block (Resnick 1996). Unlike traditional construction kits' blocks that enable children to build structures and mechanisms, the programmable brick adds a new level of construction by enabling children to create behaviors for the objects that they build. The "Cricket," a newer member of the programmable brick family (Martin 2000) can control two motors and receive information from two sensors. Crickets are equipped with an infrared communication system that allows them to communicate with each other. Children can write LOGO (2003) programs on the computer and download them to cricket-based objects that they construct. By designing behaviors for these objects, children can experiment with the physical embodiment of their programs.

Informed by such work I have decided to bring constructionist concepts to the field of music by developing instruments and applications that would




allow learners to construct their personally meaningful musical artifacts. In particular, I was interested in developing infrastructures that would facilitate collaborative musical construction through interdependent social interaction in a group. Such networks bear the promise of leading to the creation of shared emerging musical behaviors and provide hands-on access to deep and thoughtful musical experiences. A variety of topologies and interconnections between the instruments can be explored and their social effect on players can be studied. This calls for investigating some human-computer interaction aspects and their manifestation in IMNs, as discussed below.

3.3 Human-computer interaction

Children, novices and the general public can gain access to rich and insightful musical experiences through active participation in music creation. But in order to allow such access without compromising figural intuitions and without enforcing a long theoretical learning process, a new set of musical instruments and applications is required. Historically, the development of digital musical controllers focused on single player instruments for experts and virtuosi. Common approaches for designing such controllers have been augmenting traditional instruments with sensors, imitating traditional instruments and gestures with purely electronic controllers, musically modifying familiar objects that usually serve another purpose, and inventing utterly new ways to play music with new controllers that call for new gestures and playing metaphors (see for example Roads 1996, Chadabe 1997, Paradiso 1997, Cook 2001).

The development process of such a new controller often starts with an unexplored interaction or gesture that the designer is interested in exploring musically. This usually leads to assigning or designing the appropriate sensor around which a controller is to be developed. With a working prototype of the new controller, many designers then turn to investigate the appropriate mappings between players' gestures and the

musical output. Much work and study have been done regarding this “mapping” challenge. In particular, designers have looked for meaningful ways to constrain the close-to-absolute freedom provided by digital technology where any gestural input can theoretically be assigned to any musical output. Generally, solutions for the problem can be seen on an axis where on one extreme the mapping is simple and forms a direct connection between a particular gesture and a particular sound. On the other extreme the mappings are based on complex rules, taking history, input derivatives, and other gestures into account when determining the musical output. A heated debate is affiliated with the question of locating effective spots on this axis while arguments are usually informed by a variety of human-computer interaction principles such as usability, ease of learning, and functionality (see for example Orio et al., 2001, Hunt et al., 2002.) When the mapping problem is resolved and the prototype is ready, designers typically complete and fine-tune the musical context in which they want to use the new controllers. Although this process is never strictly structured and often the different stages coincide and intermingle with each other, its direction can be generally portrayed as:

Interaction  sensor  controller  mapping  musical idea

My personal view is that this process is faulty and has led in the past to the development of musical controllers with no clear purpose and no added value over traditional instruments. Most traditional acoustic instruments already excel in capturing a wide range of subtle and expressive gestures and in “mapping” them to produce rich and diverse acoustic sound. I believe, therefore, that if we are to develop a digital musical controller at all, the process should be motivated by a musical idea that cannot be realized by traditional instruments. When the musical idea is defined and the challenge is clear, designers should focus on the kind of mappings and applications that would best address their research challenge, which should lead to the design of a controller, and finally to the appropriation or invention of a sensor for the desired interaction. The design process,

therefore, should proceed in the opposite direction, starting with a musical idea and ending with the interaction that would best serve it:

Musical idea → mapping → controller → sensor → interaction

The two musical ideas that serve as the motivations for my interest in developing new musical controllers are derived directly from my research goals:

- To allow children an access to expressive and thoughtful musical experience. This goal should ultimately lead to defining the interaction that would best serve and challenge children's and novices' cognitive and educational skills and interests.
- To create expressive social networks for musical group collaboration. This goal addresses mainly the challenge of designing effective network topologies that would facilitate interesting and rewarding socio-musical dynamics.

One approach for addressing the first goal is to find effective ways to restrict musical possibilities in an effort to allow for easier learning curves (Cook, 2001). An extreme utilization of this approach can be found in the abundance of commercial musical toys that require simple discrete input for triggering prerecorded sounds. Most musical toys, from Simon in the 70s to more interesting efforts from companies like Tomy today, use the simple triggering mechanism to provide simple challenges and competitions with no apparent musical value. More serious efforts can be found in musical software applications such as Morton Subotnick's "Making Music" (Rothstein 1994) or Jeanne Bamberger's "Impromptu" (Bamberger 2000), which allow children and novices to learn and create music by interacting with a computer graphical user interface. Although such programs can offer interesting, thoughtful and intuitive activities, they usually center on either recreating and studying familiar music or composing abstract non-guided musical pieces. More importantly, the lack

of physical interaction with gestural musical instruments impairs the expressive and personal connection that the users have with their creation.

Tod Machover's Brain Opera project addresses this challenge by introducing new musical instruments for novices and the general public. Machover's work, which had started with the goal of developing digitally expanded musical instruments in an effort to provide extra power and finesse to virtuosic performers (Machover 1992), was later extended to the design of interactive musical instruments for non-professional musicians, students, music lovers and the general public (Machover 1996). Current research in Machover's group attempts to push the envelope in both these directions by designing high-level professional systems that measure subtle and sophisticated human performance and by building interactive entertainment systems for novices and the general public. As a member of Machover's group, I had in the past been especially interested in developing musical instruments for children by appropriating familiar play gestures and interaction patterns to musical contexts. The controllers I developed as part of my Masters thesis, such as the musical crib (Weinberg 1998) or the musical playpen (Weinberg 1999) were not based on augmenting or imitating traditional musical instruments (which are not necessarily more familiar to the untrained than other play objects) but based on metaphors and gestures that are intuitive and familiar for children from other play activities. For my Ph.D. work I decided to appropriate this approach to the development of intuitive and expressive IMNs.

The second goal that motivated my interest in developing new controllers – the facilitation of meaningful social musical collaborations – has been the subject of much recent study as well. One of the research fields that inspired my interest in developing such musical networks is System Dynamics in general and Decentralized Systems in particular. Many biological, social, and physical systems, (such as in ant colonies, traffic jams, or particle collisions, see Resnick 1999) are based on a large number of simple rule-based individual behaviors with no apparent central control. When interconnected with each other, these ruled-based individuals

behaviors can lead to interesting high-level emerging patterns and behaviors. In a musical context, decentralized rule-based individuals, which are mapped to interconnect with each other in a social manner, bear the promises of creating cross-bred emerging musical behaviors. (see the Scale-Ships software application, in Weinberg 1999 b.)

Another research area that informs my interest in human computer interface aspects of IMNs is the field of Computer Supported Collaborative Learning (O'Malley 1995). Jeremy Roschelle, for example, shows how his computer supported collaborative learning application leads learners to deep conceptual shifts in their shared knowledge of physics. Roy Pea describes how CSCL learners experience "transformative communication," which changes the way they look at the world, themselves and each other. In a musical context, some researchers have recently looked at the principles guiding the design of collaborative musical systems for novices. Blain and Fels (2003) have suggested five main context guidelines for the design of such systems: focus (players or listeners), location (public space or networked), media (pure sound or multi media), scalability, and player interaction (similar activity to all players or not). Other context elements according the Blaine and Fels are the musical range, physical interface/sensor, directed interaction, learning curve, pathway to expert performance and level of physicality between players and instruments. However, in their analysis of a number of such collaborative systems (which includes the Squeezables and the Beatbugs among others) the writers fail to address issues such as learning and the musical value of the experience, and do not account for the measures taken by the systems to encourage thoughtfulness and musically meaningful participation. Their analysis, therefore, addresses only one aspect of the balance between expression and thoughtfulness that should be supported by successful collaborative musical systems.

4 Hypothesis and assessment criteria

Informed by the research in these fields of study, I am suggesting that by embedding algorithms for high-level control and constructionist-learning schemes in interconnected musical instruments we can provide expressive collaborative musical experiences for children and novices that offer rich educational experiences and a worthy artistic product. In an effort to address this hypothesis I have developed a number of interconnected musical networks that explore a variety of design approaches for collaborative interdependency, learning, and composition. I have defined three main assessment criteria for evaluating these networks.

- Collaboration – The first criterion is based on my goal to create network topologies that would facilitate effective and unique social collaborations. It addresses issues such as the quality of interpersonal interactions in the network, the coherency of the interaction, the level of interdependency and the system's scalability.
- Education – The second criterion addresses my goal to provide an intuitive and rich educational experience for novices and children. It addresses subjects such as the effectiveness of the high-level control algorithms, the system's support for novice musical perception, the shape of the learning curves it provides, and the height of the learning floors and ceilings.
- Music – The last criterion addresses my goal to design these networks so that players would be able to create a worthy musical product. This criterion is more difficult to assess as it touches objective matters such as aesthetics and artistic value. My discussion, therefore, will be descriptive in nature. I will also present my personal view of the compositions and the artistic community's regard to the music.

4.1 Collaboration

My goal here was to develop a variety of network topologies and interactions and evaluate their effectiveness in facilitating compelling social dynamics, encouraging teamwork, and providing infrastructures for a musical community to evolve. The networks that I developed as part of my thesis work utilized a wide range of social approaches, topologies and architectures – synchronous, sequential, centralized and decentralized. There are a number of design elements and considerations that are instrumental for maximizing the benefits of each of these approaches and for creating meaningful social interactions. One important tool for improving the system's coherency without compromising the interdependent collaboration is the use of multiple modalities for conveying the interaction to players and audiences. Visual elements such as computer graphics or lighting as well as tactile reinforcement for the interaction can help portray the interaction even in the most immersive synchronous systems. Another important design consideration that is instrumental for facilitating meaningful musical collaborations is the balance between goal-oriented and abstract exploratory interaction. Here, too, there is a continuum between the two extremes, with pros and cons for the various solutions. Extreme goal-oriented activities are more likely to draw players toward an involved participation since games and competitions have a strong motivating appeal. However, whether it is a competition against peers or a self driven game with a tangible reward, extreme goal-oriented systems bear the risk of marginalizing the musical value of the activity as players might be more interested in achieving the reward than in the musical outcome of their actions. Extreme abstract systems, on the other hand, may allow participants to concentrate on the music, but they must offer alternative compelling features that would keep players engaged over time. The last design consideration that I will discuss and evaluate in that regard is the scale of the system and its ability to adjust to groups of different sizes. The networks that I developed as part of my research use a variety of synchronous and sequential, centralized and

decentralized approaches as well as a variety of scales and multimodal interaction conveyance enhancers. I will address their respective advantages and shortcomings in the Assessment Section. Below is a summary of the main concepts and balances that will be addressed when assessing aspects of collaboration, group interaction, social dynamics, and teamwork in the network.

- The level of interdependency – How interdependent is the network? How immersive and coherent? What approach does it take for achieving a balance between coherency and immersion? What musical parameters have been used for autonomous and interdependent interaction?
- The balance between goal-oriented and exploratory interactions – Does the musical activity in the network have a goal or a reward? How does the goal encourage teamwork and social dynamics? Does it distract players from concentrating on the music they create?
- The effectiveness of multi modalities – What additional media does the network use and for what purpose? Do visual and tactile reinforcements help in portraying the interaction to players and audiences?
- Scalability – How well does the network adjust to different numbers of participants while maintaining the intuitive nature of the interaction?

4.2 Learning and expression

The second assessment criterion addresses my goal to provide a meaningful learning experience for participants through expressive high-level musical controllers that are designed to bridge between thoughtfulness and expression. Here, too, I am interested in exploring a number of design approaches and to assess their advantages and drawbacks in creating intuitive and expressive learning processes. One of

the most important goals, in that regard, is to keep the learning floor as low and intuitive as possible while pushing the ceiling towards rich and challenging domains. As described before, some novice systems lower the learning floor by allocating significant parts of the musical creativity to the computer, basically providing the user with simple triggering mechanisms. This approach, however, would significantly compromise the ability to provide a high learning ceiling. A more promising direction would be to keep the creative and expressive power for the player while using the computer as a guide for deeper musical aspects through algorithms for high-level control. These algorithms should provide novices with an intuitive access to lower level musical concepts while facilitating challenging learning curves that are accommodated to players' cognitive skills and abilities.

Other related balances that should be maintained in that respect are the role of the designer or the composer in determining the musical outcome. Some systems only allow players to modify pre-composed musical material which usually leads to coherent and organized musical results but significantly compromises players' creativity, learning, and expressive power. On the other extreme, we can find systems that provide full freedom for players to generate their own materials, but also risk cacophonous musical results and incoherent interaction. In general, we can define systems on this axis as those that center on improvisation vs. those that focus on interpretation. This categorization bears some correlation to the skills and pre-possessed knowledge that are required by the systems. Improvisatory systems would aim mostly at highly skilled participants and would provide them with more freedom to generate their own musical material. Interpretatory systems would aim more at the untrained and would be more likely to provide them with pre-composed material for manipulation.

The interconnected systems that I developed present a variety of heights for learning floors and ceilings, a number of curve shapes for learning (some require a full week of workshops and others just minutes of

experimentations) different algorithms for high-level control, various requirements for pre-existing skills and knowledge, and several approaches for the composer's and the system's role in defining the musical outcome. In the Assessment Section, I will evaluate these criteria in an attempt to define the most effective balances for facilitating expressive and thoughtful learning experiences. Below is a summary of main concepts and balances that will be addressed when assessing aspects of learning, expression and creativity supported by the network.

- Learning content and adaptability – What can be learned by interacting with the network?
- Pre-requirements and depth – How low is its learning floor and how high is the ceiling? What are the pre-required skills and knowledge for having a meaningful experience? What sorts of learning curves does the network support?
- Balance between thoughtfulness and expression – What software and hardware solutions are used for providing intuitive access to thoughtful musical interaction? How effective are these in addressing both intuitive introduction and thoughtful contemplation?
- balance among composer, computer and performer – How important a role do the performers have in determining the musical output? How do the composer and the system help players achieve coherent and interesting musical results without comprising players' contribution? Is the network improvisational or interpretational in nature?

4.3 Composition

The last aspect by which I plan to evaluate the networks relates to the more abstract goal of creating worthy music that would engage and touch listeners and general audiences. This is a more difficult criterion to assess

due to its subjectivity. Moreover, not all the networks that I developed would qualify to be assessed by this criterion as some of them focus solely on players' experience. The role of the music in these participant-oriented systems is to enhance the social interaction and facilitate learning, and not to be a valuable product by itself. In general, the more important the role of the composition and the listeners in the network, the more difficult it is to maintain meaningful learning, expression and collaboration for the players. Other design considerations that are relevant for assessing the musical value of the interaction are the role of pre-composed materials in the interaction and the freedom granted to players to generate their own material. When addressing this criterion I will try to describe the compositional thinking that motivated my work, my personal and subjective assessment of the music, and the artistic establishment's regard for the musical outcome. Below are the main concepts and balances that will be addressed when assessing aspects of composition, music and artistic value. (These assessment criteria will not be relevant to systems that focus mainly on performers' experience and learning, such as the Musical Fireflies for example.)

- The compositional goals and intentions – What were my artistic motivations and what were the tools that were used to achieve them?
- My personal subjective evaluation of the music – What do I like about the music, performance and the composition? What can be improved?
- The artistic establishment's regard for the music – Was the music performed and evaluated publicly? How well was it received by peer musicians, performers and audiences? What did the critics think?

5 Thesis work

In this section I will describe a set of three IMN projects that I developed in an attempt to address my research goals. Each project presents different focuses and balances in regard to the design challenges and assessment criteria that I posed. This section will be descriptive in nature while in the following Assessment Section I will present a critical and reflective compression between the different systems and approaches. The first project that I describe here is the “Squeezables” which began as part of my Masters work but was presented, performed, and published in the framework of my Ph.D. work. This project sparked my original interest in IMNs and is instrumental for presenting the full range of approaches that I have taken in my research. The next project that I describe in this section is the “Musical Fireflies” which took an utterly different direction for learning and group collaboration and is the most education-oriented project in my work. The Musical Fireflies triggered the development of a much larger scale project, the “Beatbugs,” which is the last IMN presented in this section. As part of Tod Machover’s Toy Symphony, the Beatbug project was presented in several venues in Europe and the US featuring week long workshops, open houses, and public concerts.

5.1 Squeezables

The Squeezables (Weinberg 2001), which was developed in collaboration with Seum Lim Gan, is a computer music instrument that allows a group of players to perform and improvise musical compositions by using a set of squeezing and pulling gestures. The Squeezables, comprised of six squeezable and retractable gel balls mounted on a small podium (see Figure 32), was the first instrument that I developed in an effort to addresses challenges in interconnected group playing. It also addressed a number of hardware and software challenges in electronic music interface design by providing an alternative to asynchronous interactions with discrete musical controllers, allowing multiple channels of high-level continuous and simultaneous input. As a test case for a particular high-



Figure 32. The Squeezables

level control and interdependent mapping scheme, I created a notation system for the instrument and wrote a musical composition for three players.

Electronic musical controllers that use keys, buttons, knobs, and menus tend to favor sequential operations by the performer, which promote a sequential manipulation of musical parameters. While serving an effective and practical function, such asynchronous interactions might also impair flow and musical expressivity when they are not supported by a more immersive, large-scale musical approach (Langer 1942; Weinberg 1999). Previous solutions for these shortcomings focused on digital modifications and enhancements of traditional acoustic instruments (Chadabe 1997), as well as utilizing novel sensing techniques, such as electric field sensing, for musical applications (see for example, Paradiso and Gershenfeld 1997). These approaches usually fail to provide an immediately responsive malleable interface that can offer novices and children a tactile and immersive musical experience. One of the main challenges in designing the Squeezables, therefore, was to provide "organic" and intuitive control (using soft squeezable materials like fabric, foam, and gel), and capturing multiple players' synchronous and continuous hand gestures. The Squeezables is also designed to provide an alternative to the low-level analytical reasoning that is often required by asynchronous and discursive controllers. By mapping the sensed gestures to algorithmic imitation of high-level musical concepts such as stability and contour, the instrument offer expressive and intuitive musical experiences without requiring a long learning process, virtuosic performance skills, or an analytical knowledge of music theory. As a synchronous multi-player instrument, the Squeezables provides an infrastructure for addressing challenges in interdependent group playing. Wired and wireless communication systems as well as Internet-mediated interactions can enhance the traditional experience of musical group playing by providing players with new ways of manipulating each other's music in real time. Such an enhanced interaction can lead to new creative and expressive experiences that may give a new perspective to the prospect of group collaboration. As

discussed before, high levels of interdependency might lead to uncertainties regarding the control of participants over their specific roles. On the other hand, simple one-to-one mappings might obscure the immersive interdependent experience from beginners who are not yet skilled enough to construct such a collaborative sensation on their own. The main challenge faced by the Squeezables was creating effective network topologies using the appropriate musical parameters that would provide enhanced yet controllable musical experiences for novices as well as professionals, and to find a well-balanced equilibrium between full autonomy on the one hand and complex interdependency on the other.

5.1.1 The instrument design

Both hardware- and software-oriented issues were considered when addressing these goals and challenges. The hardware design centers on developing sensing techniques that provide soft, malleable, and synchronous interaction, whereas the software design focuses on developing mappings for high-level musical control for interdependency.

Hardware and Sensing – The Squeezables is comprised of six squeezable and retractable gel balls that are mounted on a small podium. Each player around the podium can simultaneously squeeze and pull the balls (one ball per palm) and control a set of musical parameters based on the algorithms described below. The combination of pulling and squeezing allows players to employ familiar and expressive gestures to manipulate multiple synchronous and continuous musical channels. As a whole, the Squeezables instrument supports up to twelve simultaneous input channels of squeezing and pulling. Several materials have been tested to provide a soft, organic, and expressive control for these continuous gestures. The first versions of the instrument used a cluster of soft foam balls that flaked easily and lost their responsiveness over time. For the final prototype, soft gel balls were chosen. These proved to be robust and responsive, providing a compelling sense of force feedback control owing to the elastic qualities of the gel. Buried inside each ball is a 0.5 x 2.0 cm plastic block covered with five pressure sensors that are protected from the gel by an elastic

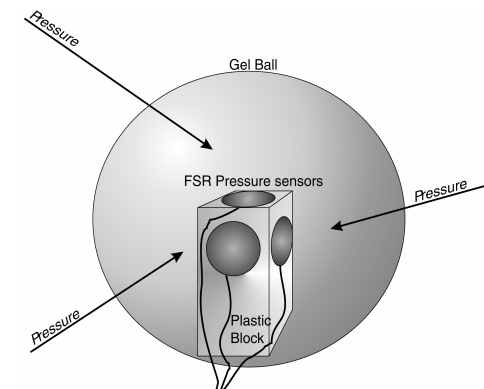


Figure 33. The sensor block. The combined signal from five force-sensing resistor (FSR) pressure sensors indicates the level of squeezing around the ball.

membrane (see Figure 33). The analog pressure values from these sensors are transmitted to an Infusion Systems I-Cube digitizer and converted into MIDI format. The pulling actions are sensed by a set of six variable resistors that are installed under the table. An elastic band connected to each ball adds opposing force to the pulling gesture and helps retract the ball back onto the tabletop. Here, too, a digitizer converts the analog signal to MIDI and transmits it to the computer.

Software Mapping Principles – The digitized data that represents players' pulling and squeezing gestures is transmitted to a Macintosh computer running a Max patch that maps the digitized data into musical output. In an effort to explore the concepts of expressive high-level control and interdependency, I constructed the Max patch with two main goals in mind. The first was to provide a mixture of low-level and high-level control that would allow an intuitive and expressive interaction with the instrument. The second goal was to create a setup that allows for a well-balanced interdependent collaboration among a group of players to enhance their interaction while maintaining the system's coherency. To better evaluate the instrument's high-level control implementation, I decided that some of the mapping algorithms should control relatively low-level musical parameters. For example, the Synth ball employs a one-to-one mapping between the squeezing and pulling of the ball and the modulation rate and range of two low frequency oscillators, respectively. In other balls, higher-level algorithms such as musical "stability" were used. Parameters such as register's height, interval size, dissonance level and rhythmic variance were entered into a probabilistic "Stability" lookup table to be manipulated by pulling and squeezing the Arpeggio ball. The more this ball is squeezed and pulled, the more "unstable" the arpeggiated sequence becomes (see details below). Based on studies that show the perceptual significance of melodic contour (see Schmuckler 1999, Sloboda 1985) I decided to allow players to control these high-level percepts by manipulating the pitch curve and not the actual pitches. Such an algorithm was implemented in the "Melody" ball. (A detailed mapping description is given below.)

My approach for addressing the coherency-immersion tension, on the other hand, involves an automatic system that provides different kinds and levels of interdependency to the different players based on their musical role. This Democratic-Synchronous-Centralized “Flower” topology also utilizes weighted gates, as described below. The balls, therefore, are divided into five accompaniment balls and one melodic soloist ball. The accompaniment players are provided with fully autonomous control so that input from other balls cannot influence their output. However, their output is not only mapped to the accompaniment parameters (described later) but also significantly influences the sixth Melody ball. While pulling the melody ball controls the pitch contour of the melody so that the higher it is pulled, the higher the melody becomes, the actual pitches as well as the key velocity, duration, and pan values are determined by the level of pulling and squeezing of the accompaniment balls. This allows the accompaniment balls to affect the character of the melody while maintaining a coherent scheme of interaction among themselves. In addition, squeezing the Melody ball controls its own timbre and manipulates the accompaniment balls' weights of influence over their own output in an interdependent reciprocal loop (see Figures 34 and 35).

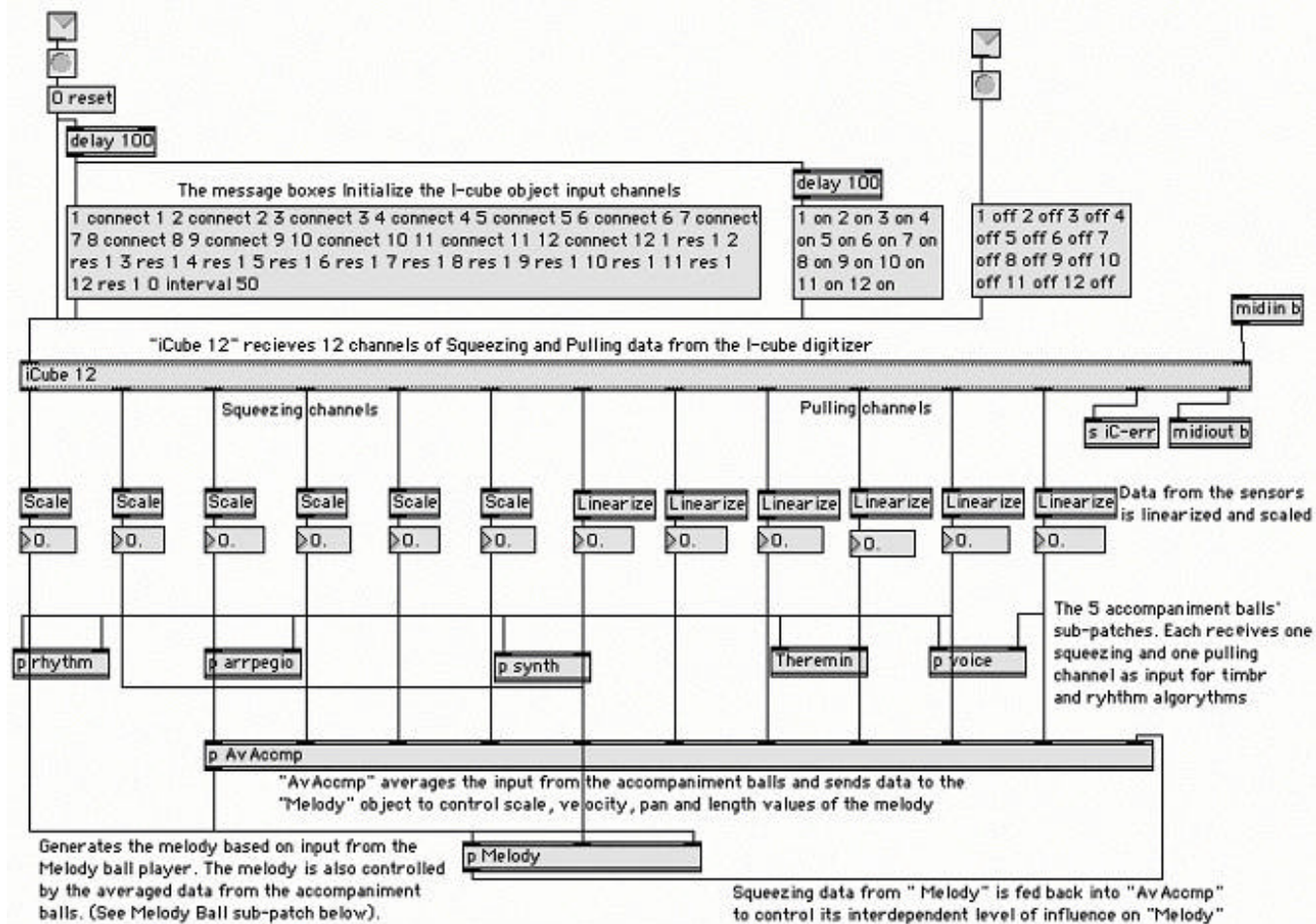


Figure 34. The Squeezables main Max patch. Data from squeezing and pulling the balls is sent to six different sub-patches (one for each ball). The output of the five accompaniment balls is also sent to the Melody ball sub-patch through the AvAccmp object. Input from the Melody ball is sent to manipulate AvAccmp in an interdependent loop.

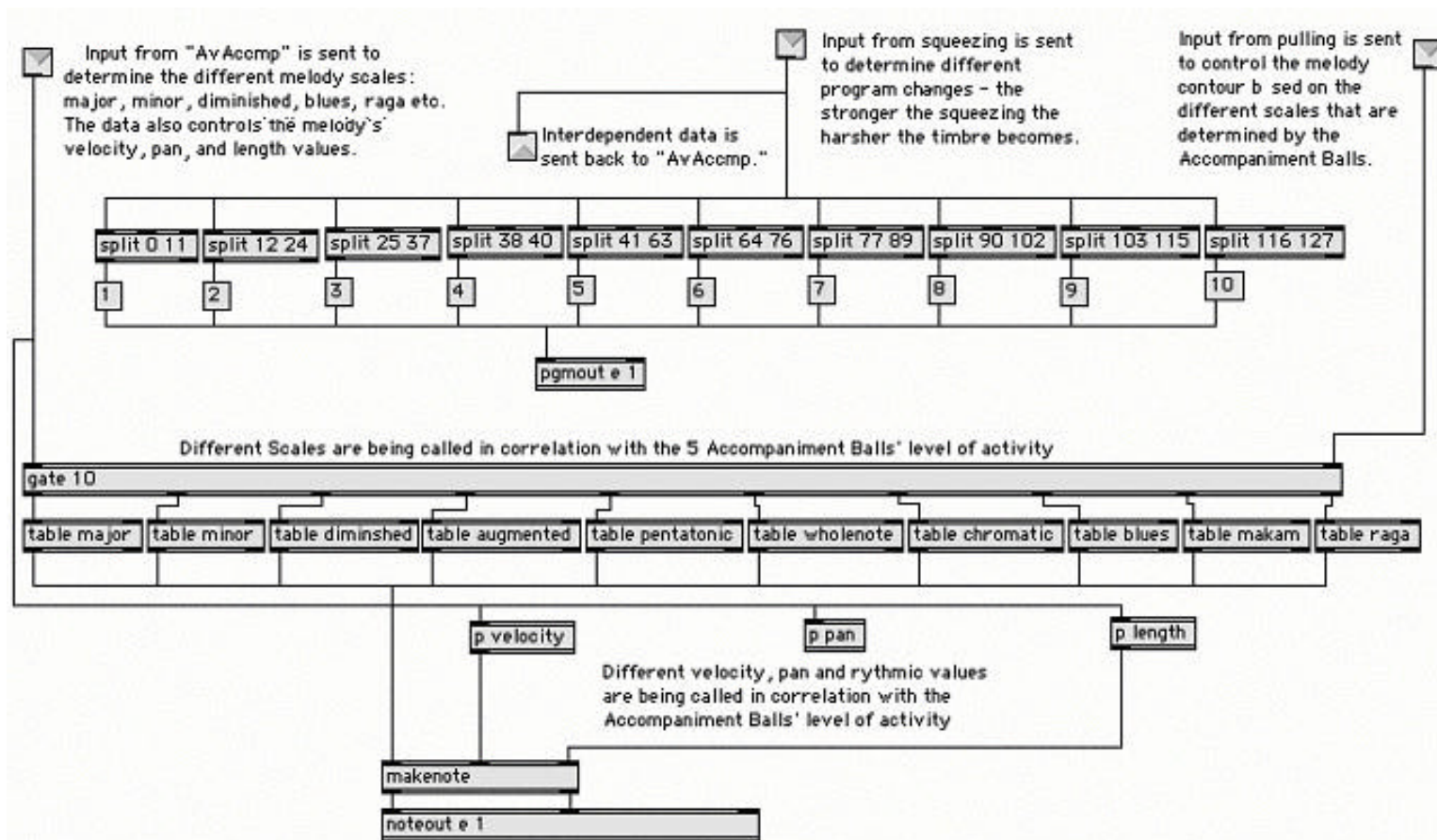


Figure 35. The Melody ball Max Patch. Data from the AvAccmp object is mapped to different scales as well as key velocity, pan, and length values, which are then applied to the melody. The Melody ball player merely controls the melody's contour and timbre.

Mapping details - Three of the accompaniment balls, named "Synth," "Voice," and "Theremin," mainly control timbre-oriented parameters on a Clavia Nord Lead 2 Virtual Analog synthesizer. These balls highlight low-level one-to-one control and serve as a balance to the other higher-level control accompaniment balls, named "Arpeggio" and "Rhythm," which are mapped to control intervals and rhythmic parameters in Steinberg's Rebirth software program. The Melody ball controls contour and timbre parameters on an E-mu Ultra-Proteus sound module. Each ball employs a separate mapping scheme, which I now describe in greater detail. The Synth ball manipulates the timbre of a sound that was digitally programmed to imitate the quality of an analog synthesizer. Pulling the ball controls the range of a low-frequency oscillator mapped to amplitude, while squeezing the ball controls the oscillator's frequency. The higher the ball is pulled and the harder it is squeezed, the higher the oscillator's range and rate become, respectively. A derivative of the sum of pulling and squeezing is also mapped to other timbre factors such as envelope parameters, amount of frequency modulation, and noise frequency. The Voice ball manipulates filter parameters of a sound with singing voice qualities. Pulling the ball changes the filter frequency so that the more it is pulled, the higher the frequency becomes; squeezing it increases the filter's resonance amount. Because these two parameters are interconnected, they create a wide spectrum of timbres. In addition to controlling timbre qualities such as filter and noise parameters, the Theremin ball includes the added functionality of direct pitch and amplitude-level manipulation, similar to the functionality in Leon Theremin's classic instrument (see, for example, Darreg 1985). The higher the ball is pulled, the higher the gliding pitch becomes; the harder it is squeezed, the louder the sound gets. The Arpeggio ball is designed to explore notions of musical tension and stability as discussed above. The default state for this ball is an arpeggiator based on thirds that ascend and descend in a constant quarter note pulse. The higher the ball is pulled, the higher the probability that an unresolved dissonant interval may occur. When the ball is retracted, the probability for dissonant intervals is reduced and the ones that do occur are more likely to be resolved. The tonality for these manipulations is determined in real time by the current scale of the Melody ball. Squeezing the Arpeggio ball manipulates the rhythmic variation so that the harder it is squeezed, the more likely it is for

faster rhythmic values to occur. The ball is also mapped to the pitch of accented notes, such that the harder the ball is squeezed, the higher the pitch of the accented notes becomes, and the higher it is pulled, the louder the accents get. A derivative of the sum of squeezing and pulling is also mapped to the frequency of directional changes in the arpeggio, so that the higher levels of activity with this ball result in more frequent changes in directionality. The Rhythm ball centers on the manipulation of high-level rhythmic variations. The higher the ball is pulled, the more irregular the rhythmic values of a pre-recorded sequence become. This action controls the probability for half, quarter, sixteenth, and thirty-second note values. The harder the ball is squeezed, the higher the probability is for triplet rhythmic values (triplets, quintuplets, and septuplets). Furthermore, the sum of pulling and squeezing the ball controls timbre variations via filters, modulators, and envelope parameters, as well as subtle manipulations of tempo. As described above, pulling the Melody ball controls the pitch contour of a scale selected interdependently so that the higher it is pulled, the higher the melody becomes. Squeezing the ball cycles through a list of sampled timbres so that the harder it is squeezed, the more percussive the sound becomes. The ball is mapped to instrumental sounds such as piano, xylophone, marimba, glockenspiel, and woodblocks, among others (see Figure 36.)

5.1.2 The composition and performance

As a case study for the instrument's sensing and mapping design, I composed a musical piece for the Squeezables for three players. The 6'25" composition is based on the functional and timbral tension between the accompaniment balls and the melody ball that is being shaped by them. Special notation was created for the piece, as shown in Figure 37. Two continuous graphs are assigned for each one of the six balls. One graph indicates the level of squeezing over time, and the other indicates the level of pulling. In certain parts of the score, the players were encouraged to improvise and to give their own interpretation to the written music. While paying close attention to their personal contribution as well as to interdependent influence, the players modified the written piece and created several other versions (see Figure 38).



Figure 36. Interdependent pulling and squeezing interactions between the Melody ball player and the accompaniment ball players.

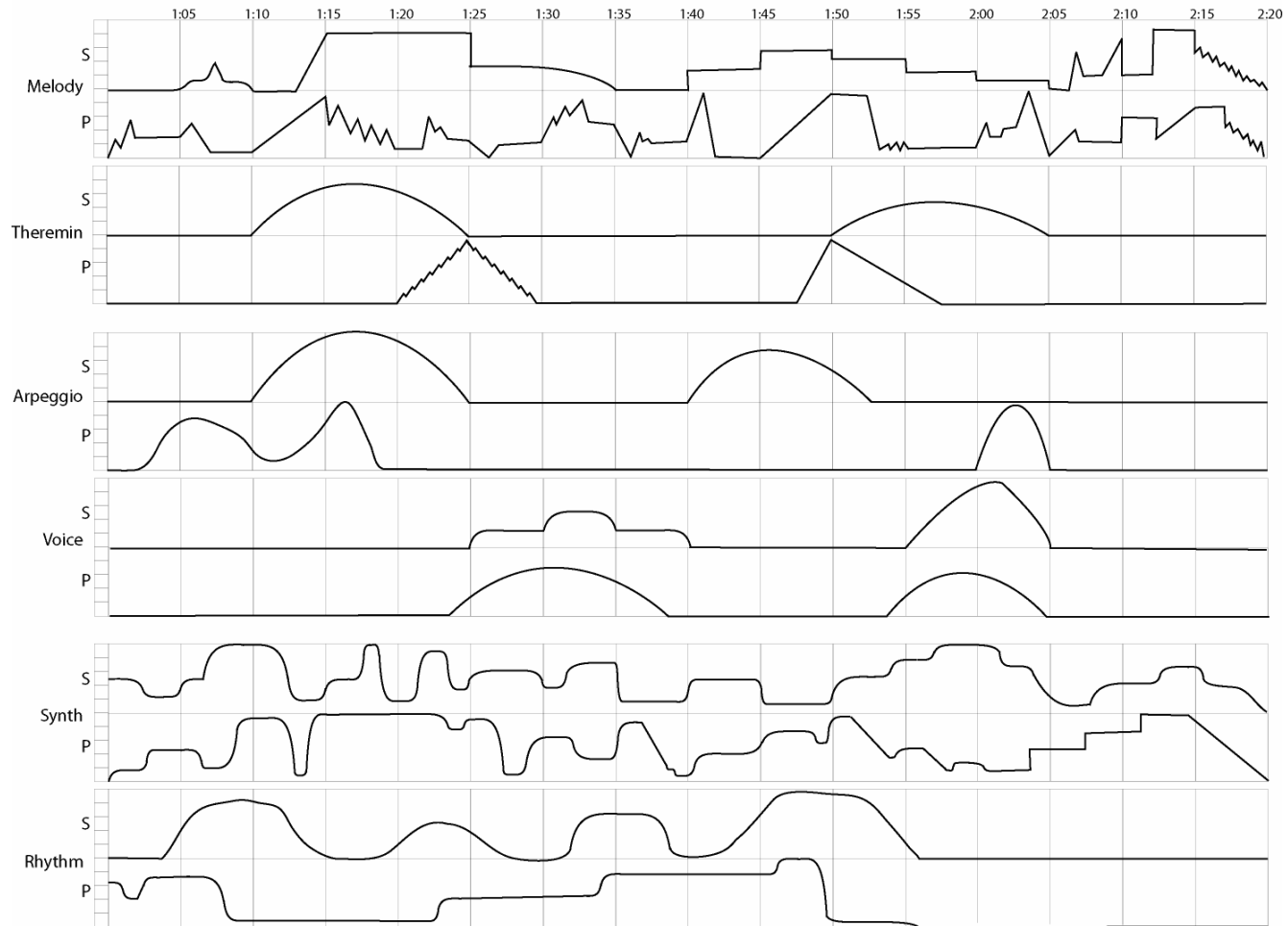


Figure 37. The composition notation includes twelve separate level/time graphs for pulling and squeezing for each ball.

5.1.3 Discussion

The process of writing and performing the composition served as a useful tool for the evaluation and criticism of the design decisions that were made. In addition, I conducted several discussions with novices and professionals who experimented with the instrument, which led to some interesting findings. Children and novices were more inclined to prefer playing the balls that provided high-level control such as contour and stability manipulation. They often stated that these balls allowed them to be more expressive and less analytical. Professional musicians, on the other hand, often found the high-level control somewhat frustrating because it did not provide them with direct and precise access to specific desired parameters. Some professionals complained that their personal understanding of high-level controllers such as stability is different than the ones that were implemented in the instrument. Both novices and professional players found the multiple-channel synchronous control expressive and challenging and the pulling and squeezing gestures comfortable and intuitive. These gestures allowed delicate and easily learned control of many simultaneous parameters, which was especially compelling for children and novices. The organic and responsive nature of the balls was one of the features that were mentioned as contributing to this expressive experience.

Several interesting findings came from evaluating the effort to implement a democratic interdependent topology. In general, players enjoyed controlling other players' music as well as being controlled by their peers, stating that this provided a new layer of creativity to their experience. However, some comments were made in regard to the democratic-heterogeneous nature of the interdependent connections. As was mentioned above, the Melody Ball players (functioning as the leader) received the highest level of external input and were capable of controlling only some interdependent aspects in the other balls. The accompaniment balls (as “the people”), on the other hand, received little external input, but

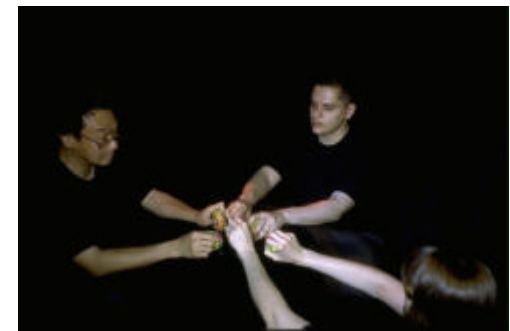


Figure 38. The Squeezables performance.

their output substantially influenced the melody. In providing different players with such varied sorts of interdependent control, I attempted to prevent confusion and enhance the coherency of the experience. This division, however, led to significant variations in players' responses to and enjoyment of the various balls they played. Some Melody Ball players described their experience as “a constant state of trying to expect the unexpected,” which required a high level of concentration in an effort to create meaningful musical phrases. One player's impression was that she was not playing the instrument, but rather the instrument was “playing her.” When the accompaniment players were particularly experienced and skillful, playing the Melody Ball felt to another player almost like “controlling an entity that has a life of its own.” This unique experience was intriguing and challenging for some but difficult and frustrating for others.

Playing the accompaniment balls led to a completely different experience. Here, players could control and manipulate the melody without being significantly influenced themselves. However, full collaboration with the other accompaniment players was essential to create a substantial effect on the melody, because the melody's algorithm used the sum of the signals from the other five balls. In a manner similar to chamber music group interactions, body and facial gestures had to serve an important role in coordinating the accompaniment players' gestures and establishing an effective outcome. Such collaborations turned out to be especially compelling for children, who found the accompaniment balls social, intuitive, and easy to play with. Some complaints were made, however, regarding the difficulty for a specific player to significantly influence the melody without trying to coordinate such an action with the other accompaniment ball players. Some players felt that this interaction prevented them from expressing their individual voices.

A number of technical drawbacks were identified as well. The main hardware-oriented drawback came from the implementation and installation of the pressure sensors inside the balls. Although the gel balls

turned out to be more robust than the foam ones (they kept their original shape and did not flake), they did tend to leak when sensors were inserted into them. Later versions of the instrument utilized other sensing techniques such as conductive fabric and capacitance sensing, such as in the Musical Shapers that were used in the Toy Symphony (Machover 2002.) The applications for these later versions, however, focused on single player interactions and therefore will not be discussed in this thesis.

5.2 Musical fireflies

The Musical Fireflies (see Weinberg 1999) were developed in collaboration with Jason Jay and Tamara Lackner in an effort to address some of the drawbacks and weaknesses that were identified in the Squeezables. As discussed above, the Squeezables' purely continuous and synchronous interdependency led to confusion for some participants and viewers. The hierarchic / democratic architecture and the lack of goal-oriented activities left some players frustrated, hampering the educational value of the experience. The Musical Fireflies were developed to explore the extreme alternatives to these design decisions, promoting constructionist learning through a decentralized network topology, sequential interactions, game-like activity and discrete control. The Fireflies were designed to introduce mathematical concepts in music such as beat, rhythm and polyrhythm without requiring users to have any prior knowledge of music theory or instruction. Through simple discrete controllers players can tap rhythmic patterns on the Fireflies, embellish them in real time by adding rhythmic layers, synchronize patterns with other players in a group, and trade instrument sounds. The Fireflies motivate collaboration and social play as interaction with other players increases the richness and complexity of the music, providing players with the goal of collecting their peers' timbres.

Table 2. Squeezables vs. Fireflies: a comparison table of the motivations, social approaches, topologies, focuses and controllers of both systems.

	Squeezables	Fireflies
Motivations	Collaboration, music	Learning, rewards
Social approach	Democratic	Decentralized
Topology	Flower (synchronous, centralized)	Stairs (sequential, decentralized)
Control	Continuous	Discrete

As part of traditional musical education systems, conventional tools and methods for learning rhythm tend to separate the figural intuitive experience from the formal analytical internalization of the material (Gardner 1983.) When learning rhythm in the formal mode, certain important musical aspects, which came naturally in the figural mode, may be temporarily hidden when the learner tries to superimpose analytical knowledge upon their felt intuitions. The Musical Fireflies utilize a variety of techniques to help bridge this gap. By employing digital interaction and wireless communication, the Fireflies provide players with expressive hands-on rhythmical experiences that can be easily transformed into an analytical and formal exploration. For a single player, the instrument can provide figural as well as formal familiarization with musical concepts such as accents, beats, rhythmic patterns and timbre. During the multi-player interaction, a wireless network is formed, which can provide novices, as well as professional musicians with an interactive group experience that leads to a deeper internalization of advanced musical concepts such as the correlation between monorhythmic and polyrhythmic structures.

The development of the Musical Fireflies is informed by the notion that interaction with digital physical objects, also known as digital manipulatives, can enhance learning (Papert 1980, Resnick et al., 1996, Turkle et al., 1992). The Musical Fireflies extend these studies to the musical realm by providing an expressive experience that can draw players into a meaningful musical exploration without requiring an exhaustive learning process, virtuosi performance skills, or an extensive knowledge of music theory (Weinberg et al. 1999, Weinberg 2000). Access to and manipulation of LOGO code for customizing the Fireflies also provides a basic and friendly introduction to MIDI programming and electronic sound. Advanced players can therefore deepen their learning experience by reprogramming the Fireflies and adjusting their functionality to match personal musical interests and abilities.

The Fireflies are designed to provide simple and immediate musical interaction for single players at preliminary stages, which leads to richer, more complex musical experiences when multiple players, using multiple instruments, interact with each other. Through infrared communication, players can synchronize their instruments with other Fireflies, which are programmed in the same manner by other participants and enhance their simple, monorhythmic patterns into a polyrhythmic experience. It is in these synchronized social interactions that the further mathematical aspects of the toy arise where individual users can obtain an understanding of their rhythmic patterns in relation to the group's composition (Handel 1984.) Players can further explore their individual contribution to the group by trading their instrument sounds with their peers. This can be helpful for the perceptual separation of the timbre-oriented characteristic from the numerical aspects of the patterns.

5.2.1 Modes of interaction

Interaction with the Musical Fireflies occurs in two distinct and sequential modes – the single player mode, where players convert numerical patterns into rhythmical structures, and the multi-player mode, where collaboration with other players enhances the basic structures into polyrhythmic compositions. In the single player mode each Musical Firefly is equipped with two default drum sounds that are operated by two buttons. When a Firefly is first turned on, it awaits the input of a rhythmic pattern from the buttons. The left button records an accented beat and the right button records a non-accented beat, using the same drum timbre. After two seconds of inactivity, the Firefly plays back the entered pattern in a loop, using a default tempo of $\frac{1}{4}=80$. This activity provides players with a tangible manner of entering and listening to the rhythmical output of any numerical pattern they envision, which leads to an immediate conceptualization of the mathematical-rhythmical correlation. For example, Figure 39 depicts the playing of the numerical pattern 4 3 5 2 2:



Figure 39. A pattern of accented and non-accented notes as played BT the Musical Fireflies. ● = Accented note played by the left button ○ = non accented note played by the right button

During playback, players can input a second layer of accented and non-accented notes in real-time, using a different timbre. Each tap on a button plays a beat aloud and records its quantified position so that the beat becomes part of the rhythmic loop. Pressing both buttons simultaneously at any point stops the playback and allows the player to enter a different pattern.

In the multiplayer mode, when two Fireflies that are playing different patterns using different timbres "see" each other (i.e., when their infrared signals are exchanged), they automatically synchronize their rhythmic patterns. (A similar interaction occurs when the firefly insects synchronize their light pulses to communicate in the dark). This activity provides participants with a richer, more complex rhythmical composition and allows for a fun and interactive introduction to polyrhythm. For example, Figure 40 depicts how a 7 beat pattern played by one Firefly player and a 4 beat pattern played by another player diverge and converge as the patterns go in and out of phase every 28 beats, the smallest common denominator:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
7/4	●	○	○	○	●	○	○	●	○	○	○	●	○	○	●	○	○	○	●	○	○	○	●	○	○	○	●	○	○
4/4	●	○	○	○	●	○	○	○	●	○	○	○	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Figure 40. Two patterns (7/4 and 4/4) played by two Fireflies divergence and convergence as they go in and out of phase every 28 beats

While the two Fireflies are synchronized, players can also initiate a "Timbre Deal" in which instrument sounds are traded between the devices. Pressing either the left or right button trades both layers of the accented or non-accented timbre respectively. Each Firefly continues to play its original pattern but with one button triggering the two new timbres that were received in the timbre deal. This provides players with a higher level of musical abstraction since they now can separate the rhythmical aspect of the beat from the specific timbre in which it is being played. Because the Fireflies network is richer after the interaction (i.e., each instrument now contains four different timbres) the system also encourages collaborative play where players are motivated by trading, collection and playing games by sending and receiving different timbres from different Fireflies.

5.2.2 Hardware and software

The Firefly's casing is made of a 7.5''x5.5''x2.5'' 3-D printed fabrication, which is designed to be held with both hands while tapping the top-mounted buttons (see Figure 41). The buttons are connected to two A/D converters on the embedded "Cricket" (Martin 1999) – a tiny computer that is responsible for the musical algorithms. The Cricket, which is mounted at the front of the Firefly, is based on the Microchip PIC series of microprocessors. It can receive information from a variety of sensors and is equipped with an infrared system that allows for communication with other Crickets. The Cricket is programmed in a dialect of the LOGO programming language. Application programs can be downloaded to the Cricket via its infrared communications port, allowing players to easily rewrite and download applications and data to the Firefly. The entered rhythmic patterns are converted into musical messages using Cricket LOGO general MIDI commands. These are sent through the Cricket's serial bus port to the "MidiBoat" (Smith 1999) – a tiny General Midi circuit, which supports up to 16 polyphonic channels, 128 melodic timbres and 128 percussive timbres. The audio from the MidiBoat is then sent to a top-mounted speaker.

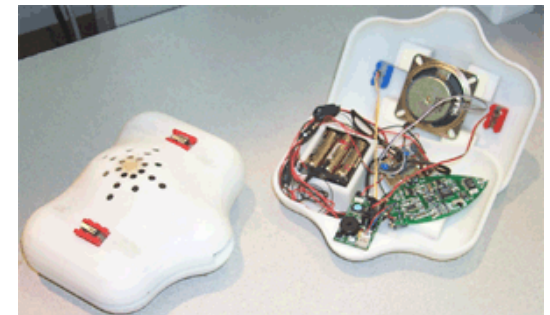


Figure 41. Two touch sensors on each Firefly are connected to a central microprocessor with infrared capabilities, which also serves as a driving force for the MIDI board, amplifier, and speaker. Each Firefly requires a power source of 6 AA batteries.

5.2.3 Discussion

Several challenges were addressed in the process of designing a musical interaction for bridging the gap between the figural and the formal learning modes. One of the main challenges was to balance between the simplicity of operation and the depth of the musical interaction, between allowing for an intuitive and expressive activity and providing a meaningful educational experience. In order to address this challenge I tried to design a varied and rich infrastructure that would apply to a variety of players, located in different places on the figural-formal axis. The Fireflies, therefore, allow novices with little formal education or experience to experiment with stand-alone simple patterns using a single layer of rhythm. The instruments can also accommodate more advanced users, who can play with complex multi-layered interdependent patterns as well as reprogram their instruments using LOGO. My ultimate goal was to encourage players to advance from the simple basic interaction toward the rich, enhanced, and interdependent experience.

Certain compromises were required in order to bridge between formal and figural musical aspects. For example, it was decided that the Fireflies would not capture the exact timing and rhythmic values of the entered taps. Rather, the algorithm merely records the sequence of accented and non-accented beats and plays them back in a default tempo. Although figural thinking would probably find exact rhythmic playback more intuitive and expressive, it seemed that flattening the tempo would provide a better ground for comprehending the polyrhythmic network collaborations, especially for children and novices. It was for this reason that the Fireflies do not allow the input of rests. While it is clear that the addition of rests could have provided a richer, more musical experience, experiments with a software-based version of the application showed that in the multiplayer mode, players found it difficult to formally comprehend the polyrhythmic interaction. I faced a similar problem when deciding about the ideal value for the default tempo. For two-line rhythm patterns, a

fast tempo sounded less mechanical and more compelling to listen to than a slow tempo. However, when the Fireflies played their patterns too fast it became impossible to follow the divergence and convergence of different patterns in the multiplayer mode. We hope that the tempo chosen ($\frac{1}{4} = 80$) serves as a reasonable compromise between these two extremes.

Constraining the number and complexity of the input devices in the instrument was crucial for maintaining the balance between simplicity and depth of interaction. Only two discrete buttons and no continuous controllers were installed in an effort to provide players with a simple, elegant and easy-to-learn interaction. This also served as a clear control experiment for the pure continuous input devices of the Squeezables, and later led to the discrete-continuous hybrid solution of the Beatbugs (see below). The decision to use a simple input scheme required pushing a considerable amount of interaction onto two buttons while streamlining the software design. For example, instead of having a third mechanism to stop the rhythmic patterns, Fireflies were designed so that pressing the two existing buttons simultaneously would stop the music.

The network topology, as well, served as an extreme alternative to the Squeezables' architecture. With no central hub and very simple identical rules applied on a number of self-contained nodes, the Fireflies topology can be seen as an attempt at a decentralized architecture. Without the synchronization operation, however, the network had a strong anarchic element, as players entered their own material at their own time without coordinating their actions with peers, often leading to a cacophonous blend of clicks and beeps. The decentralized synchronization operation was designed to bring some order to the system with the hope that higher-level musical patterns would immerge. In order to achieve that, it was important to carefully choose the musical content for autonomous as well as interdependent operations. My challenge was to allow for interesting multiplayer interactions that would preserve the simple and coherent nature of the interaction, while leading to higher level musical outcome. Several preliminary algorithms for interdependent control (such as trading

the numerical patterns or mixing between patterns to create more complex ones) were ruled out since they led to confusion and uncertainties among players in software simulations. Finally timbre was chosen as the parameter to be traded due to its “coloring” qualities, which do not complicate the already rich rhythmical texture, especially when more than two Fireflies are involved. Trading timbres provided an educational value by helping players to separate the instrument sound from the numerical patterns while maintaining the system’s coherency.

Observations of group playing with the Musical Fireflies were conducted (see Figure 42), followed by discussions with the players. Participants were also asked to play with a Max-based software version of the application and compare their experience with the tangible interaction that is provided by the physical Firefly objects. In general, players found the concrete aspects of playing with a physical object compelling in comparison to using a keyboard and a mouse. Subjects mentioned the unmediated connection that was formed with the instrument as contributing to the creation of personal involvement and relationship with the musical application. Tapping real buttons and listening to the music coming from distinct physical sources also helped players to comprehend and follow the trading interaction in a more coherent manner than listening to computer speakers, especially when more than two Fireflies were playing simultaneously.

These observations and discussions led me to identify a number of points for improvement and further work. One of the main weaknesses of the Fireflies is the restricted interconnectivity in the system where the only interdependent act is a simple and discrete timbre-trading operation that does not provide long-lasting play value. This limited interaction led players to lose interest in the interaction after a few trades. In order to bring back the longer lasting interdependent actions that characterized the interaction in the Squeezables, a new synchronous application has to be developed, which called for adding continuous controllers to enhance the Fireflies’ simple discrete operations. A well balanced combination of

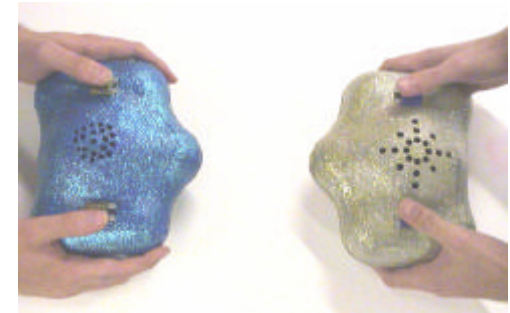


Fig 42. Two players interact with the finalized version of the Musical Fireflies.

synchronous and sequential operations, it seems, would enhance the immersive nature of the experience without compromising its coherency. Moreover, due to the limitations imposed by the line-of-sight infrared communication, the Fireflies application only allows synchronization among up to three players and timbre trading between only two players at a time. Many of the participants that I interviewed expressed their wishes to interact in larger groups comprised of several simultaneous players. But the biggest weakness of the Fireflies, in my eyes, was their disappointing musical outcome. The monotonous interlocking clicking with no time-based rhythmic values, reset, or development, although providing a unique learning experience, could not have been considered as valuable music that can stand on its own. For the next project, the Beatbugs, I decided to try and enhance the role of the music and the composition without compromising other aspects of the experience.

5.3 Beatbugs

The Beatbugs (see Figure 43) were developed in collaboration with Rob Aimi (hardware design) and Gautam Jayaraman (programming assistance.) The Beatbugs project is the most comprehensive project in my thesis work in its attempt to address all my assessment criteria – promoting social dynamics and collaboration, providing expressive high-level control for novices, providing a constructionist learning experience, and supporting the creation of worthy music. In order to achieve these goals I attempted to bring together successful elements from both previous projects and to try to avoid their drawbacks. Several balances had to be maintained by such a system. For example, I was interested in designing an interaction in which musical rewards motivate players for long and rich experiences without compromising the learning and musical value. Or systems that support democratic elements such as the separation of soloist leaders and accompaniment players, while maintaining a decentralized feeling to the experience. In order to address the downside of pure sequential interaction such as in the Fireflies, in which players have to wait their turn and might lose interest, the Beatbugs were meant to combine sequential elements for maintaining order and coherency along with synchronous elements for promoting immersion and long-term collaborative engagement. From a technical aspect, I was interested in combining continuous sensors and velocity sensitive discrete sensors in an effort to address the Squeezables’ total lack of precise control on one hand, and the Fireflies’ limited on/off button-based interaction on the other. Moreover, unlike the Fireflies which only recorded non-rhythmic sequences of accented and non-accented notes, the Beatbugs were meant to capture time-based events including rests, quarter notes, eighth notes and triplets, in a variety of velocities, in an effort to make the interaction more expressive, accurate, and musical. The Beatbugs network was also designed to support larger scalable groups and to offer pedagogical activities with a variety of learning curves for short and long term workshops. Table 3 summarizes the design balances that are addressed by the Beatbugs.



Figure 43. The Beatbugs.

Table 3. Design balances addressed by the Beatbugs project.

	<u>Squeezables</u>	<u>Fireflies</u>
Motivation	Process	Product
Social Approach	Democratic	Decentralized
Interaction	Exploratory	Goal-Oriented
Topology	"Flower"	"Stairs"
Focus	Music, Collaboration	Learning
Control	Continuous	Discrete

The Beatbugs were therefore developed as hand-held percussive instruments that allow for the creation, manipulation, and sharing of rhythmic motifs through a simple interface. When multiple Beatbugs are connected in a network, players can form large-scale collaborative compositions by interdependently sharing and continuously developing each other's motifs. Each Beatbug player can discreetly enter a rhythmic motif that is then sent through a stochastic computerized "Nerve" Center" to other players in the network. Receiving players can decide whether to develop the motif further (by continuously manipulating pitch, timbre, and rhythmic elements using two bend sensor antennae) or to keep it in their personal instrument (by entering and sending their own new motifs to the group). The tension between the system's stochastic routing scheme and the players' improvised real-time decisions is designed to lead to an

interdependent, dynamic, and constantly evolving musical outcome. Additionally, for short term workshops and concerts, I wrote a more structured composition, entitled “Nerve” in which the rhythmic patterns and their routing are pre-composed. The piece was presented in workshops in a number of venues in Europe and the US, which culminated in a series of public concerts as part of Tod Machover’s Toy Symphony project.

5.3.1 System Description

The Beatbug is a bug-shaped musical controller that has a speaker for a mouth, two bend-sensors for antennae, and a velocity-sensitive drum trigger on its top. White and colored LEDs mounted in its translucent shell providing visual feedback when the Beatbug is hit, or played through. The shell is made of clear cast acrylic that has been lightly painted on the inside to allow the light to shine through. (see Figure 44) Each bug contains a PIC microcontroller that reads the sensors, controls the LEDs, and communicates with a central system via tail-like cables that carry MIDI, trigger, audio data, and power. The physical interface of the bug facilitates a variety of play gestures and attempts to make what is happening clear to viewers and listeners. The piezo drum sensor measures when and how hard it is hit, while the two antennae allow for subtle control over different aspects of the sound. Bending the antennae causes a proportional change in the color of three LED clusters, and a ring of white LEDs flash each time the bug is hit, providing additional visual feedback to the player and audience (see Aimi 2002 for technical details).

The Beatbug processor is responsible for operating the sensors and LEDs, while a central computer system controls the actual musical interactions and behaviors. The “brain” of the system is written in Cycling 74’s MAX environment. By controlling all of the behavior from the computer, it was easy to experiment quickly with a much broader range of interactions than would have been possible if we had constantly reprogrammed the Beatbugs for small changes. Similarly, all sound synthesis also occurs on the central computer system and plays through each corresponding



Figure 44. The Beatbugs design. Two bend-sensors antennae and a velocity-sensitive drum trigger allow for entering and manipulating rhythmic motifs

Beatbug's speaker. For performances or large-scale workshops, the direct sound from the bugs was supplement with 2 and/or 8-channel PA speakers. Moving the burden of sound synthesis from the Beatbugs to the computer enabled higher quality sound and richer real-time manipulations. The tradeoff was that the bugs cannot make any sound away from the central system. For the software synthesizer, Reason by Propellerhead Software was chosen, which provided a broad palette of timbres and effects with continuous control over many parameters of the sound. (see Figure 45 for systems schematics.)

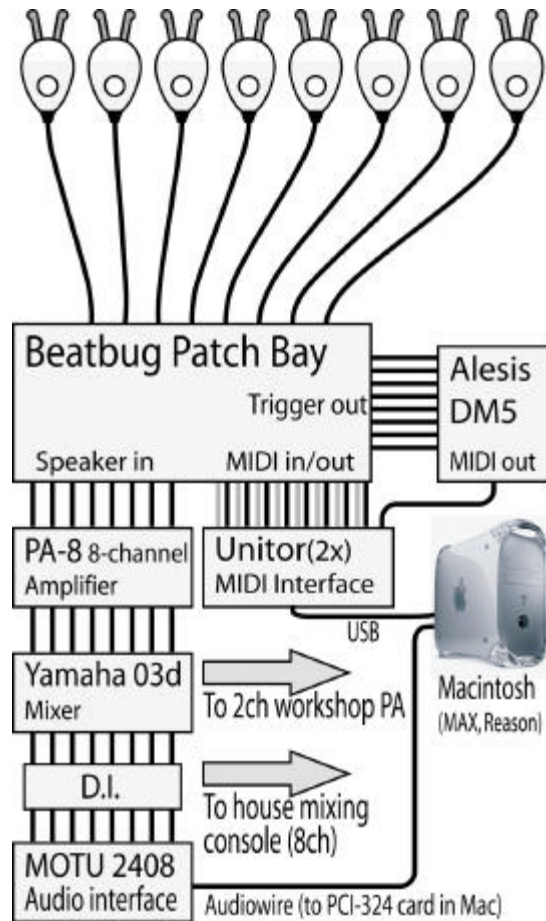


Figure 45. The Beatbug system schematics

Eight Beatbugs can be plugged into one central rack which consists mostly of standard, off-the-shelf equipment including a Mark of the Unicorn 2408 audio interface, 2 Emagic Unitor MIDI interfaces, a Lectrosonics PA-8 8-channel amplifier, an Alesis DM-5 Drum trigger unit, and a Yamaha 03d

Mixer. The only non-standard device is a custom patch box, which provides power to the bugs and converts each bug's 10-pin Neutrik Minicon connector to MIDI in, MIDI out, trigger, and audio in. The entire system, including the mixer, and the computer, fits in a single Mixer rack.

5.3.2 General system function

The Beatbug system enables children to participate in the process of making and performing music in a variety of ways. Three different interaction modes were developed for the instruments, each one offering successively more sophisticated control of the musical output. The modes, entitled "Free-Play," "Drum-Circle," and "Snake," are gradually introduced to children during a week-long of workshops.

"Free-Play" mode - This mode is designed to introduce the players to the Beatbugs. Each Beatbug in this mode functions similarly to a standard electronic drum, with its unique range of sounds for different hitting velocities. All 8 players can experiment, hitting the bugs freely, familiarizing themselves with the bugs' response and sound. The bend sensors antennae are not used in this mode.

"Drum-Circle" mode - Drum circle mode presents a more complex musical and social interaction and requires a session leader who in addition to playing a Beatbug also conducts and manages the interaction. The leader starts the session by generating a metronome beat (based on the tempo of the first four hits, or by choosing from a predefined preset.) While the metronome is playing back, the leader can enter a rhythmic pattern, drumming the Beatbug for a predefined number of bars (usually two 4/4 bars) after which the system automatically plays back the quantized recorded pattern in a loop. The quantization algorithm nudges the notes towards the closest quarter note, eighth note or quarter note triplet. When the entered pattern is played back (causing the white LEDs to flicker as each note is played), the leader can manipulate the pattern by bending the two antennae, (causing a proportional color change in the multicolor LED clusters). The left antenna continuously transforms the sound's pitch and timbre using a variety of predefined filters, low

frequency oscillators, frequency modulators, noise generators, and envelope parameters in Propellerhead's Reason Subtractor synthesizer. The right antenna adds rhythmic ornamentation to the pattern by controlling the values, length, accents, and feedback of a delay line. For example, in correlation to the level and the timing of bending, the player can ornament the pattern with notes in different values (ranging from sixteenth notes to quarter notes, including triplets), add accents to these added notes in different intervals, and control the duration of ornamentation by modifying the delay feedback. I chose to use a controllable delay line for the rhythmic manipulation since I believe that it allows players to transform the pattern while keeping its original nature. Changing or editing the pattern's notes themselves might have made the motif sound too different from the original, losing the "motif-and-variation" nature of the interaction. When the leader feels that his variation is ready, he can hit his Beatbug again, which randomly activates another Beatbug in the network. The chosen bug lights up and its player can add a complementary rhythmic motif, which is looped and quantized in the same manner. The new player can then manipulate her pattern in a similar way to the leader, controlling different timbre and rhythmic parameters. As the session progresses, more and more players are randomly chosen to add their personal patterns to the polyphonic drum circle with their own unique manipulations. The most recent bug always plays louder than the others, in order to sustain the system's clarity. An alternative Drum-Circle application allows a computer operator to activate specific bugs in order. This application was used successfully in public open houses where it was required to have more control over the exact bugs that are played by each visitor (see Figure 46). In both applications, after all the patterns are entered, the system awaits for a simultaneous hit by all 8 players (conducted by the session leader) which evenly mixes all 8 motifs to the same level (see Figure 47). Players can then independently manipulate their patterns until the next simultaneous hit, conducted by the leader, which ends the music.



Figure 46. The Beatbugs demonstrated in an open house for Boston children.



Figure 47. A simultaneous multiple-player hit generates random grouping of players in the Finale mode.

“Snake” mode - Snake Mode provides the most advanced interaction. Here, players can explore the network’s interdependency by sharing their motifs with others, and adding their own unique voice to their peers’ patterns. In this mode, after the leader enters the first pattern, it is automatically sent to be played from a different random bug. (In the concert application the order of the receiving bugs is predefined.) The receiving player can now decide whether to develop the motif further (by continuously manipulating the timbre and rhythmic antennae) or to keep it for himself (by entering and sending her own new motif to the group). If a player decides that the received motif is ready, and does not require further manipulation, he can enter a new pattern. In this case, he keeps the received transformed pattern in his bug at a soft accompaniment level, while his new pattern is sent to a new random player, who becomes the new “head-of-the-snake.” If the receiving player decides that the motif is not ready he can further transform it with the antennae and hit the bug hard to send his transformation to the next random bug. The transformations are recorded and layered in each cycle until a new pattern is entered. Each player faces the same two options when randomly receiving a motif or a transformation, until all the players have entered their patterns and kept their favorite transformations.

During this pattern accumulation phase, the “head-of-the-snake” can “conduct” the other players who already have “accompaniment” patterns in their bugs (see Figure 48). By pointing her bug to a specific player, the “head-of-the-snake” gesture the beginning of a musical dialog with her peer. The duo then pursues a short turn taking session, ornamenting their patterns in a call-and-response manner. The “head-of-the-snake” is the “conductor” in charge and can choose to switch her partner at will. I encouraged players to participate in the conducting process in an effort to balance between providing ruled-based ordered interaction (there is always one “head-of-the-snake” that controls the foreground music) and maintaining continuous and engaged participation by all players (one never knows if or when the “head-of-the-snake” would point at him to start the dialog.) This feature, which was added to the interaction later on in the



Figure 48. “Conducting” in Snake Mode

process, turned out to be very successful, bringing elements of surprise, excitement and dance-like nature to the performance (see Appendix IV, the Project Zero report). In the second “Finale” section in Snake Mode the system awaits a series of simultaneous hits by all players (conducted by the session leader) that causes random grouping between different numbers of players who can improvise with each other. The first four simultaneous hits randomly group players into duos, the next two hits randomly group them into quartets, then the whole octet, and the last hit ends the session.

5.3.3 Development process

The first **Beatbug prototype** (see Figure 49), entitled Kaossfly, was based on the design of the Musical Fireflies. It was developed in an effort to add continuous control to the Fireflies’ discrete functionality. Rob Aimi, who was responsible for the hardware design and development, connected the components of a Firefly to the touch pad and the effect processor of a commercial Korg Kaoss pad (Korg 2003.) He embedded this construction in a table-top case, replaced the Firefly speaker with a larger higher quality one, and the input buttons with switches with large flaps that can be slapped or tapped. Players could then enter their sequences of accented and non-accented notes and apply a variety of Kaoss sound effects, such as filters, pitch shifters, reverberation, low frequency oscillators, and delay line to the playback. The continuous timbre and rhythmic manipulations did not improve the limited collaborative aspect of the interaction or the monotonous nature of accented/non-accented sequences. However, the new application seemed to be engaging for players who were drawn to longer, more elaborate and expressive interaction with the instrument. As a result of these experiments, we decided to continue and improve the prototype in two stages. The first stage was aimed at improving the hardware, making the instrument smaller, lighter, and easier to carry. We also decided to improve the sound quality of the instrument as well as the discrete and continuous sensors by making them more sensitive and engaging. Only a few software modifications were introduced in this first



Figure 49. The KaossFly

stage. For the next stage I focused on rethinking the software and the interaction design, trying to utilize the new hardware for the creation of a meaningful and rich collaborative IMN experience.

The **first generation Beatbugs** (see Figure 50) were cased in a baseball-sized egg-shaped enclosure. The Kaossfly's buttons were replaced by velocity sensitive piezo sensors in an effort to provide more dynamic and expressive input. The touch pad was replaced by two resistive bend sensor "antennae" which were designed to create a creature-like identity and to allow two hands (or fingers) to continuously control two separate sound effects. In order to improve the timbre manipulation quality, we decided to generate the sound on a dedicated remote machine. It was important, however, to send the sound to be played in real-time through the Beatbug's speaker in order to provide a sense of a self contained instrument and to maintain spatialization. The first generation Beatbugs used a pic microcontroller to measure the bend sensor positions and to send this data to a MIDI interface connected to Macintosh iBook running MAX/MSP. The piezo sensors were connected to a Yamaha TMX MIDI drum module. The MIDI data, along with the drum trigger signal, speaker-level audio, and power were carried by one DB-9 cable connected to the computer through a specially designed patch box (designed by Rob Aimi). The MAX patch on the iBook received the MIDI drum trigger and sensor data and mapped them to trigger and control the Beatbugs' sounds which were generated by a Clavia Nord Rack virtual analog synthesizer. The left/right stereo outputs from the Nord Rack were connected to the two Beatbugs' speakers respectively.

Interaction with the First Generation Beatbugs was based on the same accented/non-accented pattern scheme that was used in the Fireflies and the Kaossfly with a few notable exceptions. After entering a pattern and listening to the recorded sequence, players could use the two antennae to change the speed, volume and timbre of the playback. The left antenna allowed for continuous control over the cutoff of a resonant bandpass filter and discrete control over two tempi (normal and double speed). The right



Figure 50. First generation Beatbug

antenna provided continuous control of reverberation time, volume, and the resonance of the same bandpass filter. I chose these parameters in an effort to provide a clear and noticeable audible outcome, which was especially important when both Beatbugs triggered and manipulated sounds simultaneously. It was surprising to find out that the “double-speed” function, although discrete and rudimentary, provided the most effective and engaging interaction for players. The timbre manipulations, being more detailed and subtle, were often lost in the dense texture. (This effect was also apparent in the final version of the instrument, where the rhythmic manipulations were more effective and noticeable than the timbre transformations.) In this manipulation phase, hitting the piezo sensors triggered new drum sounds that played over the looped sequence without recording. Players were able to stop the looped sequence at any moment by pressing a stop button installed on the instrument’s top, and to enter a new accented/non-accented pattern. Additionally, I experimented with providing simple interdependent control between two Beatbugs. When switching to an “interdependent mode” (using a computer keyboard shortcut) the two Beatbugs’ antennae intercrossed so that playing with one Beatbug’s antennae controlled the sound of the other Beatbug and vice versa.

The first generation Beatbugs presented some clear incremental improvements in respect to their predecessors, but as transitional instruments, they still carried some of the fundamental flaws of the Fireflies. On the positive side, the interface was easier and more inviting to play, the bend sensor antennae provided much more dynamic and interesting sound transformations, and the sound quality, in general, improved significantly. However, for single players, generating the monotonous accented/non-accented sequences without controlling velocity or rhythmic information hampered the musicality and expressiveness of the experience. Some hardware deficiencies were also apparent such as the lack of visual feedback that could have made the interaction easier to follow and better antennae implementation that would be robust and avoid hysteresis. Most importantly, it was clear that the collaborative IMN

interaction was extremely limited, providing only two players with very simple interdependent actions. In order to provide a full, rich IMN experience, an interconnected networked application had to be built that would support larger, richer, and more meaningful group interactions. These challenges were addressed in the final version of the instrument.

The main redesign decision for the **final version of the Beatbugs** was to allow for intuitive and more musical way to enter the rhythmic motifs. We were interested in allowing full-hand drumming and not just finger tapping as in the previous versions, by allowing players to hold the instrument in one hand and to tap it with the other. This led to mounting a piezo sensor on the top of an egg-like structure. With the help of Gautam Jayaraman, an undergraduate MIT student, we designed the shape of the new Beatbugs with a 3D modeling software. Pete Colao then modeled the instrument with clay, so we could experiment holding and playing it. Other hardware improvements were the addition of LED lights (see Figure 51) to better convey the interaction and more robust antennae mounting. See Aimi 2002 for more technical details.

Once we had the prototype for the new Beatbug, I started developing the software that would allow players to enter time-based rhythmic notes. I decided to introduce a metronome beat that would allow players to enter a variety of rhythmic values including rests. The risk in this approach was that the metronome beat would lead to a mechanical feeling to the music. But the introduction of timing, rests, and dynamics constituted such a significant improvement in expression and musicality that I decided that the metronome would be a worth while addition. Much consideration was directed to deciding if and how much quantization should be applied to the rhythmic motifs. I decided not to use quantization in real-time, so regardless of the drumming level of the player, when entering a pattern the sound was always heard with no latency in an effort to provide intuitive playing experience, similarly to playing an acoustic instrument. For the playback, on the other hand, I decided to use quantization and to provide a controllable coefficient that would allow setting how much a note will be



Figure 51. Clusters of color LEDs in the final version of the Beatbugs. Flushing white LED signifies the rhythmic motif. Red and yellow LED clusters signify bending the left and right antenna respectively.

pushed toward the closest predefined rhythmic value. Gautam Jayaraman designed and programmed the quantization algorithm. My plan was to allow real-time adjustment of parameters such as the metronome tempo, the rhythmic values, and quantization percentage based on the playing skills of the performers. In this scheme, more quantization would be applied for players who are out of beat, and less quantization would be applied for tight and synchronized playing. After several months of experimentations, it was decided to use a tempo of 147 beats per minute and rhythmic values of quarter notes and eighth notes for quantization. (Triplets turned out to be too difficult for children to control.) In most cases, the quantization percentage was set to 100 percent. Occasionally, when children had good drumming skills, we set a lower quantization percentages which provided a better “live” feel to the music. Another parameter that had to be decided upon was the length of the motifs that players enter before the pattern starts looping. Here too, a configurable system was designed by Gautam Jayaraman that allowed changing the number of bars from 1 (4 beats) to 4 (16 beats). After several months of experimentations we realized that 2-bar motifs worked well with children. This length was challenging to learn, yet short enough to remember. I also found out that dividing each bar to 4 beats (rather than 3 or 5, for example) was appropriate for the level of most children we worked with. For future longer-term workshops, I believe that these parameters can be adjusted and made more challenging. For example, longer motif lengths, more varied beats per bar, more rhythmic values for quantization, varied quantization percentages, and faster can make the interaction more interesting, providing a higher ceiling for learning.

As discussed above, one of the main motivating forces behind the Beatbugs was to provide expressive as well as thoughtful interdependent interaction. Since the Beatbugs are rhythmic instruments in nature, I chose “rhythmic stability” as the significant high-level percept to be controlled by one of the antennae. The parameters for the other antenna were chosen to be melodic contour and a variety of timbre transformations which were tested to be successful in previous systems. In order to provide multiple

channels of high-level of sound quality I also decided to switch the limited Nord Lead synthesizer to the highly configurable Reason software synthesizer by Propellerhead.

The most important improvement in the final version of the Beatbugs, though, was the multiplayer collaborative activity (see Figure 52). Several important decisions had to be made; the social philosophy of the interaction had to be decided, as well as the architecture and topology of the network. Details such as the scale of the system and the musical parameters in play had to be chosen and adjusted. Since I was interested in combining sequential elements from the Fireflies and continuous elements from the Squeezables, I decided to use a “Stairs-of-Flowers” architecture, which includes sections of simultaneous interdependence interaction and separated sequentially in time. The idea to add synchronous “call-and-response” interactions to the sequential motif entering came only after several other ideas (such as simultaneous motif entering) were tested and rejected since they couldn’t support the democratic/decentralized nature of the proposed system. As to the scale of the system, I chose to have an eight-node network since eight seemed like a big enough number to facilitate a rich collaborative experience, yet small enough to constitute manageable increase in comparison to the previous projects that I developed. Since I was interested in creating a decentralized system that would lead to interesting higher-level patterns, I decided that every player would play as an equal role in the interaction as possible. However, I was also interested in providing a democratic flavor to the interactions, allowing one rotated leader to conduct the call-and-response interaction.

A significant part of the development was dedicated to adjusting the musical parameters for the interaction and finding a coherent and simple narrative to explain the experience. For example, it was not clear how to allow players to conduct the three basic motif interaction actions – entering, manipulating, and sending – without creating confusion in regard to the function of hitting the Beatbugs (which could be interpreted as entering as well sending). It was also not clear what action would be used



Figure 52. Beatbugs' multiplayer collaborative activity

by players in order to keep a motif that they liked. Several interaction designs were tested, before I came up with a “social” narrative: “If you like a motif, keep it by hitting and immediately sending your own motif, which will constitute a ‘contribution to society’ in return to the motif that you kept. If you don’t like the motif, try to make it better (‘for society’) by developing it with the antennae and then hit again to send it to the group for further development.”

This narrative/interaction-design worked well with players and viewers, but it had one significant deficiency: When receiving a motif, the player had to make the decision whether to hit or to manipulate it before touching any of the sensors. If entering a motif was chosen, the player had to finish entering the full 8 beats since the antennae became inactive for the next 8 beats. At the end of the 8-beat entering phase, the pattern would immediately be sent to the next player, even if it consisted of only one note. On the other hand, if a player chose to manipulate a motif with the antennae, entering a new motif was impossible for that particular round. This feature was problematic only in short demonstrations where untrained players mistakenly touched the antennae or piezo-sensor and then could not interact with the instrument in a different manner, even if they wanted to. In the longer concert workshops, players quickly became accustomed with this functionality and did not find it problematic.

After testing the finalized collaborative interaction with peers at the Media Lab, I realized that although the interaction worked well, the composition, which was based on gradual growth in texture density, was missing an appropriate ending that would balance the “motif accumulation” section. I therefore decided to develop a “Finale” mode that would start after all players entered their motifs. The section was designed to “break” the dense texture in a sudden act and to highlight the separate motifs that constructed it. The Finale, therefore, started with a strong synchronous hit conducted by all players, which immediately muted six of the bugs and left only a pair of random players to interact with each other. The next synchronous hit highlighted a different pair and so on until all motifs were highlighted.

The texture then became denser as a set four random bugs were highlighted, then the other four and the whole octet. Players then were encouraged to invent and practice their own play patterns until the last synchronous hit ended the piece. The Finale mode helped create a more cohesive structure to the piece and added excitement and anticipation, as the players looked forward to these random surprises awaiting them at the end of the piece.

After finalizing the interaction design, I started to communicate more intensely with Kevin Jennings, our music education expert, about the best way to introduce the Beatbugs to children and about designing pedagogy and a set of workshops (see Figure 53) that would support the project. One of the first suggestions Kevin had was to add two more interaction modes that would help children familiarize themselves with the instrument's functionality before they were introduced to the interdependent collaborative experience. This suggestion led to the development of Free Mode, where the Beatbugs are simply used as electronic percussion devices, and Drum-Circle Mode, where players record and manipulate their own patterns without any sharing or collaboration. These modes were introduced in the first couple of days of each workshop and helped facilitate discussions and exercises in which a variety of rhythmic and compositional aspects were explored. The Drum-Circle Mode was also very helpful for open houses and demonstrations where I had only short time to explain the interaction to visitors.

Based on the observations that we conducted in the preliminary workshops in Boston and Dublin, we decided to make some alterations to the program. In these workshops we discovered that children found it difficult to create interesting patterns that would complement each other. As a matter of fact, most children just imitated the patterns that they already had heard. Moreover, children tended to spend too much time playing with the antennae, which lengthened the piece and hampered its structure and flow. As a result I decided to write a set of motifs for the kids to practice, as well as to set a routing scheme that would force the participants to enter their



Figure 53. Public Beatbugs workshops enlarged the exposure of the system to the general public.

patterns at designated points. We also encouraged the children to keep their motif manipulation short and spend part of it in call-and-response “conducting.” This was the final alteration of what later became “Snake Mode” or “Nerve” which was kept pretty much intact throughout our concert tour.

5.3.4 Pedagogy

In order to create an expressive and accessible IMN for children, novices, and wide audiences, it was important to create a physically engaging experience and to embed intuitive high-level musical percepts and constructionist-learning schemes in the instruments. In particular, the Beatbug were designed to facilitate learning that can be accessible to the inexperienced and untrained (providing “low-floor” learning) but is also rich and thoughtful and can intrigue and enrich even the most experienced experts (providing “high-ceiling” learning). With the help Kevin Jennings, a music education Ph.D. student from Trinity University in Dublin, I designed the Beatbugs application to support both these modalities: The system enables untrained children to easily construct their own rhythmic ideas, giving them a personal connection to an artifact while introducing them to a number of high-level musical concepts, such as motif, variation, and contour. The looping function in drum-circle mode immediately and repeatedly confronts children with the results of their work and offers them the opportunity to re-do or edit what they’ve created until they have achieved a result with which they are satisfied. The familiar bug-shaped interface is designed to facilitate engaging kinesthetic interaction with the musical product in a direct manner so that the results of physical actions are immediately apparent. At the same time the Beatbug also addressed expert musicians by allowing them to experiment with detailed rhythmic, timbre, and pitch manipulation in a novel manner that is not possible by other means.

Similarly to the previous projects, I embedded a number of high-level percept control algorithms in the Beatbugs. Here, too, I used abstract

contour manipulation, informed by studies that suggest that by providing an intuitive access for continuous manipulation of contour, we can create a bridge between the expressive manner in which novices relate to high-level musical parameters, and the more thoughtful educated manner in which an expert perceives the lower-level relationships between discrete musical parameters. By giving players the power to create and phrase rhythmic patterns and then shape them by employing melodic, timbral, and rhythmic contours with the antenna, we offer them an experience that is usually reserved for highly trained experts, one that can lead to further investigations into more advanced concepts such as timbre, rhythmic stability, and even harmony. A key aspect of the system is its inherent social and collaborative nature. In Snake mode, children manipulate motifs made by their peers. When they are required to make their own motifs, they do so in the context of motifs that have been constructed by others and already exist in their auditory environment. The system allows for smaller groups (duets, quartets) to interact and manipulate sounds together in the context of the larger structure. The balance among aural, kinesthetic and social modalities provides the children with a rich and highly immersive musical environment. Another important facet of the Beatbug system is the manner in which it gives control of the musical output to the children. While the system acts to facilitate and enable musical interaction on a variety of levels, it does not impose a final outcome but rather allows the children considerable freedom of action and expression in determining the musical result.

5.3.5 Workshops

A series of workshops were run at the MIT Media Lab in Cambridge, Media Lab Europe in Dublin, SFB Studios in Berlin, the Arc Cultural Center in Dublin, Sacred Heart public school in Glasgow, the Children's Museum in Boston and the Cooper Hewitt Design Museum in New York (see Figure 54). In the preliminary workshops at MIT (see Figure 55) and MLE, children were encouraged to compose their own rhythmic motifs and to perform them on the Beatbugs in both Drum-circle and Snake



Figure 54. A Beatbug rehearsal in Berlin. Local teachers helped overcome the language barrier.



Figure 55. A child plays a Beatbug in at the preliminary workshop at the MIT Media Laboratory.

modes. After initial exposure to and experimentation with the interface in free play mode, children were asked to improvise short motifs, initially by clapping and then on the Beatbugs. When all children were comfortable at this level, motive length and tempo were increased. Relationships between timbre and rhythm were explored to guide the children to create motifs which were appropriate and effective to a particular timbre.

In the later workshops in Berlin, Glasgow, Dublin, Boston and New York children were only introduced to the random improvisatory interaction in the first day of workshops. In the rest of the workshops children collaborated with educators and professional orchestra players in rehearsing a set of pre-composed motifs and routing schemes, towards the concert performance of the piece “Nerve” which I composed for the Beatbugs (see details below). In these performance-oriented workshops the focus was put on expressive interpretation rather on composition and improvisation. Here children’s creative input concentrated on inventing and improvising with play patterns in groups, such as the Wave (a pattern introduced by the children at the Arc in Dublin where each player plays the antennae in order to create the effect of passing energy around the circle) or a 4-by-4-battle (A pattern introduced by the children at Sacred Heart school in Glasgow, where the octets divided itself to two groups of four that battle against each other with antennae playing, see Figure 56). These patterns were adopted into the program and introduced to children in later concerts.

In all the workshops children were encouraged to listen carefully to their own motifs and those of others in the group and to develop an awareness of what elements existed in the sound environment. They then were asked to describe specific aspects of what they were hearing and to experiment by manipulating particular parameters of the sound, both individually and collaboratively. Listening skills, such as the ability to hear and perceive a single voice in a multi-part texture, were practiced by manipulating the antennae and directing the child’s attention to the part of the texture that was changing. The built-in speakers in the bugs were helpful in allowing



Figure 56. Players performing the “Battle” play pattern at the Boston performance of “Nerve” .

the children to hear their own voice in the context of the overall texture. The children also quickly embraced the conducting process and were excited to take responsibility not just for their own musical part but also for giving direction to their peers in performance.

5.3.6 Concert – “Nerve”

Chance, decentralism, system dynamics and evolving musical behaviors are at the center of the Beatbug network. But it was also important for me to bring the project to the general public in the form of open house (see Figure 57) and public concerts (see Figure 58) that produce engaging and worthy music. Maintaining this balance led me to design a more structured and confined interaction for a musical piece that I wrote, entitled “Nerve” .” In this interaction players rehearse and practice rhythmic patterns that I wrote. (see Figure 61.) The routing of pattern propagation is also pre-programmed into the system so that each player knows when s/he receives a particular pattern and whether s/he has to manipulate it or enter and send a new pattern to the network. Chance and surprise are still at play in the second movement of the interaction when the system randomly groups different players for duo, quartet and octet interactions. There were a couple of reasons which strengthened the decisions to restrict the interaction in this manner:

- Early workshops in Dublin and Boston showed that it was difficult for children to come up with unique and complementary rhythmic patterns in a short rehearsal time. Some players were drawn to repeat familiar patterns, while others found it difficult to concentrate on their peers’ patterns and complement them in an interesting manner. Since in some cities we had only 6- 8 hours of rehearsal time, it was decided to expedite the process by introducing the children to pre-composed patterns. In order to keep the improvisatory and dynamic nature of the interaction, I encouraged the children to improvise their own dynamic interpretation when entering these patterns as well as improvising their antenna manipulation and conducting procedure.



Figure 57. A public open-house during the intermission allows viewers to get a hands-on experience with the instruments.



Figure 58. A small scale public concert in Dublin.

- The Beatbugs were presented as part of Tod Machover’s Toy Symphony concert which included a number of other compositions, some for a full orchestra and electronics, others for toys and a variety of other instruments. In this framework it was important to confine the Beatbug composition in time so it would fit into the full concert. Since there is no control over the length of the free improvisation Snake mode, I decided to restrict the interaction to 4-5 minutes by predetermining the routing scheme. This also helped in creating a tighter and more coherent musical composition.

The piece “Nerve” therefore can be seen as one particular manifestation of the Beatbug network that is more interpratory than improvisatory in nature. It was written for 6 children and 2 professional percussionists in an effort to create a bridge between novices and professionals (see Figure 59). The piece starts in a manner that clearly conveys the development of each motif over time. It then gradually grows into a rich and constantly evolving polyphonic texture that is driven by the tension between the system’s chance operation and the players’ improvised decisions. Similar to the free Snake mode the piece ends in a second movement where the system randomly groups different numbers of players for improvised solo sections. First in duos, then in quartets, and finally with the whole octet, players can interdependently improvise by manipulating each other’s material. “Nerve” premiered on February 2002 at Haus Des Rundfunks Berlin as part of Tod Machover’s Toy Symphony in a concert with the Deutsches Symphonie Orchester Berlin, conducted by Kent Nagano. The European tour continued with a performance in Dublin with the Irish National Symphony Orchestra (see Figure 60) and in Glasgow with the BBC Scottish Symphony Orchestra. US performances included a concert in Boston and New York with the Boston Modern Orchestra Project conducted by Gil Rose.



Figure 59. “Nerve” for 6 children and 3 percussionists premiered in, Berlin February 2002.



Figure 60. Bowing after “Nerve” performance in Dublin

Nerve
A composition for an Interconnected Musical Network

Gil Weinberg

♩ = 147

The image displays a musical score for a piece titled "Nerve" by Gil Weinberg. The score is presented on eight staves, each beginning with a double bar line. The tempo is indicated as ♩ = 147. The notation is minimalist, featuring a variety of rhythmic and melodic motifs. These motifs include horizontal lines, vertical stems, and specific rhythmic patterns such as eighth and sixteenth notes, some with beams connecting them. A vertical line divides the score into two measures. The notation is sparse and abstract, focusing on the relationships between notes and rests rather than traditional melodic lines.

Figure 61. "Nerve" Motifs – See Appendix I for the full score.

5.3.7 Software in detail

I wrote the Beatbug application using Cycling 74's Max/MSP graphical programming language with the help of Gautam Jayaraman. In this section I describe in detail the software design for the three modes of interaction - Free Play, Drum Circle and Snake.

Free Play Mode – In the heart of Free Play mode is a Max patch titled “bug-control” in which simple connections between sensor input and sound output are made. (see Figure 62.) In “bug-control,” a “Brain” object (titled here “brainfp” for “Brain Free Play”) interprets data from the bugs' sensors and sends it to the corresponding synthesizer in Propellorhead's Reason software synthesizer through the Macintosh AIP system (see Figure 63). The data is also sent to control the bugs' LED lighting through a MIDI out command. Additionally, the patch contains mute-switches for each bug as well as a general mute switch for the whole system. This functionality was added to help facilitate the rehearsal session, preventing players from generating sound when uncalled for.

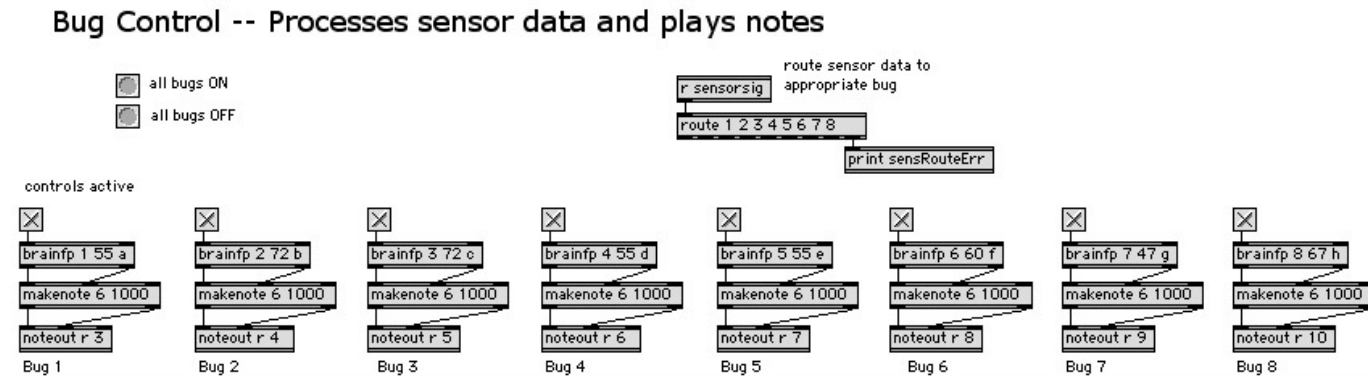


Figure 62. The “bug-control” patch in Free Play Mode – A “brainfp” object for each bug maps input gestures to generate sequences of sounds and lights.

Brain - Free Play Mode

arguments: bug number, note
pitch, bug midi channel for lights

Interprets data from bug sensors
and sends it to the synths and LEDs

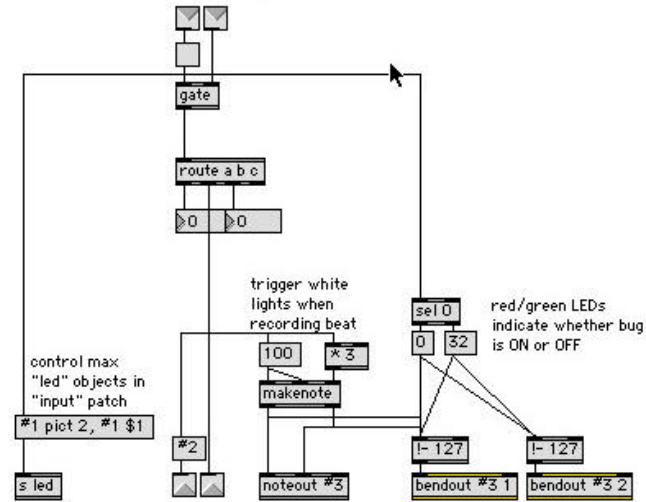


Figure 63. The “brainfp” patch in Free Play. Data from the bugs is sent to control a set of software synthesizers and LEDs.

In all three interaction modes, a patch titled “input” monitors the input activity from all eight bugs (see Figure 64). Two “slider” objects represent the bend sensor antennae for each bug, and can also be used to simulate the antenna activity through the Max graphical user interface. A “led” object represents the piezo sensor and a “piano-roll” object allows simulating hitting the bug in different velocity levels. A calibration button and a controllable offset setting allow for easy calibration of all antennae (the calibration function was written by Rob Aimi).



Figure 64. The “input” patch is used in all three interaction modes.

Drum Circle – The Drum Circle "main" patch (see Figure 65) provides a number of global functions: At the top right, a set of 4 different tempi presets allows easy switching between slow and fast tempi that are used in different levels during the workshops. (For the concert, a tempo of 147 BPM was chosen which also functions as the default value for the patch.) A set of green "led" objects at the lower left part of the patch allows monitoring the bug activity, showing which bug is active and playing. Pressing the computer keyboard numerical pads 1 through 8 activates (or deactivates) the bugs, which provides central control in demonstrations and workshops. The last major operation in the Drum Circle "mail" patch is the pattern length control. The default value for the pattern is set here to 2 bars (8 beats) but the values can be adjusted to support shorter or longer patterns as needed.

Drum Circle Mode

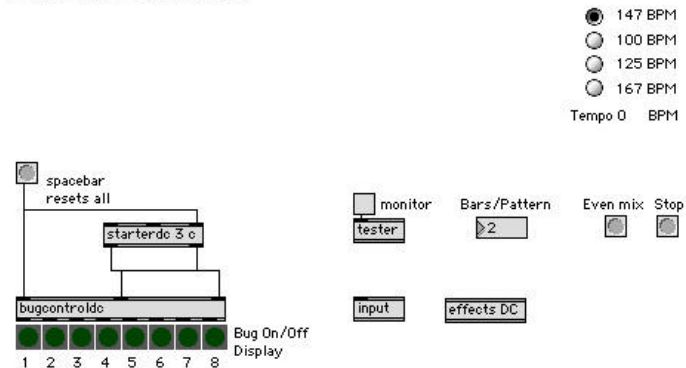


Figure 65. The “main” patch for Drum Circle mode

The “bug control” patch in Drum Circle mode (see Figure 66) is more elaborate than in Free Play mode. Here, the upper left part of the patch is dedicated to control the bug activation schemes. In the default scheme, only one bug (bug 3) is active and is ready to be played, while the other 7 bugs are inactive. This prevents the other 7 players from disturbing the session by touching their bugs when uncalled for. After entering a pattern and manipulating it, player 3 can hit the bug again in order to randomly activate one of the 7 silent bugs. When activated, the light in the randomly chosen bug turns orange to signify to its player that she can enter her own pattern and manipulate it. Bug 3's volume is then reduced to half, which allows the new player to enter her pattern as a “soloist.” After the new pattern by the new active bug is playing back, player 3, who still controls the interaction, can hit his bug again to activate a new randomly chosen bug. Again, the volume of the recent active bugs is reduced and the new randomly chosen bug plays at high volume as a soloist. In order to activate a new bug, player 3 has to hit his bug in a certain range (velocity 50-126). Softer hits will be treated as noise or mistakes and harder hits (velocity 127) will stop and reset the whole session. This process proceeds until all the bugs are active and playing.

This interaction design worked well in controlled environments such as week-long workshops, where players had time to learn the different cues and signals. In short public demonstrations, it was difficult to communicate the intricacies of the process to the visitors, and to follow the random operations of the system. For these scenarios, a second interaction scheme was designed, in which the workshop leader or an assistant used the computer keyboard to turn on and off specific bugs. This allowed for more controlled and personal interaction with the visiting participants.

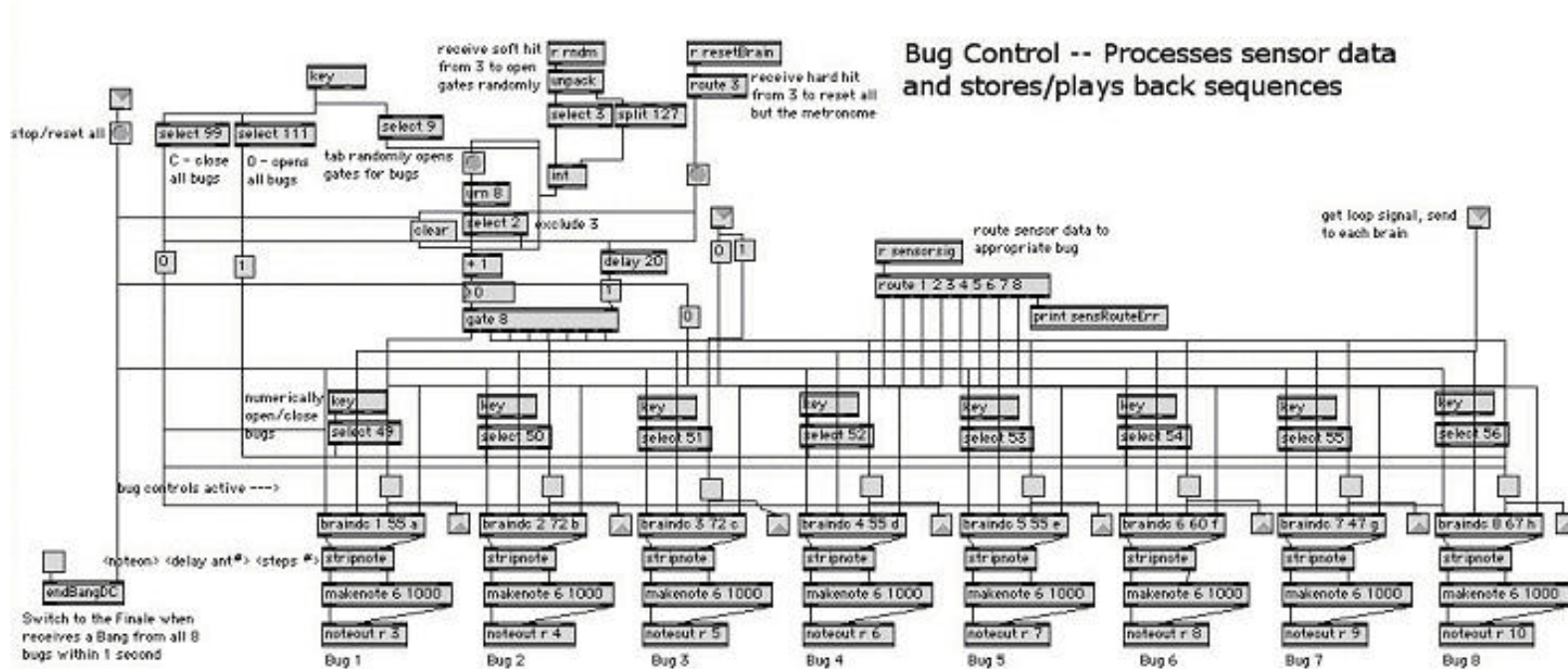


Figure 66. “bug control” patch in Drum Circle mode

The lower part of the “bug control” patch is similar to the one in Free Play mode. The idiosyncratic Drum Circle operations (recording, quantization, playback etc.) are all programmed in the Brain object, titled here – “braindc” (see Figure 67). The left part of the “bug control” patch is dedicated to recording, quantization and playing back the rhythmic patterns that are captured by the piezo sensor. The “quant” object (see Figure 68) is instrumental for facilitating these operations. Here, the right part of the patch sets the metronome and the division to measures, beats and micro-beats. The quantized data is recorded into a “coll” object based on the quantization factor, which is set at the upper left part of the patch. The “play” object plays back the quantized pattern after recording is completed. Back in the “bug control” patch, the quantized pattern from “quant” is sent to generate the sound from Reason synthesizers and to control the white LEDs in each bug, so that with each hit a flash of white light is generated. In playback mode, on the other hand, the bug stays constantly white and produces “black flashes” with every recorded hit. This functionality helps viewers and co-players to identify the “head-of-the-snake.” while getting a sense of the specific pattern at play. The middle section of “braindc” is responsible for setting the functionality of the hits, based on their velocity values. The right part of the patch is responsible for sending data from the antennae to the predetermined parameters in the appropriate Reason synthesizer. In Drum Circle mode, the antennae activity is not recorded, but rather it is sent to control the Reason sound parameters in real time in the patch titled “effectsdc” (see figure 69). Here, for each bug a “timbre” object maps data from the antennae to specific parameters in the appropriate synthesizer. The “recorder” object in this patch is not used in Drum Circle mode and will be explained in detail in the section about Snake mode.

Brain - Drum Circle Mode

arguments: # 1: <bug number>
 # 2: <note number>
 # 3: <bug MIDI channel out>

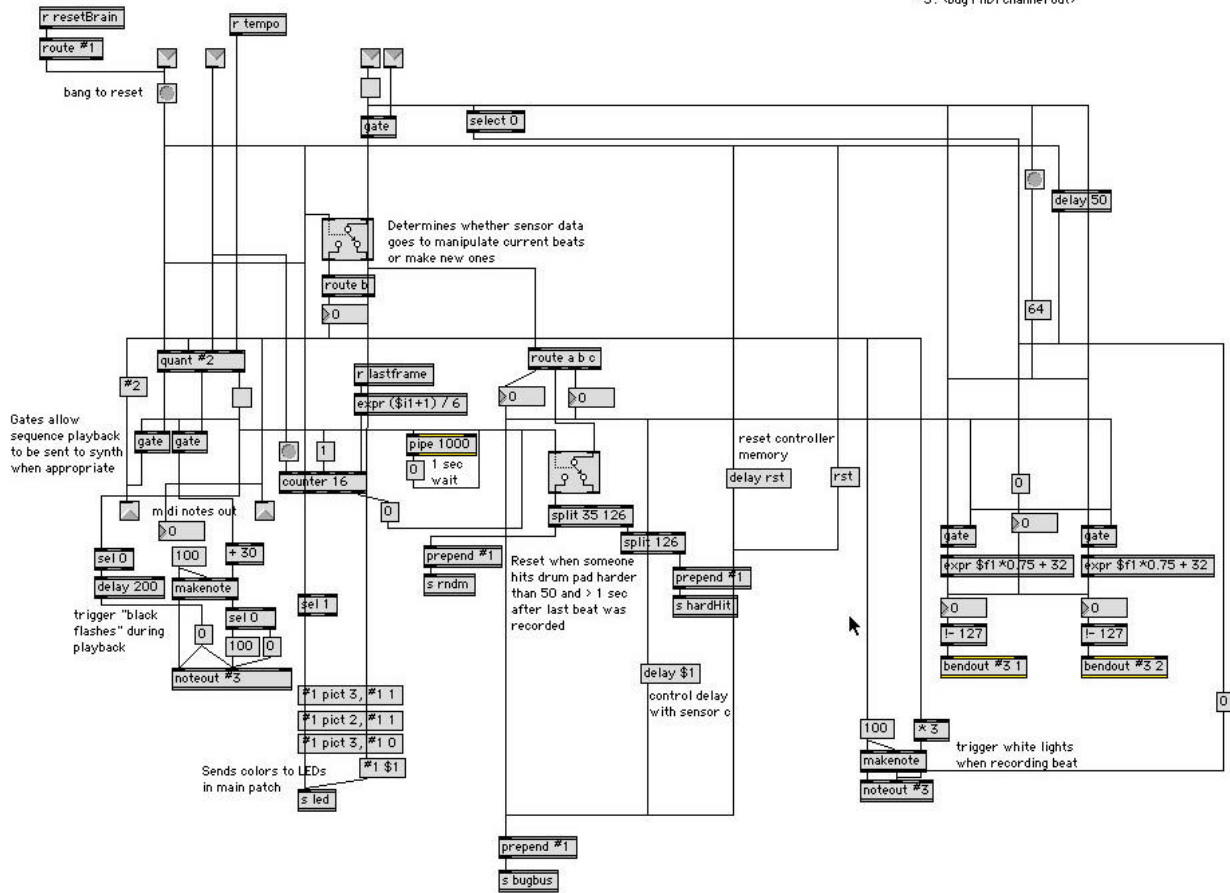


Figure 67. The “braindc” Patch – The brain of Drum Circle mode.

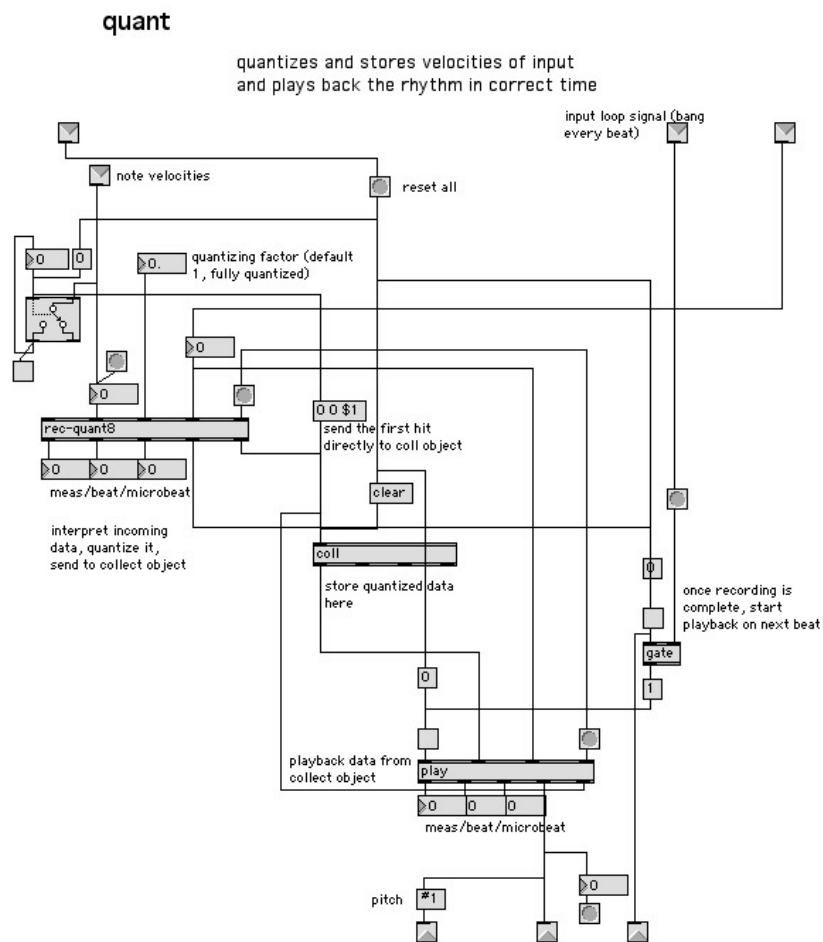


Figure 68. The “quant” patch quantizes and plays back the pattern in Drum Circle and in Snake mode.

Effects execute commands (issued by the brain)
Controllers: to adjust effects on each synth (1-8)

bugbus message format: list: <frombug> <delay> <command>
 OR list: <frombug> <command>



Figure 69. The “effectdc” patch – controls the timbre effects in Drum Circle mode

After all the players enter their patterns, the system awaits a strong hit from all bugs within an interval of one second, also known as the “multi-player simultaneous hit.” This functionality is set in the “finalebang” object (see Figure 70) where the strength of the hit can be adjusted (in the patch below it is set to 80) as well as the number of hits that will constitute a trigger. (In the patch below, as long as there are more than 3 bugs hitting simultaneously, the system switches to Finale mode.) The interaction in Finale mode in Drum Circle is simple. The first simultaneous hit brings all the bugs to the same high volume, which allows all players to interact with each other as equals. The second simultaneous hit ends the session, triggering a loud cymbal “end sound.”

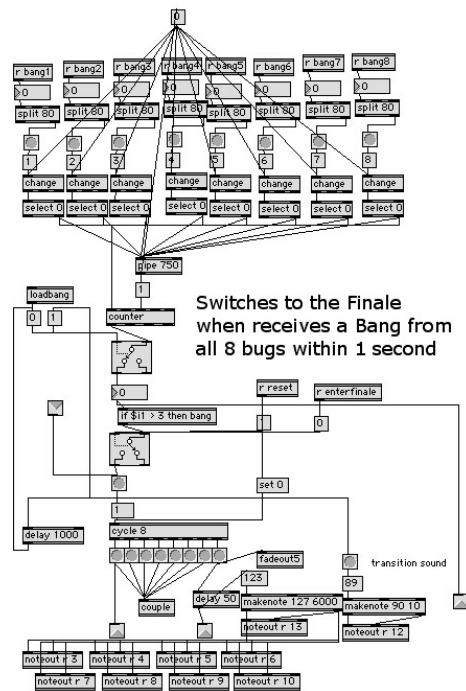


Figure 70. “finalebang” patch switched to the Finale mode in Drum Circle and in Snake mode.

Snake Mode - The main patch in Snake Mode (see Figure 71) contains a number of objects that are also used in Drum Circle mode. Some of these objects, such as “input” and “finalebang” are identical to the ones in Drum Circle. Others, such as “bugcontrol” and “synths,” have similar names, but their functionality is slightly different. Snake Mode also includes a number of new objects, such as “mixer” and “transitioner,” that conduct the collaborative interdependent interaction. In the description below I will concentrate on the new objects that are responsible for facilitating the new collaborative interaction in Snake mode.

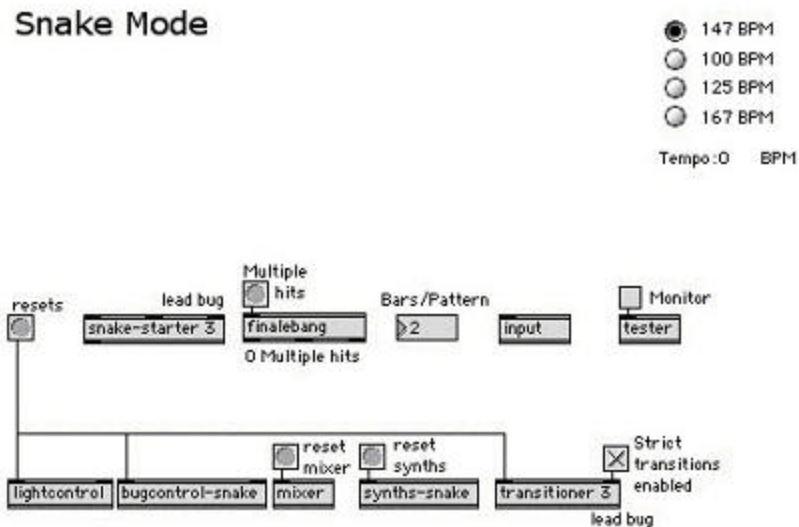


Figure 71. The “main” patch in Snake mode.

The basic operations of recording, playing back, and manipulating patterns in Snake mode are similar to the ones in Drum-Circle. The main difference in Snake mode is the facilitation of motifs routing among players, which is not taking place in the other modes. Two different

routing schemes can be used – the random routing that is used in long workshops, and the strict routing that is used in rehearsals and in the concerts themselves. I will start with a description of the random mode, which represents the original ideas of emerging musical behaviors and dynamic musical systems which motivated the development of the system. The Random Transitioner object (see Figure 72) introduces the concept of “ownerships,” conceived by Gautam Jayaraman, which allows only the “head-of-the-snake” to play or manipulate patterns at any given moment. The "random" object in the middle of the patch chooses a new random bug when the "head-of-the-snake" ends the call-and-response interaction and hits her bug. The "random transitioner" object then routes the appropriate Reason synthesizer and the LED black-flashing pattern to the new chosen bug. (Bugs that are already playing in the background cannot be chosen again.) It also plays the transition sound (a bright “ping” sound) and sends an appropriate value to the “led” object in the “input” patch to signify the new head-of-the-snake in the graphical user interface. Most of the ownership parameters are set in an enhanced Brain object, titled here “brain-snake” (see Figure 73). Routing, muting and unmuting of the appropriate synthesizer take place at the right part of the “brain-snake” patch. Processing of hit functionality (determining whether hitting data should be used for pattern entering or motif routing) is done at the middle part of the patch. Antennae data is processed in the left part of the patch. For the concert interaction, a different Transitioner was developed, titled “strict transitioner” (see Figure 74). Here a “coll” object contains a list that represents the order of the bugs in the composition “Nerve” .” For each bug, a value is set to determine whether it is available for a new pattern entering or for antennae manipulation. If a bug is to be hit, data from the antenna is ignored and vice versa.

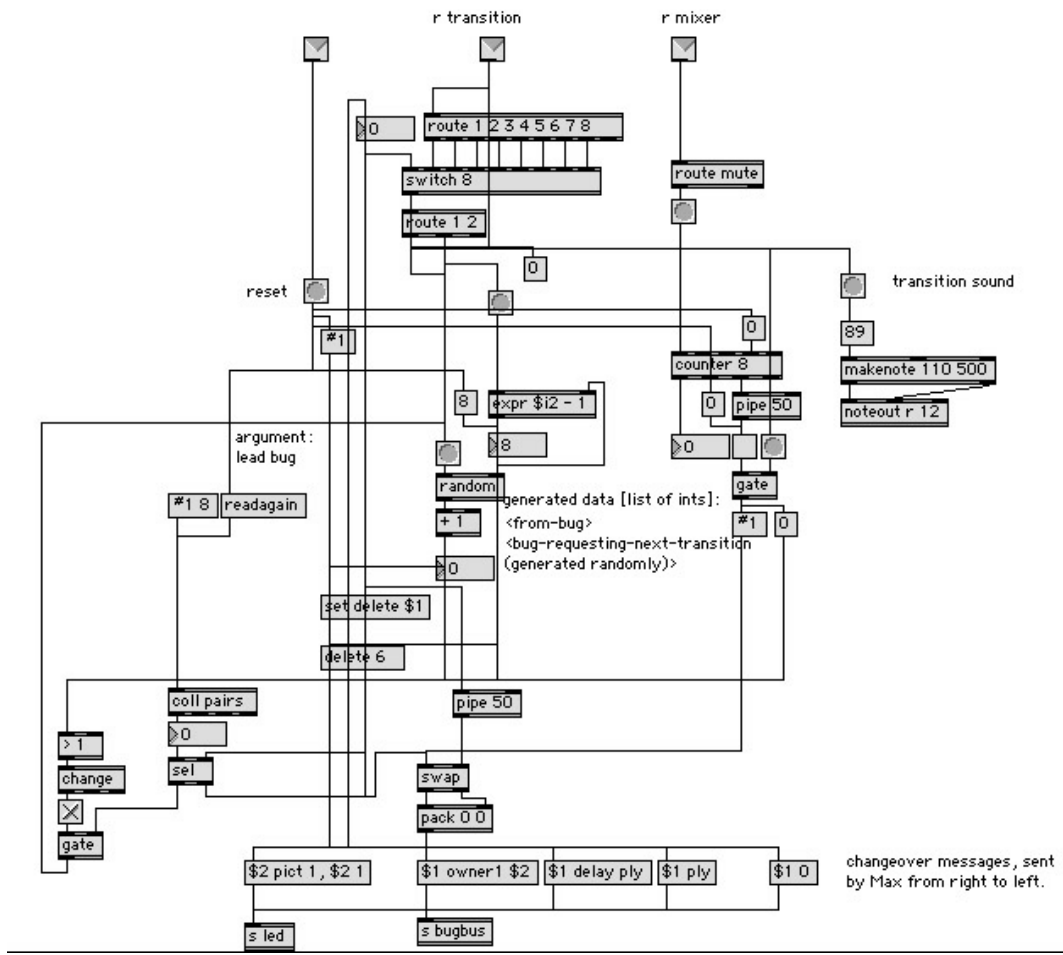


Figure 72. The "random transitioner" patch in Snake Mode

Brain - Snake Mode

interprets data from bug sensors and sends it to the mixer, the effects controllers, or the transitioner

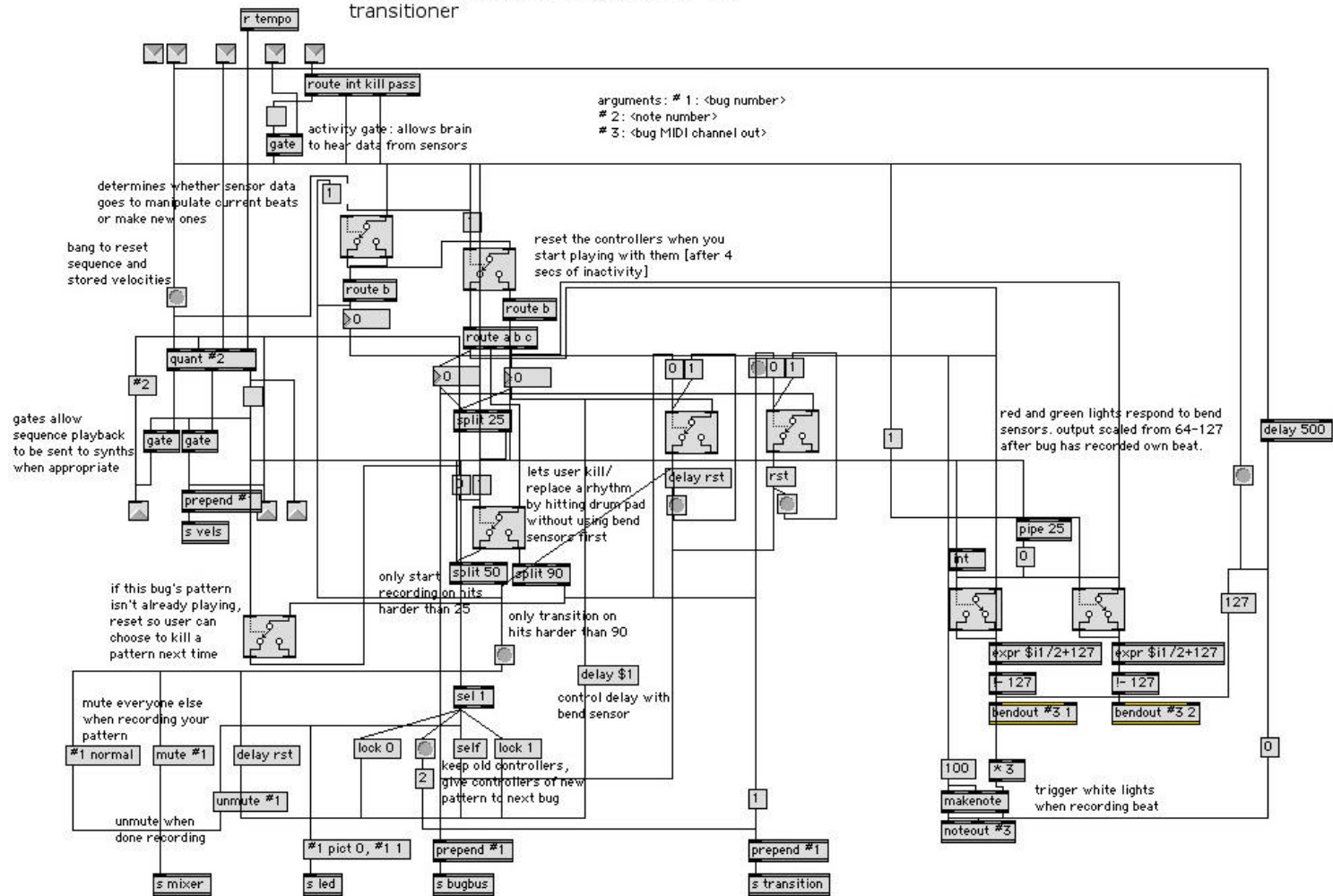


Figure 73. The “brain” patch in Snake Mode.

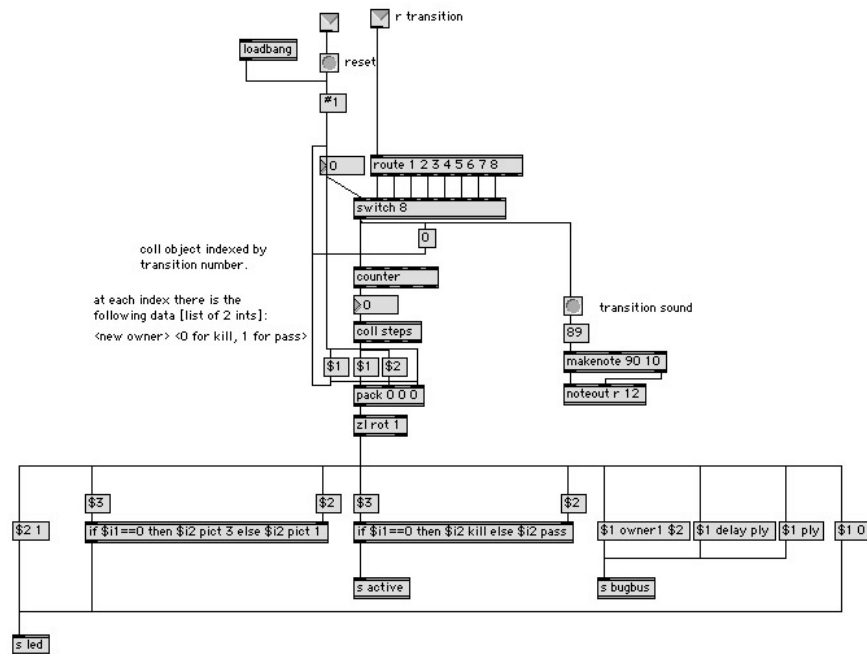


Figure 74. The "strict transitioner" patch in Snake mode

As discussed above, Snake mode allows a group of players to sequentially manipulate a single rhythmic pattern. Therefore, the timbre, pitch, and rhythm manipulation scheme in this mode are more elaborate than in Drum Circle. Here, six timbre/pitch (aka sound effects) parameters were chosen for each pattern to be manipulated by the right antenna and a sequence of rhythmic values was chosen to be applied on the pattern and controlled by the left antenna. The “synths” object (see Figure 75) regulates the sequential operation of sound effects. For each parameter, a “recorder” object constantly records the last 2 bars of antenna manipulation. When a pattern is sent to the next bug, the

“recorder” object plays back the previous 2-bar manipulation in a loop along with the pattern itself. The new player’s antennae manipulations are mapped to the next sound effect for that particular sound and are added to the previous manipulation. When a new player sends the modified pattern, the last 2 bars of manipulation will again be sent and played back in a loop from the next bug, and so on. In random routing mode, players can theoretically manipulate a pattern for more than six cycles (if no one chooses to enter a new pattern). In this case, the sound effects will cycle so that the 7th player, who decides to manipulate the same pattern, will be mapped to the 1st effect, etc. In strict routing mode for “Nerve” just some of the parameters are operative, as a pattern can be manipulated only up to 2 cycles. Figure 76 presents an example for a particular sound and the parameters that are chosen to manipulate it. The “translate” object takes any numerical range and maps it to 0-127 so that as a designer, I could find interesting sections for manipulation for each parameter and stretch them to 8 bit operation. The “ctlout” object sends the modified control data to the appropriate Reason synthesizer effect over the Macintosh AIP protocol. In some cases, as in the Flange control in Figure 69, more complex mapping schemes divide the manipulation ranges to a number of sections that are mapped to different effects.

The seventh “recorder” object for each sound (at the right corner of each synthesizer block in Figure 75) is mapped to rhythmic manipulation parameters which are controlled by the right antenna. Here, a set of delay values was chosen to be applied for each synthesizer so that the more the antennae is pressed, the louder the delayed notes are and the longer the feedback loop becomes. Similarly to the sound effect transformation, the last 2 bars of manipulation are recorded and sent to be played by the next bug. As opposed to the accumulative nature of the sound effect manipulation, touching the right antenna deletes the previous recorded manipulation cycle and the new real-time rhythmic manipulation is applied and recorded instead.

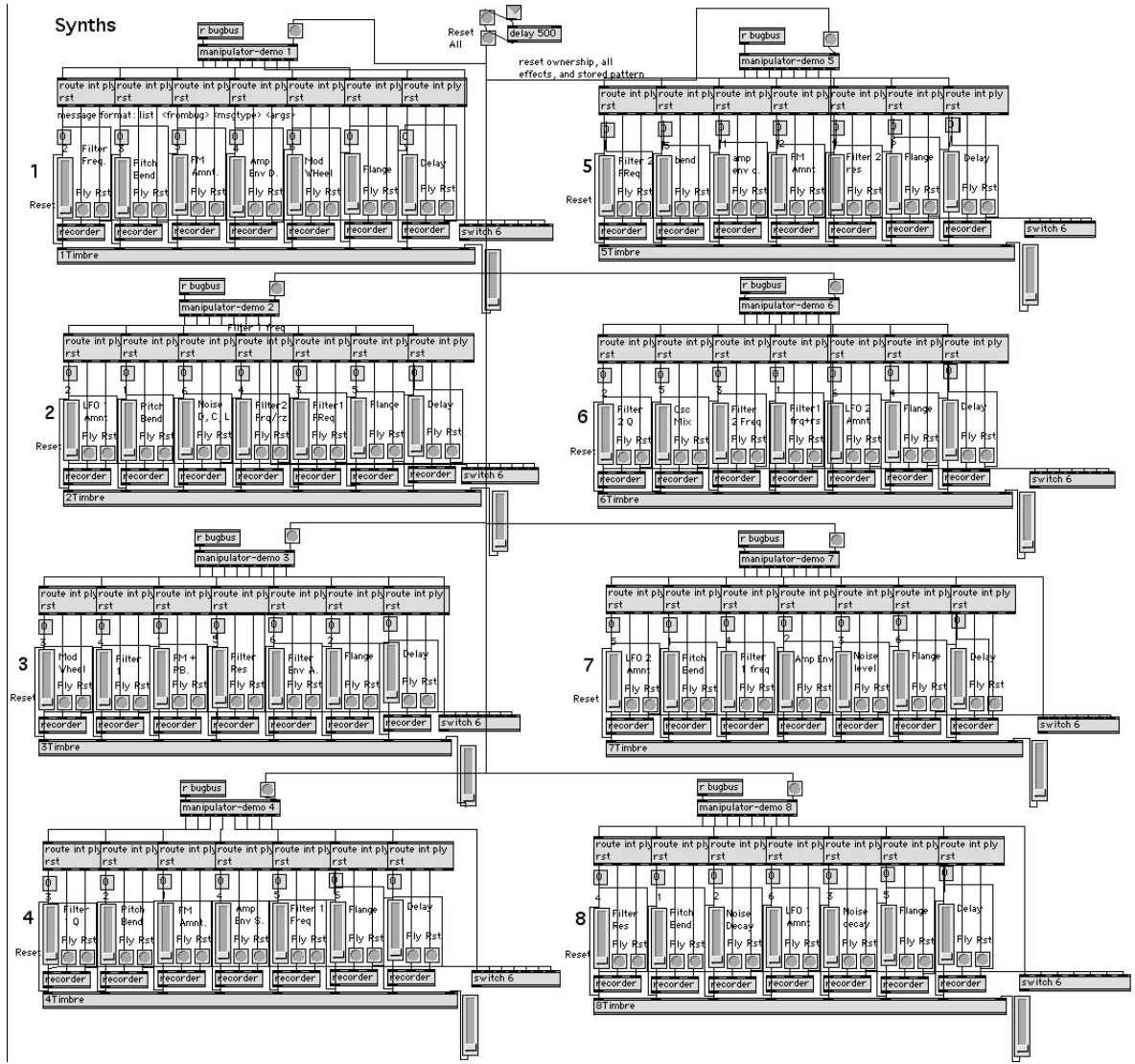


Figure 75. The “synth” patch in Snake mode

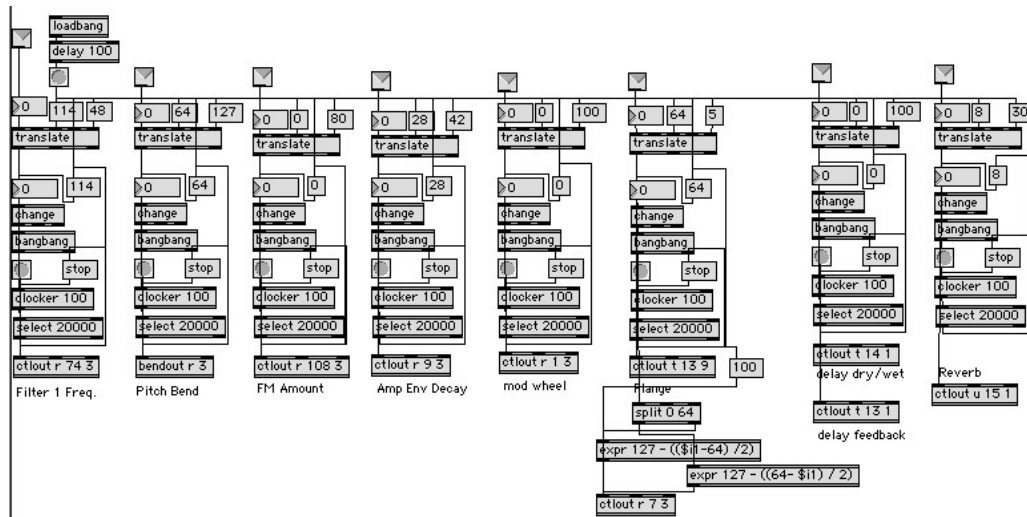


Figure 76. The “timbre” patch sends commands to manipulate the synthesizers’ sound in Reason.

The last major difference in Snake mode, in comparison with Drum Circle mode, is the interaction in the Finale. Here, a set of random decisions in the “snakefinale” object (see Figure 77) groups duos, quartets, and the whole octet for solo call-and-response interactions. The upper right part of the patch is responsible for the random operations. The “urn” object was chosen to randomize the bugs so that bugs will not be called more than once for each coupling. The patch is also responsible for constantly lighting the active bugs, and sending corresponding instructions to the Lexicon MIDI operations spot light mixer. This light mixer, which can send a spot light on the active bugs, however, was rarely used as the internal lighting of the bug turned out to be more effective and less complicated to operate.

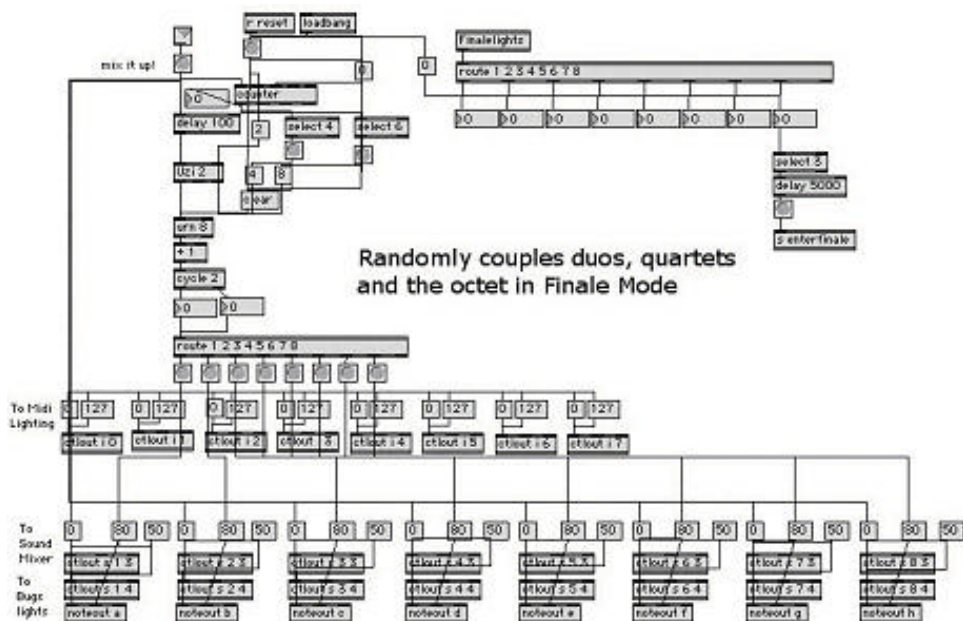


Figure 77. “snake finale” patch controls the random grouping in the Finale section

5.3.8 Sound design in detail

The Beatbugs' sounds and transformation parameters were designed with Propellerhead's Reason software synthesizer. This modular program allows for unlimited synchronous synthesizers and DSP transformations and is only constrained by the McIntosh CPU speed. The program also supports the ASIO protocol, with which it can communicate with a large number of audio interfaces, such as the eight-channel MOTU audio interface that we used for the Beatbug project. In concerts, the eight synchronous audio channels in Reason were routed through the audio interface and an external mixer to the Beatbug speakers, as well as to an additional eight Mackie monitors and stereo house PA. Due to an internal limitation in Reason, which provides only four separate auxiliaries in

each mixer, two Reason mixers had to be coupled in order to provide a fully routable eight channels of audio (see figure 78). In this setup, each synthesizer can be routed to be played through any Beatbug by receiving inter-applications commands from MAX/MSP through the IAP protocol.

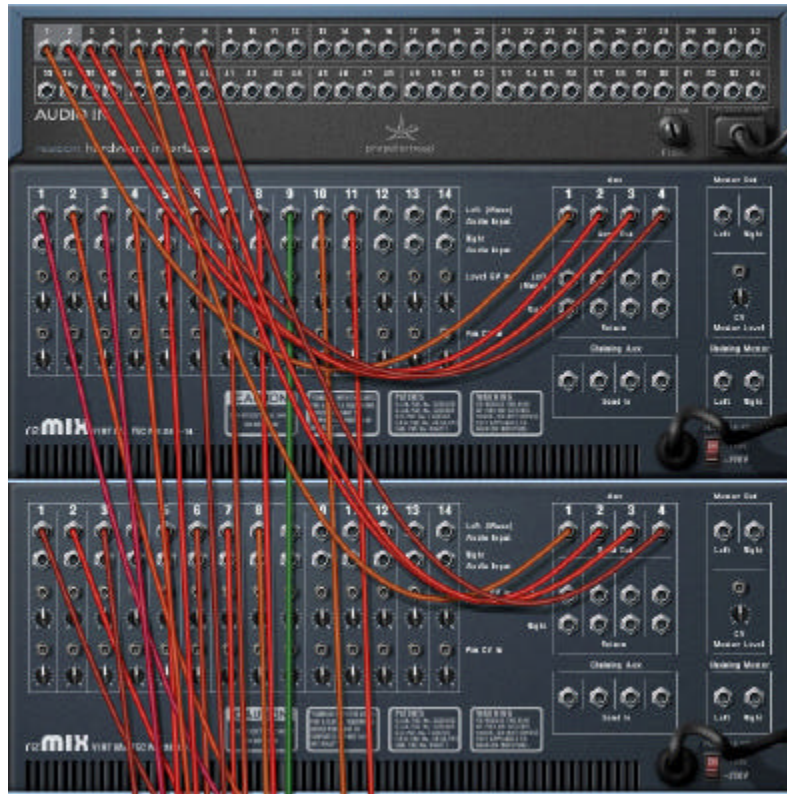


Figure 78. The back side of two eight-channel mixers in Reason that are coupled to send eight channels of audio to any of the Beatbugs through the MOTU audio interface.

In designing the sounds for “Nerve” I attempted to highlight the nature of the Beatbugs as percussive instruments, while conveying the electronic essence of the system. I, therefore, used eight Reason virtual analog synthesizers (entitled SubTractor) which allowed me to combine acoustic repression of percussive sounds with digital imitations of analog transformations. Some of the Beatbugs' sounds are more acoustic-oriented, such as Beatbug 1 that sounds like a high-hat (see Figure 79), Beatbug 2 that has a celesta-like sound (see Figure 80), Beatbug 3 that has a rim shot sound character (see Figure 81) and Beatbug 8 which has a low deep sound that is similar to a kick drum sound (see Figure 86). The other four sounds are imitation of analog sounds. Beatbug 4 has a fat rich low synthesized sound (see Figure 82), Beatbug 5 has a sharp high frequency “ping” sound (see Figure 83), Beatbug 6 has a long (2 seconds) “boing” sound that has a filter change over time (see Figure 84), and Beatbug 7 that has a low constantly-changing pitch sound, so that every hit plays a different pitch (see Figure 85). Other sounds in the system are the Metronome sound (see Figure 87), which is similar the bass drum sound, “Send” sound which is a sharp “glass” sound that is played whenever a pattern is sent to the next player (see Figure 88), and the “end” sound which has a crash cymbal characteristic and is played on the last multi-player synchronous hit (see Figure 89). For each synthesizer I attached a set of effects such as reverb, flange, equalizer, or compressor. These effect modules provided additional controllable parameters for timbre manipulation. I also connected a delay module for each synthesizer, which was responsible for the rhythmic ornamentation operations. Delay time and feedback were controlled through MAX/MSP, providing a variety of rhythmic parameters for manipulation. Two comprehensive examples for effect/delay modules sets are presented in Figure 90 and Figure 91.



Figure 79. Beatbug 1 – high-hat-like sound.



Figure 80. Beatbug 2 – celesta-like sound.



Figure 81. Beatbug 3 – rim shot-like sound.



Figure 82. Beatbug 4 – fat low synthesizer sound.



Figure 83. Beatbug 5 – loud synthesized “ping” sound.



Figure 84. Synthesizer 6 – long sweep-filtered synthesized sound.



Figure 85. Beatbug 7 – constantly pitch variant sound.



Figure 86. Beatbug 8 – bass drum like sound.



Figure 87. Metronome sound, similar to the bass drum sound.



Figure 88. “Send” sound – high “glass” sound, played when a motif is sent to the next bug.



Figure 89. End Sound – Crash Cymbal-like sound, played on the last multi-player synchronous hit.



Figure 90. Effects/Delay set attached to synthesizer 3. Includes Reverb, Flange, EQ and Delay



Figure 91. Effects/Delay set attached to synthesizer 5. Includes Reverb, Chorus, Compressor and Delay

The better part of the sound design work was dedicated to identifying sound effects that would enrich the Beatbugs' sound in an interesting and noticeable manner. As each timbre manipulation cycle was added to the one before it, it was important to make sure that all the different effects create a significant effect with any of the settings of the other parameters in the system. For example, if one player controlled the filter frequency of a sound, bringing it to low ranges, it was important to make sure that the next player, who might control the same filter's resonance, would have a noticeable and interesting effect on the filter, even in low registers. Most of the work, therefore, was identifying effects and registers that would work well interdependently. Another important aspect that had to be controlled was the dynamic breadth of the composition, as some effect parameters could have brought the dynamics to low as well as high extremes. In some cases it was required to use the Reason compressor in order to maintain listenable levels. Table 4 presents the parameters that were chosen to be controlled sequentially by every Beatbug in the random routing mode.

Table 4. The six timbre parameters that were chosen to be manipulated for each of the eight Beatbug synthesizers. Each parameter was controlled by a different bug in a sequence.

	Round 1	Round 2	Round 3	Round 4	Round 5	Round 6
Synth 1	Flange	Filter frequency	Pitch bend	Envelope decay	FM amount	LFO rate
Synth 2	Pitch bend	LFO amount	Filter Frequency	Filter resonance	Flange	Noise level
Synth 3	FM & Pitch bend	Flange	Noise Level	Filter frequency	Filter resonance	Envelope amplitude
Synth 4	FM amount	Pitch bend	Filter resonance	Envelope sustain	Filter frequency	Flange
Synth 5	Envelope decay	FM amount	Filter Frequency	Filter resonance	Pitch bend	Flange

Synth 6	Filter Freq resonance	Filter 2 resonance	Filter 2 Frequency	Flange	Oscillator mix	LFO amount
Synth 7	Pitch bend	Amplitude envelope	Noise level	Filter frequency	LFO amount	Flange
Synth 8	Pitch bend	Noise decay	Noise level	Filter resonance	Flange	LFO amount

For the composition “Nerve” the sound design work called for additional design decisions. Here, the order of bugs was predetermined, so it was important to introduce the different bugs and timbre parameters in a manner that would be noticeable and engaging and that would contribute the accumulative texture building in the first movement. In defining the order of the bugs I attempted to mix high frequency sounds with low frequency ones, acoustic oriented sounds with electronic ones, etc. Additionally, I had to choose the order and values of the delay parameters so that every new pattern manipulation would introduce new and interesting rhythmic ornamenting transformation. Table 5 presents the playing order, timbre manipulation order and the rhythmic ornamentation values that were predefined for “Nerve” ."

Table 5. Playing order, timbre manipulation order, and the rhythmic ornamentation values in “Nerve” ."

	Sends to	Rhythmic Ornamentation	Timbre Manipulation
Player 3 (Motif 3)	Player 5	1 step 1/16th note	FM amount + Pitch bend
	Player 4	3 step 1/16th note	Flange level
	Player 7	1 step 1/8th note triplet	Filter resonance level
	Player 1	2 step 1/16th note	Filter Envelope Attack length

Player 4 (Motif 4)	Player 6	5 step 1/16th note	Pitch bend
	Player 5	4 step 1/16th note	FM Amount
	Player 1	1 step 1/16th note	Amplitude envelope sustain
	Player 7	1 step 1/8th note triplet	Filter Frequency
Player 1 (Motif 1)	Player 2	2 step 1/16th note	LFO level
	Player 7	3 step 1/16th note	Pitch bend
	Player 8	2 step 1/16th note	Flange level
Player 7 (Motif 7)	Player 5	5 step 1/16th note	Amplitude envelope sustain
	Player 8	4 step 1/16th note	Noise level
Player 5 (Motif 5)	Player 6	1 step 1/16th note	Filter Frequency
	Player 2	1 step 1/8th note triplet	FM amount
Player 6 (Motif 6)	Player 8	1 step 1/16th note	Filter Freq+ resonance
	Player 2	3 step 1/16th note	Filter 2 resonance
	Player 8	2 step 1/16th note	Filter 2 frequency
Player 2 (Motif 2)	Player 8	5 step 1/16th note	Pitch bend
	Player 2	4 step 1/16th note	LFO amount
Player 8 (Motif 8)	Player 3	1 step 1/16th note triplet	Filter resonance

5.3.9 Discussion

The instrument and the interaction – Observation of the preliminary workshops in Boston and Dublin indicate that children found the Beatbugs easy to hold and manipulate, and with minimal instruction quickly adopted techniques for controlling the antennae. After two 1 1/2 hour sessions, they were comfortable with both making and manipulating motifs and had moved from the initial 2 measure units to 4 measures at a faster tempo (147 bpm). By session four they had developed a high degree of sophistication and sensitivity in using the antennae to make subtle alterations to their motifs, moving from gross random manipulations of the ‘rhythmic ornamentation’ antenna to much smaller, more carefully judged actions. In the later rehearsal-oriented workshops participants have developed an expressive playing behavior in conducting their friends, using large body movements and gestures and inventing synchronized dance-like procedures. Players also developed game-like activities by trying to surprise their friends with sudden gestures.

A number of weaknesses were identified in the system and the interaction design. One of the main drawbacks which I try to address in my current project (see “Current and Future Work” section below) was the lack of true idiosyncratic personal player identity. Although players could enter their own rhythmic pattern with their own pre-defined timbre, the system was not able to provide direct and personal connection between performers and their musical product. Players were offered with only 8 sounds to choose from and could not choose the same timbre twice. In some cases participants were left with a sound they didn’t really want, which impaired the personal connection they had with their motifs. Moreover, while helping making the musical output tighter and more coherent, the quantization that was applied by the system prevented the capturing of personal subtleties in entering the rhythmic patterns and limited the range of personal expression offered to the players. Another cause for the impaired personalization was the high number of rhythmic manipulations applied by other players in the network.

In some cases after several motif development cycles by other members in the group, the original personal motif got hidden by extensive timbre, pitch and rhythmic modifications. This drawback was less apparent in “Nerve” where the number of manipulations was limited to 1 or 2.

Another drawback in the interaction design is the confusing conveyance of the interaction to viewers. Although intuitive and clear to participants, some viewers stressed that the nature of the interaction and the topology of the network were not clear. Although Beatbugs’ lighting and the players’ large body gestures brought a significant improvement in conveying the interaction in comparison to the Squeezables and the Fireflies, the topology of the network was too complicated for viewers to follow. Additionally, some timbres got buried in the mix once all the bugs were playing, making it hard for the audience to hear what effect the antenna manipulations had on the sound.

We also detect a number of technical weaknesses in the system. The most significant problem was the embodiment of antennae, which were not robust enough to withstand use and abuse by children. The trigger system has also to be tuned to reject handling noise, while still being sensitive to intentional hits. Other hardware improvements that may be considered include making the Beatbug wireless and embedding a peer-to-peer interaction detection which will capture the physical interaction between players in “conducting” mode. These improvements were suggested by many users who liked these features in the Fireflies and liked to see them in the Beatbugs as well. On the other hand, my personal belief is that the interpersonal conducting procedure, which does not involve computer sensing or mapping, contributes significantly to the expressive nature of the interaction. In general, I believe that combining computer mediated interactions (such as in routing and random grouping) with pure interpersonal musical interaction (such as in conduction) led to a well balanced experience which benefited from both worlds.



Figure 92. Interaction between children and a percussionist from Deutsches Symphonie-Orchester Berlin.

Learning and pedagogy - In the course of the workshops there was clear development in the children's performance at all levels. Stability in entering rhythm patterns against a pulse and also against a complex shifting texture, ability to deal with syncopation, and use of accent and shaping of motifs all improved considerably. Use of rhythmic and timbral manipulations became increasingly subtle and pointed. Interpersonal interactions such as making eye contact, looking, turning and pointing in order to facilitate musical events became completely intuitive and contextualized. When participants were asked about their learning experience in comparison to traditional music classes, many pointed out concepts such as the communal music making and peer-to-peer musical interaction that are rarely addressed in the early stages of learning to play an instrument. Others talked about being more aware of the other players in the group, listening to and following each other.

On the flip side, I do not believe that the system provided wide enough variety of learning curves for all players and did not push enough the height of the learning floors and ceilings. It seems that the Beatbug pedagogy was perfect for a week long workshop. However, shorter term workshops for the general public, such as the ones we had in Dublin and New York, while introducing some basic musical concepts and activities, could not have really provided the full IMN experience for the participants (learning floor should be lower). Longer sessions, on the other hand, were not necessary since the learning value and possibilities offered by the system were pretty much maximized after a week (learning ceiling should be higher). In my current project I attempt to address the first challenge by lowering the learning floor, making involvement in interdependent collaborative experience provided by the system more immediate (see Voice Patterns below).

6 Assessment

In this section I address the assessment questions which I posed in section 4. The questions are classified into three evaluation categories – Collaboration, Learning and Expression, and Composition – and address the three main projects in my thesis work in a comparative manner.

6.1 Collaboration

- The level of interdependency – How interdependent is the network? How immersive and coherent? What approach does it take for achieving a balance between coherency and immersion? What musical parameters have been used for autonomous and interdependent interaction?

The first IMN instrument that I developed as part of my thesis work – the Squeezables – featured high levels of synchronous interdependency. In order to investigate the new medium I accentuated the level of interpersonal control, allowing players to continuously and synchronously change each others timbre and scale in real time. This led to some successful results such as the sense players described as “controlling an instrument with a mind of its own.” On the other hand, some players, and even more notably viewers, felt that the interaction was too confusing to follow, at times even incoherent. I therefore decided to constrain the level of interdependency by replacing the continuous and synchronous control with the extreme opposite discrete and sequential approach. This led to the development of the Fireflies, where players entered their discrete patterns in an autonomous manner and were able to choose when and with whom they wanted to interact interdependently by pointing their device at their peers. This goal-oriented and decentralized approach significantly improved the portrayal of the interaction to players and viewers, making it

more coherent and easier to follow. On the other hand, the discrete timbre trading provided only short and sparse interdependent interactions that did not lead to true interpersonal collaboration. Moreover, the total elimination of continuous control and synchronous interdependency impaired the immersive nature of the network. After exploring the two extremes in that regard, I decided to find a well balanced solution between continuous synchronous interactions and discrete sequential ones. This led to the interaction design of the Beatbugs. Here, players enter their discrete patterns in a sequential autonomous manner, but are also able to synchronously manipulate each other's patterns using continuous controllers during the "call-and-response" phase. This was a successful balance, which players understood and adopted immediately. The weakness of this solution, however, was that the addition of rules and operations (entering, manipulating, conducting etc.) was too complicated for viewers to follow. My observation that the collaborative interaction was effective for players but less successful for viewers was strengthened by two other expert opinions: A Project Zero researcher who interviewed Toy Symphony players (see Appendix IV for information on Project Zero and their full report) and a journalist from the audience on the other. Based on discussions and interviews with Beatbug players, Svetlana Nikitina, a research specialist from Project Zero, found the Beatbugs to be effective in improving social and collaborative skills such as "listening to each other; giving each other room in conversation; paying attention to body language and learning to adequately interpret it." A New Jersey journalist of the Start Ledger, on the other hand felt that as a viewer – "the sound was confusing and the rhythms very difficult to follow. The effect was of watching video games when you don't understand the rules. It looks like fun, but there's no telling what's going on." (Connard 2003)

- The balance between goal-oriented and exploratory interactions – Does the musical activity in the network have a goal or a reward? How does the goal encourage teamwork and social dynamics? Does it distract players from concentrating on the music they create?

None of the projects in my thesis work was designed as a pure goal-oriented activity or a competitive game. These projects' main focus was on creating expressive collaboration, educational value, and worthy music. The most abstract interaction was featured by the Squeezables, which only provided one mode of operation, with no hierarchy of levels or modes. If there was a goal-oriented activity here it was the collaborative effort by the accompaniment players to create a notable influence over the melody. However, the melody player was always able to block the accompaniment influence. Therefore, achieving this goal was not totally at the hands of the accompaniment players, which often led players to avoid trying to achieve the "reward" altogether. It also led some players to feel that at times they were "not only playing the instrument, but the instrument was playing (them)." In the Fireflies I decided to explore more goal-oriented activities in an effort to maintain engagement and long-term interest. The activity, therefore, was divided into two modes (entering patterns, and trading), while the timbre-collection experience was used as a motivating force for players to search for peers to interact with. However, technical limitations and software design flaws prevented players from saving their patterns, which weakened the drive to collect. Moreover, this goal-oriented activity contributed to undermining the musical value of this project, as it distracted players from concentrating on the music. A better balance between goal-oriented and abstract activities was presented in the Beatbugs project. Here too, the interaction is divided to modes and players are motivated to finalize one mode before progressing to the next (similarly to game levels in video games). It seems that the use of antennae for developing peers' patterns provided players with a good balance between abstract and goal-oriented experiences. On one hand, the subtle manipulation of rhythm, timbre, and pitch encouraged players to concentrate and explore the musical consequences for their actions. On the other hand, the motivation to develop a peer's pattern, making it "better" or "more personal," provided an effective reward for players. The call-and-response conducting activity was also successful in combining the concentrated collaborative musical effort with a game activity that one reporter described as "a light-saber battle from 'Star Wars' (Wright 2003).

The effectiveness the interaction is demonstrated in an interview with Sacred Heart School students who rehearsed and performed “Nerve” in Glasgow (The interview was conducted as part of a BBC3 documentary. See Appendix III for a full transcript):

Question - What was it like when you first picked up this thing and it began making the noises? What did you feel like?

Kid 1 - Famous (laughing)

Kid 2 – It’s brilliant

Kid 3 - It really good, it’s really exciting

Kid 4 - It’s because you pass sounds to each other. And it is like talking to each other.

Question - Is it as fun as talking to each other?

Kid 4 - Much more fun (laughing) because its different, its kind of different because it is sound that you are passing.

- The effectiveness of multi modalities – What additional media does the network use and for what purpose? Do visual and tactile reinforcements help in portraying the interaction to players and audiences?

There was a continuous progress in the use of multi media reinforcements through the development of the various instruments. The Squeezables were basically used as disconnected controllers, while the computation, sound generation, and audio output occurred on a remote computer. No visual or tactile reinforcements were used to help convey the interaction and the network topology, which contributed to the feeling of confusion for some players and listeners. Moreover, the balls’ sound was mixed to stereo speakers which made the connection between players’ gestures and their musical output even more difficult to follow. The Fireflies had a better sound separation scheme. As self-contained instruments, each Firefly was equipped with its own speaker which made following the respective role of

each player much easier especially in the trading mode. Moreover, the vibration of the speakers in each Firefly provided tactile reinforcement to the rhythmic patterns which helped players (although not viewers) to physically feel their music. All interviewees preferred the toy version over the GUI Max version of the Firefly interaction, stating the sound separation and the tactility of operation as a main source for their preference. The Beatbugs utilized the most extensive approach for multi media reinforcements. In addition to sound separation and speaker vibration, each Beatbug also utilized a set of LEDs that visualized both the rhythmic patterns and the antennae manipulation. Unlike the speakers' vibration, the lighting of the Beatbugs was very helpful for viewers, who used these visual queues to make better sense of the interaction. In some rehearsals a MIDI-operated light mixer was used, which sent a spot light on the head-of-the-snake at any given moment to better represent the topology of the network to spectators. However, it is important to note that due to the complexity of the interaction and multiplicity of modalities, the Beatbug multi media reinforcements, although significantly helping in conveying the interaction, were not fully successful in providing perfect and clear portrayal to all viewers.

- Scalability – How well does the network adjust to different numbers of participants while maintaining the intuitive nature of the interaction?

Scalability was not a strong feature in any of the IMNs that I developed, and only small progress was achieved through the development of the instruments in that regard. Although the Squeezables support 3 to 6 players (Each using one or two hands), its physical shape and size was best suited to support only 3 players using both hands. The mapping application was specifically designed to support exactly 6 different balls and could not have been extended without a major redesign. The Fireflies' application, on the other hand, due to its full sequential nature, was more scalable and could have theoretically supported any number of players. Practically, however, only 3 Fireflies were built and due to the hardware limitation of

the infrared communication, only two players were able to effectively interact with each other at any given time. The Beatbugs system came back to a closed-system architecture similar to the one used in the Squeezables. Here, too, although the application could have theoretically supported different numbers of players, the system's hardware rack was custom made to support 8 players, and the "Nerve" software patch was specifically written for precisely 8 players.

6.2 Learning and expression

- Learning content and adaptability – What can be learned by interacting with the network?

Due to its synchronous interdependency and artistic nature, the Squeezables was the least successful in providing learning value. The instrument, which was not supported by workshops or pedagogy, seemed to be much more adequate for professional musicians with previous experience in group playing. The Musical Firefly was much more geared to facilitate learning but was focused on one specific task of introducing polyrhythm in a constructionist manner. The most studied project in terms of learning value, however, was the Beatbugs. Here, in the extensive workshops, such as in Dublin, children were slowly introduced to concepts such as pitch, scale, contour, timbre, syncopation, stability and a variety of rhythmic values. The children were asked to sing, clap and notate their own motifs using the new concepts they learned. Later in the process, the group activities were introduced and provided new musical experiences that are rarely accessible to young students in early learning stages, such as motif-and-development, call and response, collaboration, improvisation, etc. The most extensive study about children's learning with the Beatbugs was conducted by Harvard University Project Zero researchers (see Appendix IV). In their report they list the musical skills that were learned:

Social (interpersonal)

- *listening to each other; giving each other room in conversation;*
- *paying attention to body language and learning to adequately interpret it;*
- *children in workshops became better friends overall.;*

Interpersonal (confidence building)

- *self-esteem, confidence, overcoming shyness and introversion;*
- *sense of mastery, fostering “I-can-do-it” mentality.*

General learning/cognitive skills enhanced:

- *concentration, increased attention span;*
- *greater participation of children in the discussions, and better listening to each other;*
- *greater learning motivation;*
- *ability to work under pressure;*
- *energy and focus;*
- *public behavior skills;*
- *technology helped to break down the barriers between children and teachers/adults by putting both in the learning mode.*

Musical Skills

- *children learned complex musical patterns, stage behavior, gained an understanding of rhythm, learned some musical vocabulary (“motive,” “pattern,” “orchestra”)*
- *they reported that they might apply it to Scottish/Irish dance, acting, learning instruments – guitar, fiddle, piano;*
- *the kinesthetic experience on stage might help some children to be more expressive with their body as they play the fiddle, for example. Musicians reported similar things: The TS experience made them less inhibited on stage and gave them more freedom of movement with and around their instrument (trumpet, double base);*

- *the children commented on the sense of ownership and connection to music through the experience of “making it” directly;*
- *they learned that music involves practicing, and that you don’t get it right the first time;*
- *the experience of following conductor cues, timing movement and sound, and playing with the orchestra;*
- *technology, according to Mary Troup, helped children cope with the solitude of music practice, which could be frustrating and isolation for young children. TS made it possible and imperative to practice in small groups, giving a chamber ensemble experience.*

A longer-term study will be required in order to evaluate how well these concepts were learned and whether children are able to transfer these experiences to other contexts.

- Pre-requirements and depth – How low is its learning floor and how high is the ceiling? What are the pre-required skills and knowledge for having a meaningful experience? What sorts of learning curves does the network support?

The Squeezables facilitated expressive interaction using familiar gestures with high level percepts such as contour and rhythmic stability. However, its synchronous interdependent architecture could not have allowed novices to isolate and follow their actions. It worked better with skilled musicians, who were not necessarily interested in the educational material. The Fireflies were more successful in providing a low-level floor for hands-on experience but the learning activity they offered was narrow (focusing mainly on polyrhythm), which made them unsuccessful general purpose learning tools. The Beatbugs, on the other hand, were effective in addressing children with different levels of prior experience, providing the lowest floor and the highest ceiling, when compared with the other instruments. In some cases, such in the workshops in Glasgow, inner city kids with no prior exposure to music making or instrument playing were able to participate in an expressive and thoughtful performance within four

days of workshops. Some of their thoughts about their experience were voiced in an interview after the concert: “*it makes you want to play instruments because when you play the Beatbugs you enjoy it,*” and “*With some instruments ... you go... mmm.. this is too hard...but Beatbugs show you that it is not always so hard. You can enjoy yourself*” (see Appendix III for full interview). Parents were also interviewed about their impression of the experience: “Well it is like a game, but it is actually more than a game... it is a fun way to learn,” and “This is something I feel that can empower them to feel that music does have something to do with them. And maybe it is something to do with just not knowing that that’s possible within them. Suddenly they can hear something and Wow, I did that.”

It is important to note, though, that the Beatbugs’ learning ceiling was not as high as originally desired. This is demonstrated by children’s answers when asked by Svetlana Nikitina from Project Zero about how they would improve the toys. Some of answers were:

- *Add more buttons, make it “look like a little piano on top”*
- *Make a musical effect specific to the kinesthetic (in Gili’s terminology it may suggest a move from “immersive,” purely kinesthetic play to some analytical thinking)*
- *More controls, more things to push and play with besides antennae*

These answers indicate that some children felt that they exhausted the instruments after a week of workshops, and were interested in having more possibilities and functionalities in them.

- The balance between thoughtfulness and expression – What are the software and hardware solutions that are used for providing intuitive access to thoughtful musical interaction? How effective are these in addressing both intuitive introduction and thoughtful contemplation?

In both the Squeezables and the Beatbugs, the software approach for providing expressive access to thoughtful musical experiences focused on the idea of high-level controls. In particular, children were able to create their own melodies by manipulating contour as well as controlling the rhythmic stability of their creation. These engaging and personally meaningful hands-on activities motivated children to inquire and further investigate the musical concepts described above. The interaction with the physical instruments significantly contributed to players' engagement and their motivation to learn. By mapping familiar play gestures such as squeezing, pulling, tapping, bending, and pointing to clear musical results children were able to immediately and intuitively get access to more analytical musical thinking. In general, I believe that the Beatbugs' physical controllers and use of high-level percepts were more successful in bridging the gap between the expressive and the thoughtful than the Squeezables'. Some reviewers, such as James Gorman from the New York Times, addressed this balance, highlighting the expressive nature of the instruments:

“When I tried the Beatbugs and Music Shapers I felt a tactile surge of pleasure more than an intellectual one. The instruments are, of course, less demanding than traditional ones, and in the end might be less enriching. But they are not designed as ends. They are designed to offer the pleasure of music before the pain of making fingers do unheard of things. Who really knows what's going on when the muscles are being trained? Perhaps, if children's hands are speaking to their brains during violin practice, they are shouting: "Help! Get me out of here!" I don't know what they're saying when they play with Beatbugs and Music Shapers, but I'll bet they're laughing with pleasure.” (Gorman 2003)

The Fireflies, on the other hand, took a different approach for learning. Here the interaction in solo mode was direct and very simple to follow as no higher-level algorithm mediated the relation between what was played and what was heard. The more interesting learning part occurred mainly in the multi-user mode when players were exposed to the wider and more

mathematical perspective of their musical creation. Here too, in the spirit of constructionist learning, the physical interaction with the instruments contributed to personalizing the experience for players, making it more meaningful and engaging.

- The balance between composer, computer and performer – How important a role do the performers have in determining the musical output? How do the composer and the system help players achieve coherent and interesting musical results without comprising players' contribution? Is the network improvisational or interpretational in nature?

The Squeezables and the Fireflies represent two extremely different approaches for composer/computer/performer's role in IMNs. The Squeezables was developed as an instrument for a particular composition. Players had to follow detailed notation written by a composer and were given just a little freedom to improvise or bring their own ideas to the music. To compensate for these restrictions, the Squeezables' central computer provided a flexible and interdependent infrastructure which led to a wider variety in musical results based on surprises and interconnections. The combination of following a detailed pre-composed score and the confusion created by the system's high levels of interdependency significantly impaired the learning value of the instrument. The Fireflies, on the other hand, offered a free and open-ended experience for participants with no pre-composed score to follow. Players were encouraged to enter their own rhythmic patterns and to trade freely with their peers. But at the same time, the Firefly's system restrictions were extremely confining, only allowing for simple sequences of accented and non-accented notes. As opposed to the Squeezables, the combination of free player input, little composer intervention, and highly restricted system led to better learning results. However, learning goals were limited by the system to few musical concepts and ideas which did not allow for a wider, more open-ended learning process. Here, too, the Beatbugs represent an attempt to find a better balance between composer, computer

and performer that can support creative and educational input from performers while still allowing the composer's voice to come through. Here, players are provided creative freedom in entering and manipulating their patterns as well as in conducting musical dialogs with their peers. The system's role is to provide surprises in routing and grouping while the composer is responsible for defining the basic musical material and the interaction design. The Beatbugs, therefore, encourage performers to both interpret and improvise. The computer helps in organizing and ordering the interaction to prevent confusion as well as in adding liveliness and dynamics by introducing some random operations. As the composer in the system I was still able to project my general aesthetics and artistic ideas by defining the timbral, rhythmical, and interactive nature of the piece.

6.3 Composition

- The compositional goals and intentions – What were my artistic motivations and what were the tools that were used to achieve them?

Only two of the instruments – the Squeezables and the Beatbugs – can actually be addressed in compositional terms. The Fireflies, as discussed above, were not designed from a compositional incentive or with listeners in mind, but rather focused on supporting learning and unique playing experiences for the players themselves. The Squeezables was my first attempt at creating an IMN. As such, I went all the way in establishing elaborated continuous and synchronous interconnections between players. The composition objective, in that regard, was to confine this immersive and possibly overwhelming web, and to help coherent interdependent collaborations to emerge from the pandemonium. The Squeezables, therefore, can be considered the most “composed” instrument as its goal was to allow composers to create particular detailed and structured interdependent compositions. It offered me, as the composer, high levels

of freedom in determining the musical outcome by mapping user input to a variety of high- as well as low-level parameters, allowing me to be fully in control over shaping curves of tension and release, stability and instability, and melodic contours, while subtly providing an interconnecting influence among players. “Nerve” on the other hand, was derived from a different compositional motivation. Here, my role as a composer centered on designing the interaction for players, trying to provide them with as much as freedom as possible for creativity and learning, while maintaining my artistic voice as a composer. While the composition process for the Squeezables focused on programming musical parameters to be controlled by the players and writing a detailed score for them to follow, for the Beatbugs I was much more involved in “interaction composition.” The composition process for the Beatbugs was also more complex as the system supported more players, offered more modes of operation, discrete as well as continuous controllers, and tactile as well as visual reinforcements. The process, therefore, involved organizing these multiplicities in an effort to create coherent musical infrastructure that would allow players to express themselves within the boundaries of a well organized structure. My idea for structure was to start with a simple floodable motif-and-variation movement that slowly grows in polyphony and complexity as more and more players enter the interaction. When the tension peaks, as all players have entered and developed their motifs, creating a dense and intricate rhythmic texture, the composition evolves to the Finale section. Here the dense texture suddenly dissolves, allowing a couple of motifs to come to the front, creating a link to the first build-up movement. Here, after re-introducing the motif duos, the texture gets denser as four and later the whole eight motifs are brought back again to a climax. In order to maintain this structured frame I “composed” the order of entering, manipulating, and grouping motifs, addressing questions such as who can manipulate these motifs and when, how the conducting process occurs, when and how the systems will introduce random operations etc. Unlike the Squeezable, therefore, the musical output of the Beatbugs is the product of all these interaction composition, combined with the creative input from players, and the random intervention of the system. “Nerve”

therefore, sounded different at each performance, better serving my original goal of creating a dynamic system that supports constantly changing and emerging musical outcomes.

- My personal subjective evaluation of the music – What do I like about the music, performance and the composition? What can be improved?

For a composer and a designer of interactive musical systems, there is an inherent constant struggle between “composing” and “interaction designing,” between controlling the “structure” and letting go for the “process” to evolve. The Squeezables and the Beatbugs represent two different approaches for addressing this tension, with the Squeezables tending more towards structure and the Beatbugs leaning more towards process. Although IMNs in general represent a process-music approach for composition, it is important to note that both Squeezables and Beatbugs include structural as well as procedural elements, but maintain different balances. As a traditionally trained composer, before starting my thesis work I was more familiar with structured composition, and was more hesitant to provide much control to the players and the system. The Squeezables composition, therefore, was more structure-oriented while the process-based interdependencies served as coloring elements to the accurately composed gestures. In “Nerve” on the other hand, I decided to give away more control over the actual musical output, and to focus on composing the infrastructure and the interaction. This task, while challenging and exciting, was pretty risky as my performers were to be untrained children who would have very little time to rehearse and practice. And in fact the musical outcome in most concerts was quite different than what I anticipated. Some of these inconsistencies were caused by players’ inexperience and lack of skills - performers were not able to keep the beat when entering the motifs, tended to spend too much time manipulating the motifs and in many cases deviated from the flow of the composition as I saw it. On the other hand, many of the unanticipated behaviors from the rehearsals and the workshops, such as the unique play

patterns the children developed in conducting and interacting with each other, were warmly embraced in the performance and were noted by many as the most exciting part of the project. However, since the Beatbugs composition cannot be separated from the performance and the interaction, I feel that the piece cannot really stand on its own as a pure musical composition. The Squeezable composition, on the other hand, better stands on its own as a composition and was actually presented in an art festival as a recording, without the performance element (see below.) In that sense, the Squeezables can be considered as a better traditional composition. My personal preference, however, is to continue and compose for process-oriented IMNs, in a quest of finding the ultimate equilibrium that will generate worthy music while providing players with true expressive and creative experiences.

- The artistic establishment's regard for the music – Was the music performed and evaluated publicly? How well was it received by peer musicians, performers and audiences? What did the critics think?

The Squeezables was performed as at the Media Lab and did not have a wide public outreach. The recording of the composition, however, was presented as part of the Tissue Culture and Art project at Ars Electronica and was received with interest. The acceptance of the piece without the full live interdependence performance was encouraging as it hinted at the possibility that the musical product of IMNs can “stand alone.”Nerve” on the other hand, as part of Tod Machover’s Toy Symphony project, was performed widely in concerts in five cities in Europe and the US in collaboration with orchestras, museums, and public schools’ educational programs. For the premier in Berlin the conductor required me to send a demonstration video of the piece before it was approved for the program. For the rest of the concerts “Nerve” was an integral part of the concert and was received warmly by the audiences. Critics, in general, received the piece positively too. Comments ranged from describing “Nerve” as having “verve and propulsive energy” (Powers 2003), stating that it “brought

down the house with sheer rhythmic exhilaration” (Dyer 2003) to more critical comments such as describing the piece as “ably show(ing) off the invention, though the percolating music was more fun for the jousting it incited between the players than for content.” (Tommasini 2003.) Some critics focused on the performance, describing the children as giving “balletic performance... throwing complex rhythmic surprises between one another like a game of pass the parcel” (Walton 2002). Others addressed the composition in more neutral terms, describing it as “demonstrating effective and pleasing composition (Wang 2003) or as “engaging and interactive (Waleson 2003). The most critical comments that I found in the printed media described the children’s performance: “They all looked serious and wildly active, as if playing a fast sport, at one point splitting into teams of four. But the sound was confusing and the rhythms very difficult to follow. The effect was of watching video games when you don’t understand the rules. It looks like fun, but there’s no telling what’s going on.” (Connard 2003.) See Appendix II for full reviews.

Table 6. A comparative assessment of the Squeezables, Fireflies and Beatbugs networks.

	Squeezables	Fireflies	Beatbugs
Motivation focus	Collaboration, music	Learning, rewards	Collaboration, music, learning, rewards
Social approach for collaboration	Mostly democratic, can turn to monarchic during the interaction	Mostly decentralized, might turn anarchic with synchronization	Mostly decentralized with elements of rotational democracy
Music	The most “composed” instrument, composition aimed at listeners, though confusing for players and viewers	No real musical value, mainly for players experience and learning	Music is as important as the interaction. Instruments aim at players as well as for audiences
Learning	Low learning value,	High, but narrow, learning value	Comprehensive and wider ranged pedagogy
Topology	Synchronous, centralized – “Flower”	Sequential, decentralized – “Stairs”	Hybrid – “Stairs of Flowers”
Control	Continuous Control	Discrete control	Discreet and continuous
High-level percepts	Contour and rhythmic stability	none	Contour and rhythmic density
Multimedia reinforcements	None	Tactile, spatial	Tactile, spatial, visual
Scale	3 players	2-3 players	8 players

7 Transitional projects

In an effort to improve a number of weaknesses that I identified in the Beatbugs network, I am currently developing a couple of transitional projects. These projects are designed to address two main challenges:

1. To provide a more personal connection between players and their musical creation in order to facilitate a more engaging interaction, therefore better serving the constructionist learning process. The rhythmic motifs in the Beatbugs, while intuitive and expressive for most players, couldn't have been differentiated enough from each other to support a true feeling of ownership.
2. To provide an immediate and unguided access to meaningful IMN experiences for visitors in public spaces in an effort to enlarge the accessibility of IMN to the general public. With the Beatbugs, due to the multiplicity of modes and the intricacies of the interaction, a set of teacher-supported workshops were necessary for providing a full and rich experience. In order to have wide exposure for the project, some important aspects of the system had to be left out in short sessions or demonstrations.

7.1 Voice Network platform

The Voice Network project was designed to address these challenges - to provide more personal connections for players with their musical creation, and to capture and engage visitors with no musical background or training in an immediate IMN experience. In order to address the first challenge I decided to use the human voice as a personal musical input material rather than the less distinctive Beatbugs' rhythmic tapping. I chose the voice since it is one of the most idiosyncratic traits one possesses, and it can preserve its core characteristic features even after significant

modifications. In order to address the second goal I designed Voice Network as a walk-in museum installation, with the support of the New York Hall of Science, a science museum that was interested in presenting the installation as part of the forthcoming “Connections” exhibition that focuses on the concept of networks.

The Voice Network platform is installed around a 4’ high square podium. The podium surface dimensions are 2’x2’. Four control stations, each consisting of a microphone (Sure Beta 58) and touchpad controller (Korg Kaoss pad), are installed on each side of the podium (see Figure 93). All stations are facing each other so that players can see (and listen) to their peers while playing. A flat screen monitor for visualization is installed on the top of the podium in between the stations. Four speakers, one per station, are located on the floor facing their respective players. A Macintosh computer running Max/MSP with a MIDI interface (E-magic AMT8) and an audio interface (MOTU 896) are located inside the podium.

Interaction at each station starts by pushing the record button on the Korg Kaoss pad, which communicates via MIDI to a Max Patch running on the central computer. Players then can record up to 30 seconds of their voice to their respective microphone which connected to the computer through the audio interface. A second push on the record button stops the recording and immediately starts playing the recorded buffer in a loop through the respective speaker. Players can then change and manipulate their looped voice by moving their fingers on the Kaoss touch pad, which serves as a pure controller (all the DSP manipulation are all done in MAX/MSP). I developed two different applications for this setup. In the first application, entitled “Voice Patterns,” players collaborate by synchronizing their voice manipulation gestures in order to trade voices with each other. In the second application, entitled “Silent Pool,” players interact with each other’s sound through the central system which generates random operations to control the appearance and disappearance of voice “motifs” throughout the interaction.



Figure 93. The Voice Network Installation

7.2 Voice Patterns

“Voice Patterns” is designed to encourage players to synchronize their transformed voices by synchronizing their gestures with each other. The reward for successful synchronization is trading one’s sound with the synchronized peer. Therefore, the musical output of the system is quadraphonic propagation of voices that successively get in and out of synchronization.

7.2.1 Network topology

The application uses four audio buffers that can be recorded to at any given moment. Players can use the Kaoss touchpad to send MIDI commands that are used to manipulate their recording in MAX/MSP. A synchronization engine constantly checks for matching MIDI input patterns from the Kaoss pads and executes a voice trade when a match lasts long enough. All buffers can be routed to receive sound input from all four microphones and to play back to all four speakers. In idle state, each buffer is routed to its respective microphone and speaker in each station. When trading a sound, the buffers’ output is rerouted to the new respective speakers and the input is rerouted to the corresponding microphone. Trading will also lead to the rerouting of MIDI connections to the new respective Kaoss pad, so that players will be able to continue recording and manipulating their new sounds to their new buffers.

Solo voice transformation All four stations utilize identical voice transformation algorithms. The Kaoss pad is divided into four quadrants; each features a unique voice transformation effect with two real-time user-controlled parameters (see Figure 94). The bottom right quadrant lets players change the speed of the looped voice in the buffer (the x axis is mapped to change the speed from x0.5 to x2 of the original speed) as well as the volume (from x0.5 to x1.2 of the original level on the y axis). The bottom left quadrant offers the same speed and volume manipulations, but

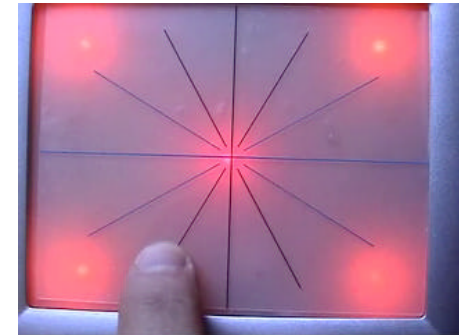


Figure 94. The Kaoss Pad is divided into four quadrants for manipulation of effects



Figure 95. Solo Playing in Voice Patterns

here the voice buffer is played in reverse. The top right quadrant allows players to manipulate the parameters of a low-frequency oscillator mapped to modulate the amplitude of the recorded audio. Players can change the LFO's amplitude (2 to 6 DB on the x axis) and the frequency (1 – 20 Hz on the y axis) which creates a variety of pulsation effects. The top right quadrant allows players to interact with a delay effect by continuously manipulating delay time (x axis) and feedback (y axis).

Group interaction algorithms and visualizations – Players can record and re-record their voices to the assigned buffer at their leisure. Pressing the Record button again ends the recording and the buffer immediately plays back in a loop. Players can then interact and transform their sounds while the system is looking to match their gestures with players that are manipulating their own voice at the same spot in their pads. Animated graphical representation on the central monitor helps players visualize their and their peers' location in each of the pads. When a match is detected, a yellow connection bar appears between the matching stations. As players continue to synchronize their manipulation movements over time, their voice transformations continue to synchronize. The audible effect depends on the specific sound manipulation in the specific quadrant, for example, synchronized LFO pulsation rate, speed and pitch, volume or delay time. During synchronization, the yellow connection bar slowly turns to red to represent the continuity of the successful synchronization (see Figure 96). After 5 seconds of synchronized gestures, when the connection bar becomes full bright red, the system trades players' buffers with each other. A distinctive sound is played from all four speakers to signify that a trade has occurred. If players go out of sync in their gestures during these 5 seconds, the connection bar disappears and the trading process is canceled. The reward for successful synchronization is for the trading couple to play solo with their new sounds for the next 5 seconds. At this time the volume of the other two stations is significantly lower, functioning as accompaniment for the duo (see Figure 97). If more than three players are synchronized at the same time, the system trades voices between the first couple to enter the synchronization mode.

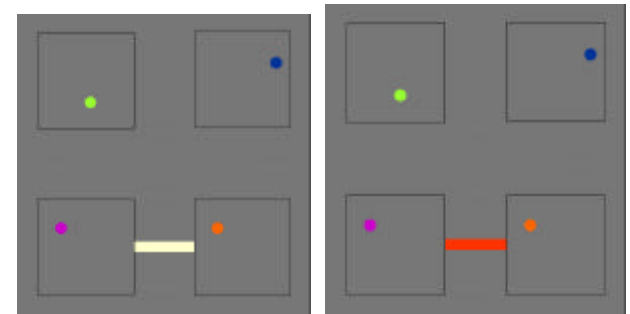


Figure 96. A yellow bar signifies the beginning of a voice trade; a red bar signifies the end of the process.

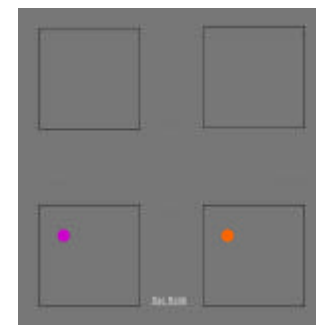


Figure 97. The reward for trading is solo playing with the synchronized peer.

7.2.2 Software in detail

The “input” patch in Voice Pattern (see Figure 98) includes four input “blocks,” one block per station. Each input block receives three channels of information from the Kaoss pad – discrete data from the Record button, and continuous data from the X and Y touch axes. This data is sent to a “multigate” object which routes it to the appropriate station through the “r gate” object (based on the information it receives from the “switch” and “trade” objects, see Figure 101 and 102).

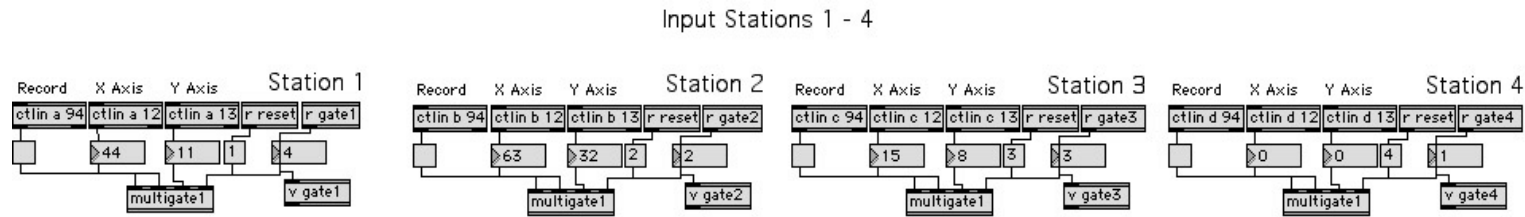


Figure 98. Input Stations in Voice Patterns

The control data is sent to one of four “effects” objects (see Figure 99). Here, the audio from the buffer goes through four different effect combinations including MAX/MSP speed and direction and two VST plug-ins - LFOrez and “DubDelay from MDA. The “effect” patch is also responsible for dividing the touch pad into four quadrants and for assigning the four different effect combinations to each quadrant on the pad, as described above.

The control data from the touch pad is constantly sent to the synchronization engine. (see Figure 100.) Here the four pads are coupled

with each other for finger location similarity test. The results of these tests are presented in the six real-time graphs at the lower part of the patch. The similarity sensitivity value is configurable (in the example below it is set to $< .15$) and so is the time value for triggering a buffer trade. (In the example below $- 12.5$ seconds.)

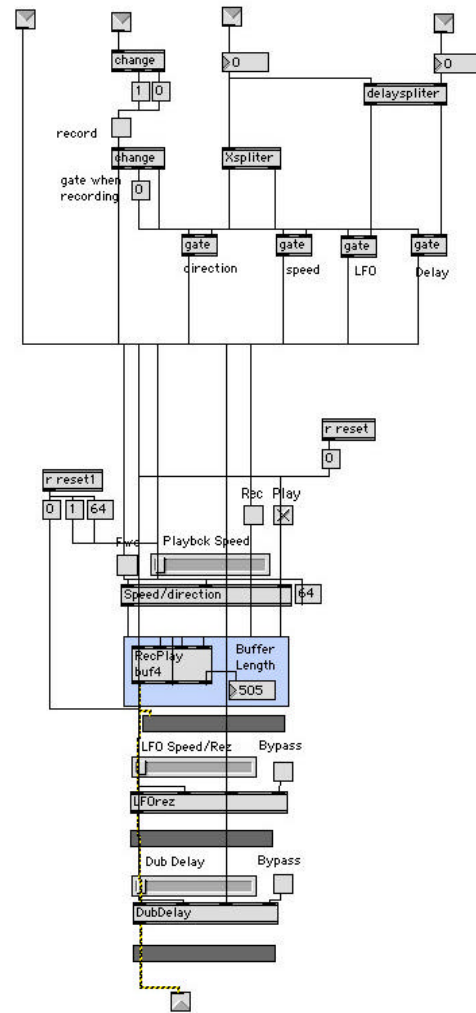


Figure 99. The “effects” patch

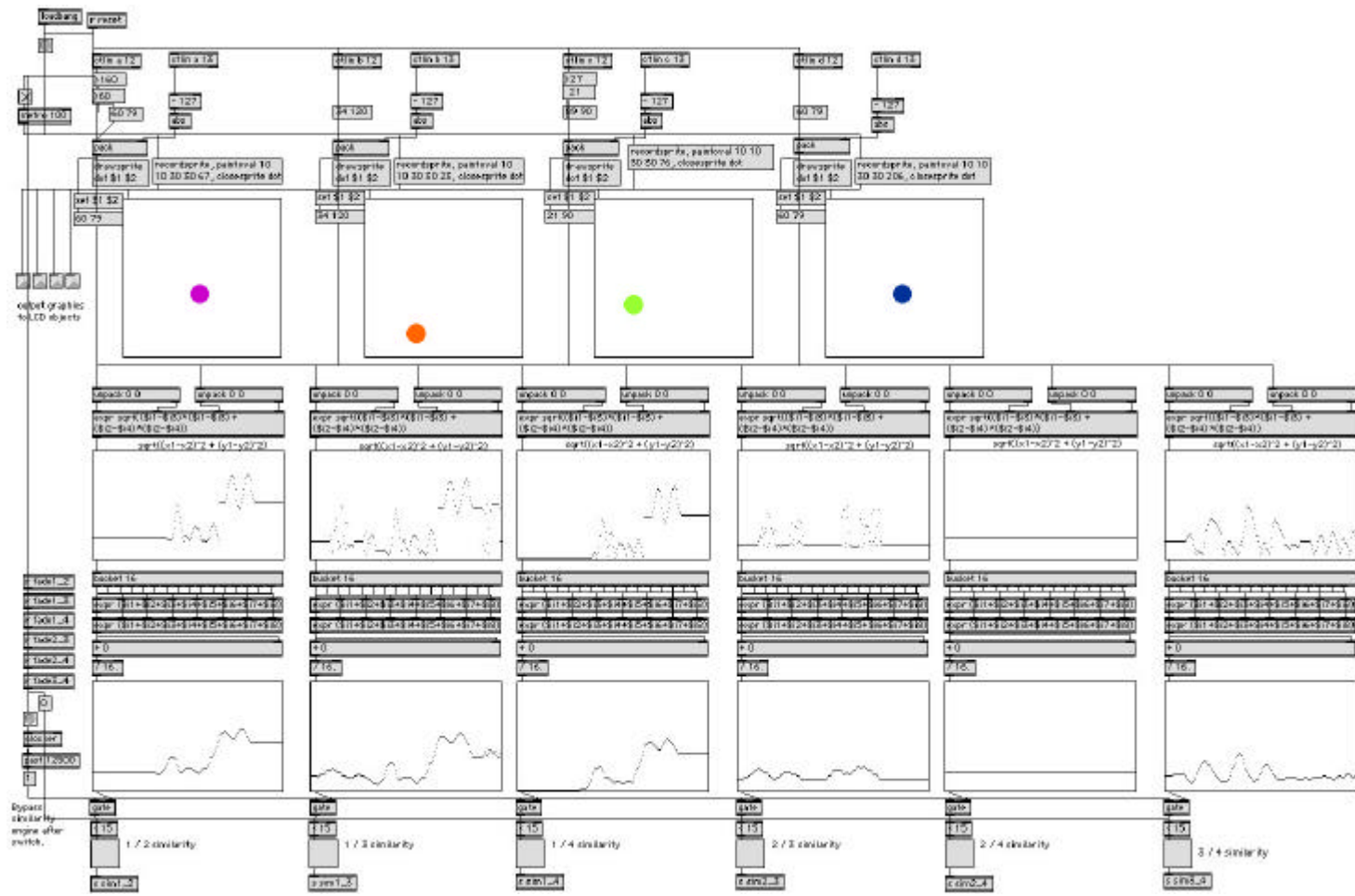


Figure 100. The “synchronizations engine” patch in Voice Pattern

The re-routing of audio buffers is conducted in the “trade” and “switch” objects. (see Figure 101 and 102). A variety of functions are performed in these two objects, such as fade-in and fade-out for smoothing the buffer trade, trade-sound triggering, and sending GUI information to the main patch. Figure 103 presents the input and output audio matrixes. Here, each microphone and speaker can be assigned to any of the buffers. The patch also displays the input and output signal levels.

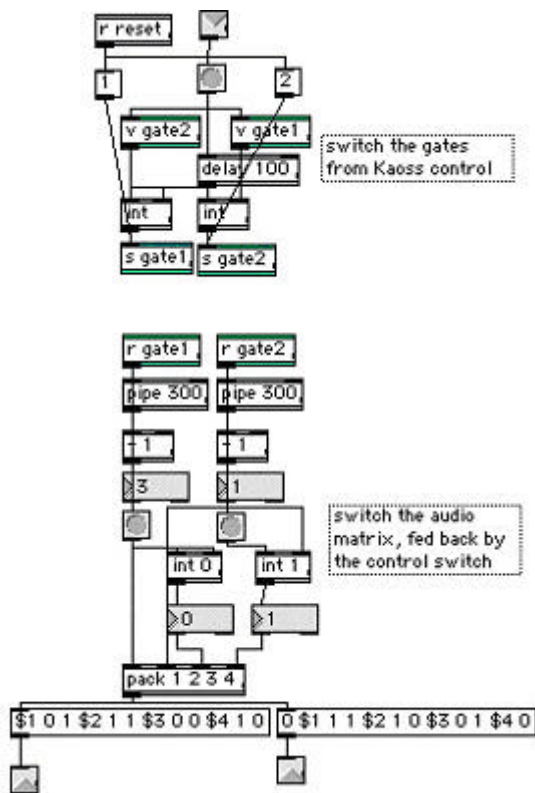


Figure 101. The “trade” object in Voice Patterns

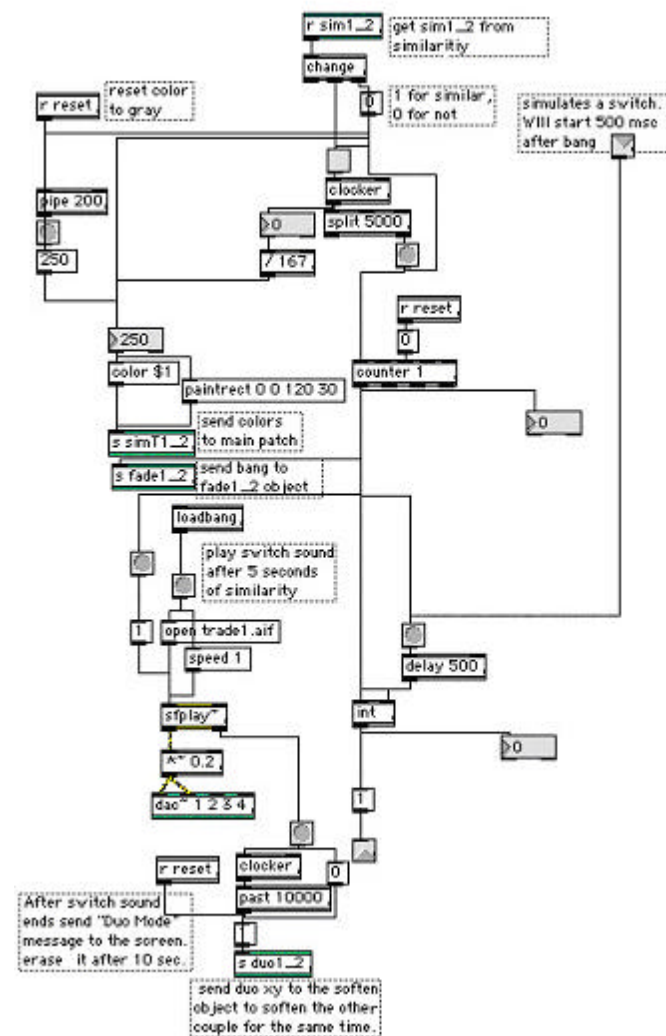


Figure 102. The “trade object in in Voice Patterns

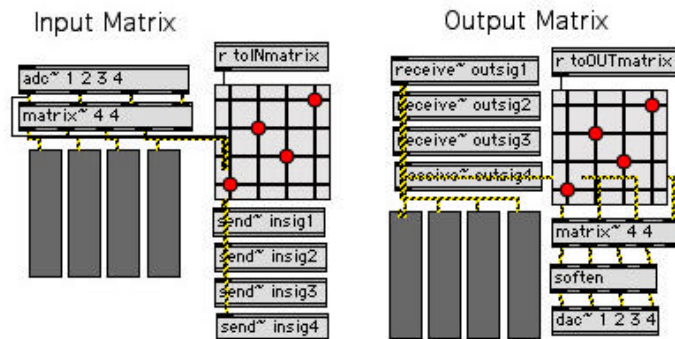


Figure 103. The “matrixes” patch routes audio in and out from the microphones and to the speakers from the appropriate buffers

7.2.3 Discussion

The main goals for Voice Patterns were to provide more personal connection for players to the musical material they create as well as to appropriate the system’s learning curve to short walk-in experiences in a public space. Based on preliminary observations that I conducted at an open house at the media lab in February 2003, the system was pretty successful in achieving these goals as players found the system easy to operate and spent anywhere between 1 to 5 minutes manipulating their own voice and interacting with others. This is an encouraging observation when compared with the museum industry standard for a successful installation (which is 30 seconds to 3 minutes of interaction according to NYHS 2002). Using voice as malleable material for manipulation allowed almost anyone to have some degree of meaningful interaction with the system. Players sang, spoke, clapped, whistled, tapped on the microphone, or played with a variety of percussive instruments that were available in the room. The most successful interaction, however, was the use of the voice, such as in speaking, laughing, or singing as players were more intrigued to follow the different transformation that their voice was about to go through.

But in order to achieve a high level of personalization for a wide range of untrained participants in a short time, there were some difficult compromises that I had to make in the design of the system. The voice transformation algorithms, for example, were designed to apply to almost any type of possible audio input, from soft low-frequency noise to loud high-frequency pitched sound, in an effort to provide almost any participant with simple access to clear and perceptible interaction. But facilitating such a noticeable effect for a wide range of sounds compromised the fine-tuning of the system to intricate manipulations for particular voices. As a result, while the system's learning floor was kept pretty low, the depth of challenges and interaction subtleties was limited. Moreover, since the input material was so varied, it was difficult to layer the different voices into a meaningful and coherent polyphonic structure. The decentralized topology of the network was not able facilitate interesting high-level patterns, but rather turned into an anarchic architecture. The most successful parameter in that regard was the pulsation generated by the low frequency oscillator synchronization (LFO), which provided some musical coherency. But even with the LFO it was not easy to create a perfect match between players that would lead to a stable and tight rhythmic beating. The general musical outcome of the system, therefore, was a collage of unrelated audio segments with sparse sections of more synchronized and coherent polyphonic structure. The musical outcome also suffered from repetitiveness and a lack of dynamics fluctuation, as the buffers were programmed to play repetitively in a loop without any volume changes until replaced by new recordings. The result was especially problematic when the system was left in idle and no manipulations were applied over these repeating monotonous loops.

Another problematic feature of the system stemmed from its goal-oriented motivation and the significant role that was given to the reward. The reward's goal was to promote players' engagement and excitement in the distracting and busy environment of a museum hall. However, many participants at the Media Lab open house seemed to be drawn only to the

goal-oriented activity of gestures synchronization, which compromised their musical attention and concentration. The central role given to the visual display only enhanced this problem since most players tended to focus on the graphical aspects of matching their patterns on the screen, rather than on the musical effect of their actions. An even more problematic effect occurred when I disconnected the graphical display in an effort to allow players to concentrate on the audio transformations. This led to unplanned and unwanted buffer trading when two players happened to be exploring the same area of the grid, or just staying statically at a particular spot.

7.3 Silent Pool

The Silent Pool application was developed in an effort to address drawbacks that were identified in Voice Patterns. Silent Pool focuses on improving the group interaction algorithms and the musical value of the experience. The 4-quadrant Kaoss pad grid and the solo voice transformations were left unchanged, using the same algorithms as in Voice Patterns. In general the main goals of Silent Pool in comparison with Voice Patterns were to provide:

- A more abstract and music-centered experience based on minimizing the role of rewards and goal-oriented activities.
- A more dynamic musical result based on the appearance and reappearance of familiar motifs and transformations in a wider dynamic range.
- More control and autonomy for the individual player over his or her sound by preventing unwanted interactions with the group.
- Less distracting visualization that would allow players to concentrate on the musical content rather than on the graphical presentation.

7.3.1 Network topology

The Silent Pool application utilizes eight audio buffers as opposed to the four that are used in Voice Patterns. In an idle mode, four of the buffers are assigned to each one of the stations and the other four are assigned to a “silent pool” where they can still play, but their volume is muted. When one of the buffers is re-routed to the Silent Pool (see Group Interaction below), the system randomly chooses one of the four muted Silent Pool buffers and sends it to the respective station where it plays back in normal volume and can be manipulated or recorded to. In all other technical, mapping, and interaction respects, Silent Pool’s topology is similar to Voice Patterns’.

Group interaction – Players can record and transform their voices in a similar manner to the interaction in Voice Patterns. However, trading in Silent Pool is performed with a random muted buffer rather than by synchronizing movements among players (see Figure 104). This design decision was made in order to encourage participants to concentrate on the audible and musical effect rather than on graphical synchronization of gestures. When a player reaches a desirable transformation result, she can leave the touch pad, allowing the transformed voice to slowly fade out into the silent pool where it is totally muted. A new random buffer from the silent pool will immediately fade in and be assigned to her station. If the new random buffer was previously recorded into, the player would then be able to manipulate the new random sound. The player will always be able to record a new sound into the new assigned buffer.

Visualization – A colored circle represents each of the buffers in the system. Each buffer has an idiosyncratic color throughout the interaction. The size of the circle correlates to the circle’s distance from the central silent pool (see Figure 105). The circle reaches its full size when it is assigned to one of the four stations. It becomes smaller as it fades out towards the silent pool where it reaches its minimum size. When a sound is



Figure 104. Players interact with Silent Pool

recorded into a buffer the circle starts to “breathe,” performing cyclic expansion and contraction in correlation to the circles’ general size. When a buffer is undergoing real-time manipulation, its “breathing” cycles become twice as fast. When a player is ready for trading, she leaves the touch pad and the circle automatically starts to move into the center silent pool over a period of 5 seconds, corresponding to its fade-out in volume. During this time its breathing rate gets slower and it continuously shrinks in size (see Figure 106). When the circle reaches the silent pool, a random unassigned circle from the pool, representing a silenced buffer, automatically moves toward the empty station over a period of a second while enlarging in size and volume.

7.3.2 Software in detail

The “main” patch in Silent Pool (see Figure 108) contains the key functional objects of the application: At the top of the patch, the four stations are depicted with their currently assigned buffer. The “brain” patch on the upper left side (see Figure 107), is responsible for conducting the buffer trades as well as routing the buffers to their respective speakers and microphones via the input and output mixers. Unlike Voice Patterns, the matrixes here are configured as 4x8 since the Silent Pool application employs 8 buffers and not 4. The random choosing of trade buffers are in the “trader” object which is location in the “4StationsTrade” object (see Figure 109). Here, four “trader” objects are communicating and constantly modifying the silent pool content which is handled by a “coll” object. The four input channels in the main patch are sent through the “DSPP” object (see Figure 110) which provides eight effect stations, identical to those in Voice Patterns, one for each of the buffers. The signal is then sent through the “fadetrade” object (as can be seen in the “main patch”), which is responsible for smoothing the fading of the traded buffers. From here the signals are sent to the speakers, in correlation to the configuration of the output matrix in “brain.”

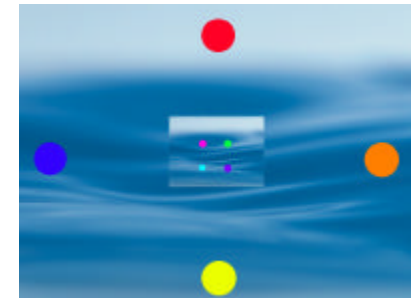


Figure 105. Idle mode – large circles for each station. Small circles in the Silent Pool.

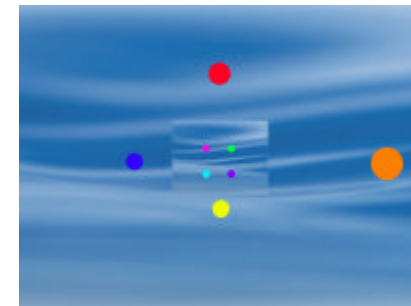


Figure 106. Buffers are faded in and out on their way to and from the Silent Pool.

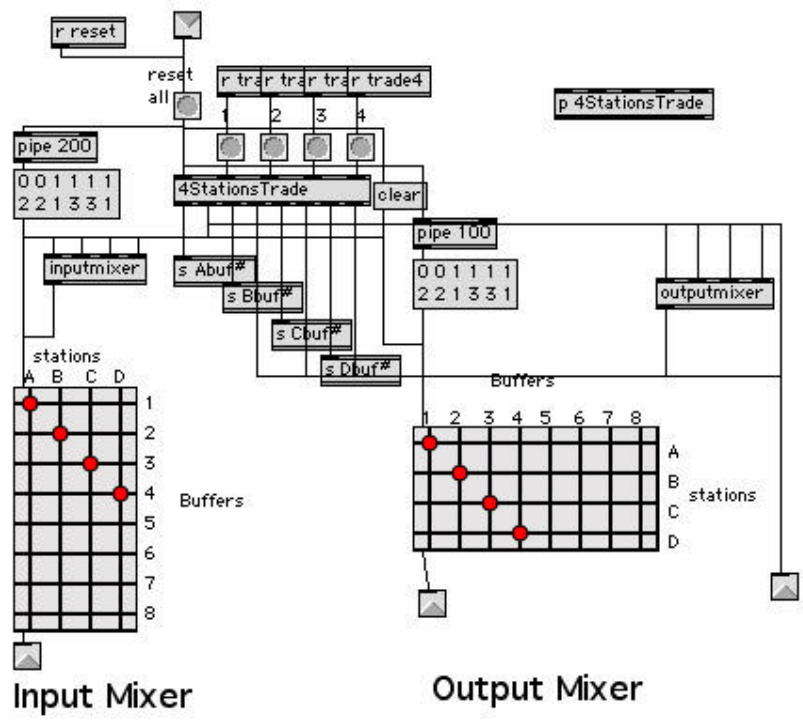


Figure 107. The “brain” patch in Silent Pool

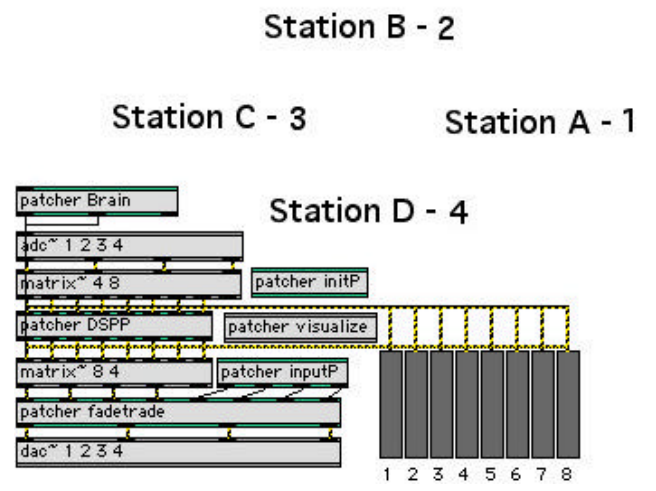


Figure 108. Silent Pool’s “main” patch

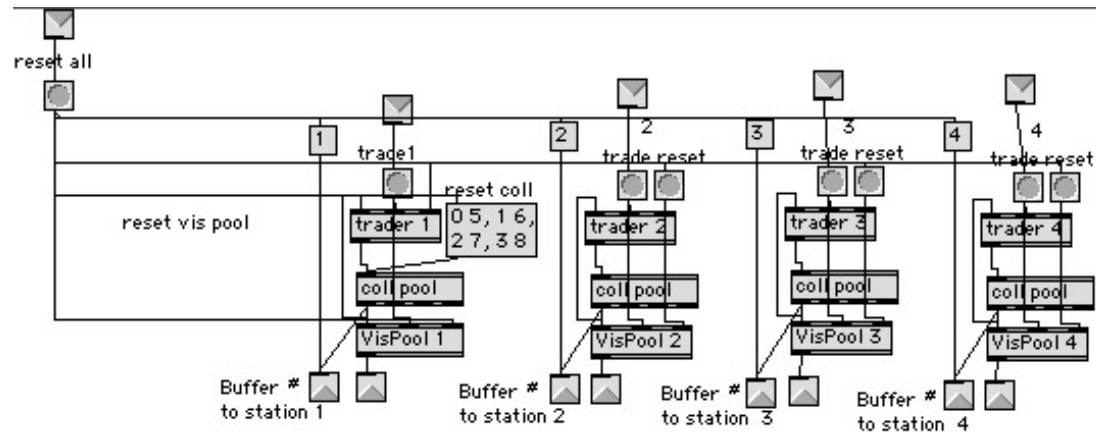


Figure 109. The “4StationsTrade” object – 4 randomizing “trader” objects modify the content of the Silent Pool.

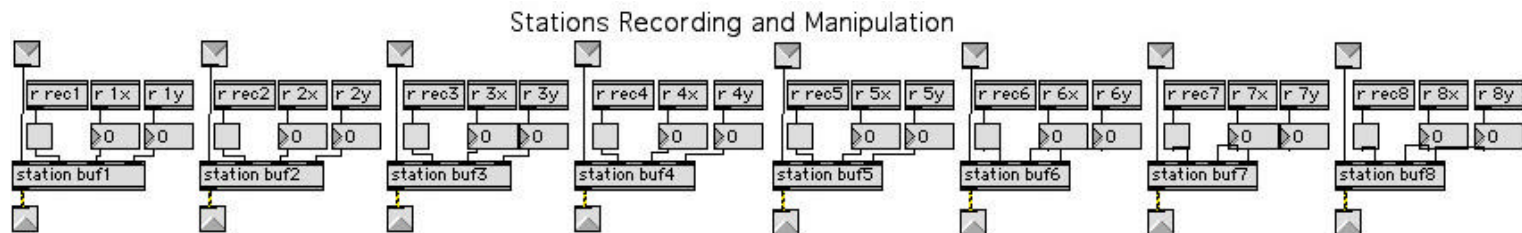


Figure 110 – The “DSPP” patch in Silent Pool includes eight “station” objects that are responsible for the sound effects.

7.3.3 Discussion

Silent Pool takes a variety of measures to address the four challenges that motivated its development. The four extra silent buffers allow players to trade with the system (i.e., the silent pool) rather than trading directly with each other. This helps turn players' attention from the graphical synchronization to more meaningful musical activities, allowing them to concentrate on the musical effect of their actions. It also grants each participant full control over the decision if and when to trade his or her sound, preventing unwanted interaction with the group. The long fading out and short fading in of sounds on their way from and to the silent pool enhances the dynamic range of the overall musical outcome. It also facilitates a more interesting motif-and-variation feeling to the experience, where a voice motif that was created and transformed in one station can be silenced for seconds or even minutes before it comes back to the foreground in another station. Here it can be further transformed, and sent to the silent pool, only to reappear later in another station. This behavior is especially effective for public space installations where the system can be left unattended by visitors for long periods of time. In such scenarios the system only needs a short initialization in which sounds are recorded into the buffers to automatically circulate all sounds around the system. Then, when new visitors approach the installation, they can record new sounds and utterly change the texture of the musical collage. Visualization is another advantage of Silent Pool in comparison to Voice Patterns. Unlike the one-to-one grid representation of Voice Patterns, Silent Pool features a more abstract visualization scheme that is focused on representing the network topology rather than each player's input. This too seemed to encourage players to concentrate on what they hear rather than on what they see.

There are, however, some weaknesses from Voice Patterns that have not been addressed by Silent Pool, as well as a number of new drawbacks that are idiosyncratic to the Silent Pool solution. Just as in Voice Patterns, the

learning floor in Silent Pool is simple and intuitive, but the learning ceiling is not challenging and intriguing enough. In comparison, the Beatbug network provided a higher ceiling and a variety of learning curves for reaching it. The main reason for the low ceiling, in my opinion, is that the system does not perform analysis of the voices, which could have led to more meaningful rhythmic, pitch or even harmonic correlations between the motifs. I believe that if players had been able to harmonize and better synchronize their voices to create more meaningful polyphonic structures, it could have led to more intriguing and accurate musical challenges and a higher learning ceiling.

The main new shortcoming that was introduced in Silent Pool is the compromised interpersonal interaction. By trying to maintain more coherent and undisturbed interaction for each player, Silent Pool only allows for synchronous interaction with the system. Interpersonal interdependency is available only in a sequential manner, which represents a step backwards from the hybrid approach of the Beatbugs. Another problematic decision was to take out the trading reward in order to encourage players to concentrate on the more abstract musical activities. While there is no doubt that Silent Pool produces more interesting and dynamic music, some players seemed to be less excited about the interaction and in most cases spent less time playing in comparison to their experience with Voice Patterns. It seems that a better balance between goal-oriented activities and abstract musical experiences is yet to be found.

8 Future work

Many of the problems that I attempted to address in my thesis work center on defining and maintain balances – How can an artistic collaborative activity cater to, challenge, and engage untrained children as well as professional experts? How can it facilitate the creation of a worthy artistic product as well provide a meaningful learning experience? How can it engage players in compelling competitive games, as well as facilitate productive collaborations? After developing a number of such artistic collaborative projects, I feel that these problems are still extremely difficult. I believe, though, that some of the IMNs that I have developed in the framework of my thesis work, particularly the Beatbugs network, presented successful methodologies and directions for balancing these motivations and challenges. I also hope that by referring to the theory of musical interdependency that I have formulated, future attempts at creating successful IMN will be more informed and successful.

However, I feel that my efforts to bridge and balance between novices and experts resulted in work that is positioned toward the lighter novice-oriented end of the axis. It seems that the IMNs that I have developed tended to be perceived as toys rather than serious tools that could facilitate the creation of a new collaborative art form. There are a number of elements that are missing from these networks, which I believe would be helpful in positioning my work more towards the artistic and thoughtful end of the gamut. One such feature is performing smarter analysis on input data from the players. By using pattern recognition algorithms to analyze gestural input, or by performing audio analysis of voice spectra, the system can know more about the intention and tendencies of players can facilitate more expressive and intuitive musical mappings. A related improvement would be to continue developing better algorithms for high-level percepts. An obvious candidate for such work is modeling the generative theory of tonal music by Lerdahl and Jackendorf in an effort to allow children and

novices to create expressive curves of tension and release in their music. More methodological and extensive work is also needed in order to evaluate the educational value of IMNs. Studies should be designed and performed during the development of the systems, while introducing the instruments to children, and later in time, in an effort to provide a wider perspective in regard to the learning process and product. More interviews and observations should be conducted with participants and viewers, using scientific methods such as control groups and statistic evaluation. The ability to transfer what was learned to other contexts should be tested over time, as well as the ability of players to move between the high- and low-level perception modes. In the long term I would like to explore whether my theoretical framework can be used in designing interdependent and collaborative experiences with other media such as text, video, animation, and speech.

Looking even further in time, I think that my work can be relevant for addressing a wider-scale problematic phenomenon – there is much talk today about the social isolation factor of technology. Parents are complaining about children spending hours alone in front of the computer or the television. Researchers show correlation between such activities and future problems in social behaviors. Only few believe that virtual or on-line relationships can serve as an alternative for in-person interaction. For most, it is clear that a physical eye-to-eye, mind-to-mind, gesture-to-gesture interactions are irreplaceable, especially when creativity is involved and multiple viewpoints are at play. I see this state of affair as an opportunity to further advance the use of technology for emphasizing, rather than marginalizing, the value of interpersonal group interaction. Music in general and IMNs in particular are just examples of a medium where such technological developments can be used. I can see a future where similar collaborative tools and instruments are used in an expressive and intuitive manner in almost every social activity, whether it is for work, leisure, study, or entertainment. I am especially excited about the possibility of facilitating and enhancing creativity with collaborative tools in social and educational environments. I am sure that successful products

of such collaborative creative and educational efforts could find public outlets and widespread recognition. And at the very least, such social instruments and applications bear the promise of encouraging their users to listen to and communicate with each other, to collaborate, to negotiate and to compromise. When transferred to other contexts, these traits should not be undervalued these days.

Appendixes

Appendix I “Nerve” score

“Nerve”

A composition for 8 Beatbugs (2–bar motif version)

by

Gil Weinberg

Nerve

Gil Weinberg

A ♩ = 147 A composition for the Beatbug Network using 2-bar motifs

Player 1 child
Player 2 adult
Player 3 child
Player 4 adult
Player 5 child
Player 6 child
Player 7 child
Player 8 child

Player 3 enters a motif, which is automatically sent to be transformed in 4 "variation-cycles" by players 5, 4, 7, and 1.
(In Free-play mode players are chosen randomly and can decide to enter their own new motif or to manipulate an existing one.)

In each "variation-cycle" players transform the motif's pitch, timbre, and rhythm using two bend-sensor antennae. (see Appendix)
Each developed motif can be sent to the next player, when ready, by hitting the Beatbug.

x 4

2

3

The image shows a musical score with eight staves. The first two staves are empty. The third staff contains a sequence of notes with stems and flags, including a measure with a beamed eighth and sixteenth note. The fourth staff contains a sequence of notes with stems and flags, including a measure with a beamed eighth and sixteenth note. The fifth staff is empty. The sixth staff is empty. The seventh staff is empty. The eighth staff is empty. The score is divided into two systems by a vertical line. The first system contains the first two staves and the first two staves of text. The second system contains the third and fourth staves of text and the remaining four staves. A double bar line is at the end of the score, with a repeat sign and a '4' indicating four repeats.

From player 1 the transformed motif is sent to player 4 who enters a new motif and sends it to 4 "variation-cycles" by players 6, 5, 1, and 7. The received transformed motif (#3) continues to play in Beatbug 4 at a soft level and can be manipulated in the background, when instructed.

As the piece progresses, more and more players will be keeping their own soft background motifs. At any given moment, the player who is in possession of the main high-volume motif also functions as a temporary conductor and can gesture to these accompaniment players to complement his playing by manipulating their own background motifs.

From player 7 the transformed motif is sent to player 1 who enters a new motif and sends it through 3 "variation-cycles" by players 2, 7, and 8.
 5 The received transformed motif (#4) continues to play in Beatbug 1 at a soft level and can be manipulated in the background, when instructed.

The image shows a musical score for 8 staves. The notation is rhythmic and includes various symbols such as 'x', 'v', and 'z' with stems and beams. The score is divided into two measures by a vertical line. The first measure contains rhythmic patterns on the top two staves, while the second measure contains more complex rhythmic patterns on the top two staves. A thick vertical bar at the end of the second measure indicates a repeat, with the text ':x 3' next to it. A small number '3' is located at the top right of the page.

4

7

From player 8 the transformed motif is sent to player 7 who enters a new motif and sends it through 2 "variation-cycles" by players 5 and 8.
 The received transformed motif (#1) continues to play in Beatbug 7 at a soft level and can be manipulated in the background, when instructed.

9

The musical score consists of eight staves, numbered 1 through 8 from top to bottom. The notation is a simplified form of musical notation, using stems, beams, and various symbols to represent notes and rests. The score is divided into two measures by a vertical bar line. A thick vertical bar at the end of the second measure is labeled 'x 2', indicating a repeat or a specific ending. The notation includes stems with flags, beams connecting notes, and various symbols such as 'x', 'v', and 'z' placed above or below the stems. Some notes have beams connecting them, while others are isolated. The overall structure suggests a complex rhythmic or melodic pattern being passed between players.

From player 8 the transformed motif is sent to player 5 who enters a new motif and sends it through 2 "variation-cycles" by players 6, and 2. The received transformed motif (#7) continues to play in Beatbug 5 at a soft level and can be manipulated in the background, when instructed.

6

11

The image shows a musical score for 8 players, represented by 8 horizontal staves. The notation is minimalist, using 'x' for notes, vertical lines for stems, and various symbols for dynamics and articulation. A vertical bar line divides the score into two measures. The first measure contains rhythmic patterns for several players, including a sequence of three notes with stems and a dynamic marking. The second measure continues these patterns, with some players introducing new motifs. A thick vertical bar on the right side of the score indicates a repeat, with a double bar line and a colon. The number '3' is placed to the right of this bar, indicating three repetitions. The score is set against a white background with black notation.

From player 2 the transformed motif is sent to player 6 who enters a new motif and sends it through 3 "variation-cycles" by players 8, 2 and 8. The received transformed motif (#5) continues to play in Beatbug 6 at a soft level and can be manipulated in the background, when instructed.

13

The musical score consists of eight staves. The notation includes various rhythmic symbols such as beams, accents, and dynamic markings. The score is divided into two measures by a vertical bar line. The first measure contains several rhythmic patterns with accents and beams. The second measure continues these patterns with some variations. A double bar line at the end of the second measure is followed by a repeat sign and the text 'x 2'. The staves are numbered 1 through 8 from top to bottom.

From player 8 the transformed motif is sent to player 2 who enters a new motif and sends it to 2 "variation-cycles" by players 8 and 3.
 The received transformed motif (#6) continues to play in Beatbug 2 at a soft level and can be manipulated in the background, when instructed.

8

15

The musical score consists of eight staves. The notation includes rhythmic patterns with 'x' marks and stems, some with beams and accents. A vertical bar line is at measure 18. A thick vertical bar at the end indicates a repeat.

From player 3 the transformed motif is sent to player 8 who manipulates it and then enters a new motif which is sent back to player 3.
The received transformed motif (#2) continues to play in Beatbug 8 at a soft level and can be manipulated in the background, when instructed.

x 1

17 **B** *Random Solo Mode. 1st Duo (For example - 1, 5)*

The image shows a musical score for a system of eight bugs. The score is divided into two measures by a vertical bar line. The notation is as follows:

- Measure 1 (Left):**
 - Staff 1: A sequence of notes with stems pointing up, each marked with an 'x' and a 'v' above it. The notes are connected by horizontal lines, indicating a melodic line. A fermata is placed over the final note of this sequence.
 - Staffs 2, 3, 4, 5, 6, 7, 8: Each staff contains a single note with a stem pointing down, representing a simultaneous hit from all bugs.
- Measure 2 (Right):**
 - Staff 1: A sequence of notes with stems pointing up, each marked with an 'x' and a 'v' above it. The notes are connected by horizontal lines. A fermata is placed over the final note of this sequence.
 - Staffs 2, 3, 4, 5, 6, 7, 8: Each staff contains a single note with a stem pointing down, representing a simultaneous hit from all bugs.

The score concludes with a double bar line and repeat dots on the right side of each staff.

On simultaneous hit from all eight bugs, conducted by player 3, the system solos a random duo.
The chosen players improvise by manipulating their motifs until the next simultaneous hit.

10

Random Solo Mode. 2nd Duo (For example - 3, 8)

19

The image shows a musical score for 8 staves. The notation is rhythmic and includes various symbols such as vertical lines with flags, horizontal lines with flags, and beams. The score is divided into two measures by a vertical line. The notation is sparse, with many empty staves. The symbols are arranged in a way that suggests a specific rhythmic pattern or sequence of events.

On simultaneous hit from all eight bugs, conducted by player 3, the system solos a different random duo.
The chosen players improvise by manipulating their motifs until the next simultaneous hit.

21 *Random Solo Mode. 3rd Duo (For example - 4, 6)*

The image shows a musical score for a 3rd Duo. It consists of eight staves. The top four staves are mostly empty, with some rhythmic markings (vertical lines with flags) and a few notes. The bottom two staves contain more complex notation, including notes, rests, and a slur. A vertical line divides the score into two measures. The right side of the score ends with a double bar line and repeat dots.

On simultaneous hit from all eight bugs, conducted by player 3, the system solos a different random duo. The chosen players improvise by manipulating their motifs until the next simultaneous hit.

12

23 *Random Solo Mode. 4th Duo (For example - 2, 7)*

The image shows a musical score for eight staves. The notation is minimalist, using vertical stems with various symbols above them: a 'v' with a horizontal line, a '7', a 'D' with a vertical line, and an 'x' with a horizontal line. The score is divided into two measures by a vertical line. The first measure contains rhythmic notation on the second and eighth staves. The second measure contains rhythmic notation on the second and eighth staves, with a horizontal line connecting two 'x' symbols on the second staff. A thick vertical bar at the end of the score indicates a repeat, with 'x 2' written to its right.

On simultaneous hit from all eight bugs, conducted by player 3, the system solos a different random duo.
The chosen players improvise by manipulating their motifs until the next simultaneous hit.

25 *Random Solo Mode. 1st quartet (For example - 1, 2, 4, 7)*

The musical score consists of eight staves. The notation is as follows:

- Staff 1:** Measure 1: x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam). Measure 2: x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam).
- Staff 2:** Measure 1: x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam). Measure 2: x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam).
- Staff 3:** Measure 1: x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam). Measure 2: x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam).
- Staff 4:** Measure 1: x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam). Measure 2: x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam).
- Staff 5:** Measure 1: x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam). Measure 2: x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam).
- Staff 6:** Measure 1: x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam). Measure 2: x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam).
- Staff 7:** Measure 1: x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam). Measure 2: x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam).
- Staff 8:** Measure 1: x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam). Measure 2: x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam), x (with stem and beam).

On simultaneous hit from all eight bugs, conducted by player 3, the system solos a random quartet. The chosen players improvise by manipulating their motifs until the next simultaneous hit.

27 *Random Solo Mode. 2nd quartet (For example - 3, 5, 6, 8)*

The musical score consists of eight staves, arranged in two groups of four. A vertical bar line divides the score into two measures. The notation is a simplified form of musical notation, using stems, beams, and various symbols to represent notes and rests. The symbols include 'x' and 'v' with stems, and various beams and accents. A thick vertical bar at the end of the second measure indicates the end of the section.

On simultaneous hit from all eight bugs, conducted by bug 3 randomly, the system solos the other random quartet.
The chosen players improvise by manipulating their motifs until the next simultaneous hit.

29 **C**

Finale - Full octet. Full volume.

15

The image displays a musical score for eight percussion players, arranged in eight staves. The score is divided into two systems by a vertical bar line. The first system contains measures 29 through 34, and the second system contains measures 35 through 40. Each staff begins with a double bar line and a 'C' time signature. The notation consists of rhythmic motifs represented by 'x' marks on the staff lines, with various stems and beams indicating the timing and grouping of the hits. Some motifs are repeated across multiple staves, while others are unique to a single player. A thick vertical bar at the end of the second system indicates the end of the piece. The score is written in a clean, black-and-white style.

On simultaneous hit from all eight bugs, conducted by player 3, the system brings up all eight motifs.
All player interdependently manipulate the motifs they kept.

16

31

The musical score is presented on eight staves, organized into two systems of four staves each. A vertical bar line separates the two systems. The notation is minimalist, using 'x' marks, stems, beams, and accents to denote rhythmic events. In the final measure of the second system, a thick horizontal line spans across all eight staves, indicating a simultaneous hit from all eight bugs. The score concludes with a double bar line.

Last simultaneous hit from all eight bugs, conducted by player 3, ends the piece.

Appendix II “Nerve” press reviews

Gil Weinberg's “Nerve” for six children, two adult percussionists, and eight networked Beatbugs brought down the house with sheer rhythmic exhilaration.

Dyer, R. 2003. “‘Toy’ Brings Joy of Music to Life.” *The Boston Globe* April 28, 2003. Art section. p.B10

When I tried the Beatbugs and Music Shapers I felt a tactile surge of pleasure more than an intellectual one. The instruments are, of course, less demanding than traditional ones, and in the end might be less enriching. But they are not designed as ends. They are designed to offer the pleasure of music before the pain of making fingers do unheard of things. Who really knows what's going on when the muscles are being trained? Perhaps, if children's hands are speaking to their brains during violin practice, they are shouting: "Help! Get me out of here!" I don't know what they're saying when they play with Beatbugs and Music Shapers, but I'll bet they're laughing with pleasure.

Gorman, J. 2003 “Playing Music as a Toy, and a Toy as Music.” *The New York Times* June 3, 2003

Gil Weinberg's “Nerve” created for rhythm computers called "Beatbugs," had verve and propulsive energy.

Powers, K. 2003. “BMOP and pals boldly explore Machover’s classical visions.” *Boston Herald*, April 28, 2003. Music Review

Gil Weinberg's “Nerve” for six children and two percussionists playing eight networked Beatbugs, ably showed off the invention, though the percolating music was more fun for the jousting it incited between the players than for content.

Tommasini A. 2003. “Music Review; Toys Take Little Ears On Trips In Sound.” *The New York Times* May 20, 2003

“Nerve” by Gil Weinberg, in which six older children tossed rhythms back and forth among networked Beatbugs, was more engaging and interactive.

Waleson, H. 2003 “With Gadgets and Fun, Toy Symphony Lures Kids Children and Music.” *The Wall Street Journal* May 21, 2003

A beat bug ensemble from Sacred Heart Primary gave a balletic performance of Gil Weinberg’s “Nerve” throwing complex rhythmic surprises between one another like a game of pass the parcel.

Walton, K. 2002 “Classical Music Review.” *The Scotsman* June 4 2002

Gil Weinberg’s “Nerve” and Tod Maccover’s Toy Symphony demonstrated effective and pleasing composition.

Wang, J. 2003 “Toying With the Limits of Music” *The Tech* April 29, 2003. p. 9

Gil Weinberg's “Nerve” demonstrated the beatbugs, the kids turning back and forth as they “threw” the rhythms around. They all looked serious and wildly active, as if playing a fast sport, at one point splitting into teams of four. But the sound was confusing and the rhythms very difficult to follow. The effect was of watching video games when you don't understand the rules. It looks like fun, but there's no telling what's going on.

W. Connard, J. 2003. “Toy Symphony Review,” *The Star Ledger* May 19, 2003

The Beatbug performers (six children and two professional percussionists) improvised duets, quartets and finally an octet that looked like a light-saber battle from “Star Wars.”

Wright, S. H 2003. “Toy is a joy in U.S. premier performance at MIT.” *Tech Talk* April 30, 2003 p.4

Appendix III Interviews transcripts

Transcribed from “Techno Alert,” produced by David Gallagher (david.gallagher@bbc.co.uk) for BBC Radio 3. Broadcasted, Sunday October 13th, 2002, 17:45-18:30 UK time.

- Question - What was it like when you first picked up this thing and it began making the noises? What did you feel like?
- Kid 1 - Famous (laughing)
- Kid 2 – It’s brilliant
- Kid 3 - It really good, it’s really exciting
- Kid 4 - It’s because you pass sounds to each other. And it is like talking to each other.
- Question - Is it as fun as talking to each other?
- Kid 4 - Much more fun (laughing) because it’s different, it’s kind of different because it is sound that you are passing.
- Kid 2 -It makes you want to play instruments because when you play the Beatbugs you enjoy it.
- Kid 3 - Some instruments you’ll have you go mmm.. this is too hard...but Beatbugs show you that it is not always so hard. You can enjoy yourself.
- Parent 1 – Well, it is like a game, but it is actually more than a game. We have two daughters and they are both very interested in

music, and especially this is more attractive than normal music (laughing). It is a fun way to learn, at home.

- Parent 2 - This is something I feel that can empower them to feel that music does have something to do with them. I mean I was sitting thinking how atonal the compositions were, I mean just that. And maybe it is something to do with just not knowing that that's possible within them. Suddenly they can hear something and Wow, I did that.
- Parent 3 - It is fantastic and we were just saying how lucky we are to be alive at this time when technology is changing so rapidly. And obviously there are a lot of refinements to be made but you can see the potential. Especially for our kids.
- Electronic Art curator - This playful interactive situation...humans you know are Homo Ludens... we are playful creatures and this technology offers us now a way not just to play in a simple childish way but really to use the strategy of playing, which we call then Interactivity, in a way that gives us new access to what art, what music really can be. ... At the moment we are still in a phase of a strong transformation. In the next years we will see more and more this development from the early experiments where we mainly had fun with trying out these new toys, to a more and more virtuoso use of these technologies, and I think there are already composers who are really extremely virtuosos of interactive music.

Appendix IV Project Zero report on the Toy Symphony

Prepared and sent to the Toy Symphony team by:
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The mission of Project Zero at the Harvard Graduate School of Education is to “understand and enhance learning, thinking, and creativity in the arts, as well as humanistic and scientific disciplines, at the individual and institutional levels.” The Toy Symphony Research Team at Project Zero includes Howard Gardner, Veronica Boix Mansilla, Caitlin O’Connor and Michelle Cheuk.

Congratulations for its success in the concert hall and in the classroom. You have pulled it off with flying colors and, importantly, have done meaningful work with school communities and the children. Nothing about it seemed easy, and you have every reason to be proud about the accomplishment.

Included is a brief summary of my observations on educational aspects of your work with children. They are based on interviews I had with children (6 Beatbugs, 4 Shapers, 3 Hyperscore = 13 children), musicians (5), and teachers (3).

Benefits & impacts of the Toy Symphony experience

For everyone I spoke with TS has been an overwhelmingly positive experience either from the musical, social or personal standpoint. Even the interviewees, who continue to question the value of technology in music and try to define its part in music education, admit that the experience provided a good foundation on which to build one's musicianship, social skills, self-confidence, and general learning dispositions (focusing, listening, and practicing).

Social (interpersonal)

- listening to each other; giving each other room in conversation;
- paying attention to body language and learning to adequately interpret it;
- children in workshops became better friends overall.

Interpersonal (confidence building)

- self-esteem, confidence, overcoming shyness and introversion;
- sense of mastery, fostering "I-can-do-it" mentality.

General learning/cognitive skills enhanced:

- concentration, increased attention span;
- greater participation of children in the discussions, and better listening to each other;
- greater learning motivation;
- ability to work under pressure;
- energy and focus;
- public behaviour skills;
- technology helped to break down the barriers between children and teachers/adults by putting both in the learning mode.

Musical skills

- children learned complex musical patterns, stage behavior, gained an understanding of rhythm, learned some musical vocabulary ("motive," "pattern," "orchestra")
- they reported that they might apply it to Scottish/Irish dance, acting, learning instruments – guitar, fiddle, piano;

- the kinesthetic experience on stage might help some children to be more expressive with their body as they play the fiddle, for example. Musicians reported similar things: The TS experience made them less inhibited on stage and gave them more freedom of movement with and around their instrument (trumpet, double bass);
- the children commented on the sense of ownership and connection to music through the experience of “making it” directly;
- they learned that music involves practicing, and that you don’t get it right the first time;
- the experience of following conductor cues, timing movement and sound, and playing with the orchestra;
- technology, according to Mary Troup, helped children cope with the solitude of music practice, which could be frustrating and isolation for young children. TS made it possible and an imperative to practice in small groups, giving a chamber ensemble experience.

Children’s suggestions for perfecting the toys or the workshops

Note that I interviewed children at the very end of the training process, so some of their responses are based on having spent time with the toys and possibly having “exhausted” some of the immediate potentialities of Shapers and Beatbugs. In other words, there are things that children put on the wish list for the next stage of working with these “toys”:

- Add more buttons, make it “look like a little piano on top”
- Make a musical effect specific to the kinesthetic (in Gili’s terminology it may suggest a move from “immersive,” purely kinesthetic play to some analytical thinking)
- More controls, more things to push and play with besides antennae
- Make them wireless

Questions raised

Sustainability of the experience – What do we do next? How do we build on this? How can we make it the whole school community thing rather than limit it to a few students? How can we use this to support music

education? Is there a piece of the curriculum that is being developed to support Hyperscore or toys? Can it be tied to a general music curriculum or the learning of an instrument? How can technology be made more reliable, relevant and accessible to any teacher? What is lost in taking the shortcut towards mastery? Is hard and solitary experience of classical training essential to the ultimate enjoyment of music and the instrument? Can the repertoire of what “toys” can do be expanded? Can children be given more control over alteration of sound in Beatbugs and Shapers?

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