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ABSTRACT OF THE THESIS

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As a composer and performer of improvised music, I find my interest drawn to the relationships formed during the act of music-making. These relationships take shape inside an ensemble, between the performers and the composer, and between the ensemble and the audience. Using Digital Musical Instruments in musical performance affords us new ways of thinking about and exploring these relationships. These instruments also provide performative and compositional challenges which need to be overcome in order to realize a successful performance.

This paper draws on concepts from the Physical Computing community in order to present instruments that solve these challenges while also describing new strategies for musical collaboration. These strategies are examined in the work of early digital music ensembles The Hub and Sensor Band, in the recent work of the Princeton Laptop Orkestra, and in work I have completed with the Physical Computing Ensemble at UC Irvine. These ensembles are examined not only for how they use technology, but also

what kind of relationships are created in their performances, how those relationships are influenced by their modes of performance, and what kinds of musical meaning we can draw from their performances.

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Introduction

The work in this paper grew out of two questions: why is music so important to me, and in what kinds of musical experiences do I want to participate? Looking over my early experience as a musician, I came to realize that it was the human relationships surrounding music that made it so fulfilling. In particular, my training in the African-American improvisatory tradition formed my belief that music should be a collaborative event, one in which the participants blend their individual voices together to make a collective experience.

As my interest in electronic and computer music grew, I looked for ways of integrating it with my interest in human relationships. In particular, I wanted to maintain a sense of meaningful interaction between performers; meaningful in the sense that the connection between the performers' actions and their resultant sound is apparent — and apparent not only to the individual performer and their fellow ensemble members, but also to the audience and other participants in the musical event.

In this paper I will describe several technical approaches to interaction in a Digital Music Ensemble — approaches which leverage the information processing potential of the computer. I will begin and end, however, with the perspective that these approaches help to articulate relationships brought into existence during the act of musicking. And for me, it is these relationships that create a meaningful musical experience — the kind of experience which drew me into music, and for which I am always searching.

1 — The Human in Computer Music

In his book entitled *Musicking*, Christopher Small argues that musical meaning derives from the relationships which are formed during the act of music-making. In particular, Small says:

> The act of musicking establishes in the place where it is happening a set of relationships, and it is in those relationships that the meaning of the act lies. They are to be found not only between those organized sounds which are conventionally thought of as being the stuff of musical meaning but also between the people who are taking part, in whatever capacity, in the performance; and they model, or stand as a metaphor for, ideal relationships as the participants in the performance imagine them to be: relationships between person and person, between individual and society, between humanity and the natural world and even perhaps the supernatural world. These are important matters, perhaps the most important in human life, and how we learn about them through musicking is what this book is about. (Small, 1998)

This argument focuses on the act of *musicking* rather than the created musical object. In other words, we must look at the act of musical performance in order to answer questions of why we create music and what music says about the world we create for ourselves. In Small's view "musical scores are created in order to give performers something to play, rather than the other way around." In this context it is worth taking a look at the history of computer music since it is closely tied with the history of recording technology, and in fact many of the most important pieces of computer music were created without performers in mind.

Certainly, it is true that the way in which we experience and disseminate music in the last half-century has predominately been in the form of recordings. However, when we look at computer music in particular, we can see that there has always been a strong movement to bring that recorded music into the physical world in particular ways. Varése's *Poéme Électronique* was an early work utilizing complex spatialization using multiple speakers (in Varése's case, hundreds of speakers). Currently, multi-speaker sound systems are not uncommon in performances of fixed media computer music compositions, compared to the common stereo speaker system utilized by most commercial music.[1]

The liberation of sound made possible by computers freed composers from using sounds generated by the acoustic world. Recently Ge Wang, the director of Stanford's Mobile Phone Orchestra (MoPho), waxed poetic about "the computer's precision, possibilities for new sounds and for fantastical automation to provide a boundary-less sonic canvas on which to experiment with, create, and perform music." (Wang, 2009) In creating work for this blank canvas, however, composers often draw inspiration from the physical world. This can take the form of the creation of imaginary "sonic spaces," utilizing psycho-acoustics for musical effects, and with systems of multiple speakers using physical location of sounds in space as fundamental musical material. These kinds of focus on the physical world reflect the reality that music only occurs when we hear it — as information on a hard drive, it is inert. It is only when we use headphones, stereo systems, multi-speaker sound systems, or other methods of sound reproduction that the relationships inherent in a musical work are made manifest. Thus playing back pre-recorded compositions in the form of "tape" or fixed media works can constitute a musical performance, with all of the implied layers of relationships. When compositions call for complex multi-speaker sound systems, we can see a little more clearly that the moment and action of these kinds of fixed media performances are closely related to the performance of music ensembles.

[1] Six or Eight Channel surround sound speaker systems are also common in commercial and home theaters, but the use of these systems for solely musical purposes is rare.

2 - Digital Music Ensembles

There is also a long history of live performance of computer music. However, there was a long gap between the beginnings of computer music composition and computer music performance. This was primarily due to the fact that with early computer music systems were non-real time; it could take up to two weeks before a composer could hear the sonic result of her composition. It wasn't until the mid-1970's that real-time computer music systems became commercially available, with the New England Digital Corporation's Synclavier being a notable example. (Chadebe, 1996)

In the following section, and throughout the rest of this paper, I will refer to *Digital Music Ensembles*. My concept of a Digital Music Ensemble (or DME) borrows from the definition of a Digital Musical Instrument, which Miranda and Wanderley define as:

> an instrument that contains a control surface (also referred to as a gestural or performance controller, an input device, or a hardware interface) and a sound generation unit. Both units are independent modules related to each other by mapping strategies. (Miranda, 2006)

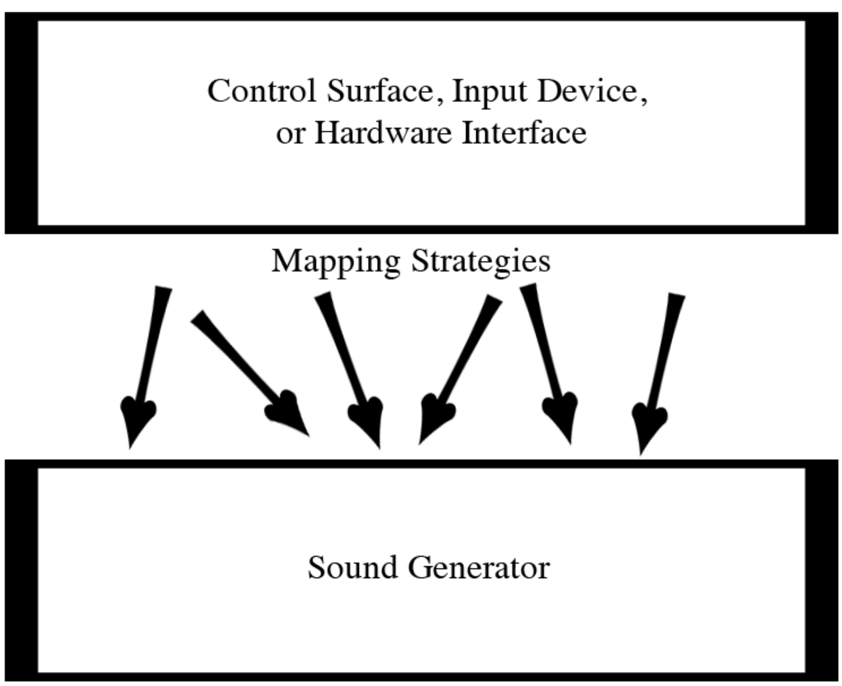

Illustration 1: Schematic of a Digital Musical Instrument

The separation of control surface and sound generator is of primary importance, for it allows many new ways of musical performance. Perhaps the simplest example of a DMI is a common synthesizer keyboard, such as a Yamaha DX7. The control surface takes the form of a piano keyboard. While the act of creating music on a synthesizer resembles playing a piano, a piano always sounds like itself while the sound created upon playing a synthesizer keyboard varies depending on the settings of the sound generator.

A *Digital Music Ensemble* (or DME) is an ensemble whose members all use Digital Musical Instruments. This restriction of instrumentation is important because it allows a DME to focus on approaches to music making which are idiomatic to computer music. Below I discuss two important DME's, The Hub and Sensorband, before taking a deeper look at one of the most influential current DME's, the Princeton Laptop Orkestra.

The Hub

The Hub grew out of the League of Automatic Music Composers, based at Mills College in the San Francisco Bay area. The primary focus of The Hub was network-based sharing of musical materials and collaborative music making. The Hub got its name from a hardware interface built by John Bischoff and Tim Perkis. Each member of the ensemble would connect a personal computer to The Hub. The compositional strategies the ensemble employed were based on strategies of interaction. (Chadabe, 1996) For example, in the piece *Is It Borrowing or Is It Stealing* "each player played a melody of his choosing and electronically reported to the group what he was playing, whereupon the other players were free to borrow or steal this melodic information and use it in some way."

In another example, *The Minister of Pitch*, different players were assigned control of different musical elements. This can be described as the parameterization of musical elements, and it is one way of performing with a DME which I explore in pieces for the

Physical Computing Ensemble. By using parameterization of musical elements one musician may be responsible for setting the tempo and meter of a composition while another may be responsible for determining the pitch material.

Sensorband

Sensorband was “an ensemble of musicians who use(d) sensor-based gestural controllers to produce computer music.” (Bongers, 1998) The members of Sensorband — Atau Tanaka, Edwin van der Heide, and Zbigniew Korkowski — were each soloists on different Digital Musical Instruments: Tanaka on the electro-myogram based BioMuse[2], van der Heide on a glove based midi controller, and Karkowski on an instrument which used infrared beams mounted on a scaffold to detect physical gestures. Sensorband also performed together on *Soundnet*, a gigantic musical instrument built as a web measuring 11x11 meters. The members of Sensorband would climb on Soundnet, which had sensors which determined how much weight was on each strand of the net. Since all three performers would be on the web at the same time, the interaction of their movements would determine the sensor data used for sound generation.

[2] Although Tanaka focused mostly on the electro-myogram, BioMuse actually contains several different kinds of bio-sensors.

3 - PLOrk

The Princeton Laptop Orkestra, or PLOrk, was founded by Dan Trueman and Perry Cook in 2006, and has been very influential in the development of a new trend in academic laptop ensembles. One of the reasons for PLOrk's influence is that in its first year Trueman, Cook, and other participants published several papers describing PLOrk's beginning, its function in an academic institution, and discussing the challenges it poses for composers and performers. PLOrk received immediate attention from around the world — in 2006, the same year as PLOrk's founding, Dan Trueman said "It's much more than I bargained for . . . I'm delighted and terrified by the level of interest." (Arendt, 2006)

Why was there such an immediate interest in PLOrk's activities? Dan Trueman begins his article entitled "Why a Laptop Orchestra?" by claiming that "the notion [that] a 'laptop orchestra' is seemingly paradoxical is one of my prime motivations for creating one: the pairing of these two inventions is perhaps obvious only because of its apparent impossibility." (Trueman, 2007) There is an element of cross-validation in this statement. The prevalence of both of these institutions in academic music comes from different sources — the orchestra being a link to the western musical tradition and the industrialist roots of western society (Small, 1998), and computer music representing the continuing achievements of a technologically oriented society. Thus the laptop orchestra is cast as being a continuation of a tradition that goes back to the roots of modern western society, giving it a legitimacy it might not have attained were it called a 'laptop band'.

However, the fascination with PLOrk goes beyond this institutional legitimization. I believe that PLOrk builds upon the common idea of the democratization of the personal computer, and in particular the laptop. Portable computers have come to be seen as an indispensable part of our lives, used for everything from communication to artistic creation. There is an ever increasing number of computer applications which attempt to allow non-musicians to create fulfilling music with little or no musical training, although these kinds of computer-based instruments tend not to have same the cultural legitimacy as traditional western orchestral instruments. PLOrk validates the laptop as a musical instrument by placing it in an academic context, with compositions by professionally trained composers and concerts in well-equipped recital halls. However, PLOrk maintains its pluralist ideals — in its first year Trueman explicitly stated that "the only requirement for PLOrk members was prior musical experience of some kind."[3] (Trueman, 2006)

One of PLOrk's defining characteristics is the design of the ensemble member's performance systems. In PLOrk, each performer has a networked laptop, which is connected to a power amplifier and a six-channel hemispherical speaker. These speakers are used "to give each performer their own spatial identity" (Trueman, 2007) similar to an orchestral instrument. The hemispherical speakers and the localization of the performer's sound can also be seen to come out of the same tradition as multi-speaker sound systems used by fixed media composers. These speakers, and the concept of each performer having their own amplification system, have been very influential in more recent DME's such as the Stanford Laptop Orchestra, and I adopted a variant of this approach for the Physical Computing Ensemble discussed below. It is interesting to note that the concept of PLOrk's performer localization is perhaps as compelling as the empirical results — at least for those of us who haven't seen them perform live and whose experience with PLOrk's music is through the documentation on their website, which is mixed in stereo.[4]

Another important characteristic of PLOrk is the emphasis on the use of the physical laptop as the primary instrument. The standard keyboard and trackpad inputs are

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[3] There is an offshoot "pro" plork band called Sideband — "professional level musicians (mostly former and current graduate student who were involved with plork) — aiming at more continuity and higher-level compositional and performance possibilities." (Trueman, personal correspondance, 2010)

[4] All PLOrk compositions discussed here can be found online at http://plork.cs.princeton.edu/

the primary source of performer control, but many other sensors embedded within modern laptops, such as accelerometers and webcams, are used as well. While there are PLOrk compositions that use external sensors, notably using the Gametrak[5] tether controller (Trueman, private correspondence), the concept of the laptop as instrument remains central to the PLOrk aesthetic. The use of the laptop/speaker performance system provides the clearest connection to a standard western orchestra, with each member physically and sonically located in a fixed position.

An important way in which PLOrk differs from the earlier DME's described above is in the instrumentation of the ensemble. In The Hub each musician designed and built their own instrument, and each instrument consisted of a unique configuration of hardware and software. (Trueman, 2007) The members of Sensorband became expert performers on instruments with radically different conceptions. In contrast, PLOrk musicians perform on identical hardware instruments, typically Apple MacBooks.[6] The laptop can be seen as the control surface of a Digital Musical Instrument as described by Miranda and Wanderley. The mapping and sound generation elements of PLOrk instruments reside in software, are developed by composers, and are frequently intended to be used only for specific compositions, as is the case for *Autopoetics I* below. It is typical for the musicians in a PLOrk composition to use identical software instruments (which may have different preset configurations). In this way, the distribution of instruments in PLOrk can be seen to resemble that of an orchestral string section.

[5] A further description of the Gametrak controller can be found at http://http://en.wikipedia.org/wiki/Gametrak.
[6] Although it is common for PLOrk compositions to utilize external sensors the laptops used as the primary instruments remain identical.

Autopoetics I

> Most of the compositional problems that stepped forward while developing the Autopoetics pieces have had to do with designing constraints of the right kind and reach. . .For better or worse, Autopoetics III[7] assumes more risk. I wanted it to be capable of producing bad sounds (it is), bad music (it is), and for players and listeners to know it (they might, depending). - Ted Coffey (Coffey, 2010)

> The piece is an ‘open work’, and probably more devoted to its system—or poetics— than to its musical success. – PLOrk Spring Concert 2009 Program Notes (PLOrk, 2009)

To get a better feel for the way PLOrk manifests itself, I would like to take a look at a PLOrk composition. Ted Coffey composed *Autopoetics I* while a PhD composition student at Princeton. *Autopoetics I* was performed by PLOrk in Spring 2009 and is based on the idea that “players share real-time control over sequences of events. Roughly speaking, 'events' consist of ca. 100 to 7000 millisecond bits of enveloped sounds of the classic synthesis variety. Any player may create, delete, and reorder the events in her sequence. She may also determine how her sequence is traversed, the 'stream' it's in, its pitch language, and lots more.” (Coffey, 2010) Players have access to a software instrument with which to modify the events in their sequence.

The piece is an open work in that no actual performance instructions are written and the score consists solely of instructions on how to operate the software instrument. Coffey suggests players can either “start from nothing, no events, just go” or “before playing, talk up a description of some big trajectory; go after it.” Coffey conducted the 2009 PLOrk performance by periodically holding up signs with predetermined performance directions on them. The piece therefore took the form of a conducted improvisation[8], however there is no indication that this is the only way in which the piece may be approached.

One of the defining structures of Autopoetics I is that players share control of the

[7] Autopoetics I was performed by PLOrk on their spring 2009 concert while the version of Autopoetics Coffey made available to me is Autopoetics III. The different versions are functionally equivalent.
[8] Similar in concept to Butch Morris’ work using Conduction.

details of the composition. There are two musical “streams” in the piece, which play concurrently. Each stream has four sequences that it plays through linearly. Three players share control of each sequence. So each musician only has control over one sequence, and must share that control with two other players. Within their sequence, a player can add, modify, delete or re-order events, as well as control whether the sequence is played forwards, backwards, or both sequentially.

When creating or modifying a musical event, a player can change six macro parameters and three sub parameters. The macro parameters are sound type, duration, frequency (pitch), gain, macro envelope, and reverb. The player can also choose to have up to nine sub events. Each sub event is controlled by both the macro parameters (except macro envelope) and the sub parameters, which are sub duration and sub envelope. The sub envelope determines the amplitude envelope for a sub event, and the macro envelope determines the amplitude envelope for the entire event.

What is important to note here is players are limited in what values they can assign to these parameters. For example, the frequency parameter can only be set to thirteen values, the available values being “integer divisors of 44100 that yield other integers.” There are twelve different sound types, five envelope types, twelve durations, and from one to nine sub events, all evenly spaced. There is a marked preference given to timbral manipulation, in that of the nine parameters, five control timbre, three control rhythm, and only one controls pitch. Also, timbre is the only element that can change within the course of the event.

This piece demonstrates several important layers of interaction. In addition to the collaborative nature of the shared sequences, I am also interested in the relationship between composer and performers. Despite the lack of performance instructions and the open form, the composer’s aesthetic sense is the dominant element in the overall sound of the piece. The question in a piece like this is what degree of control is granted to the performer by the composer, and what forms does this control take. The structure of the sequences and streams as well as the predetermined timbral options represent fairly severe performance constraints. The predetermination of possible parameter values controls the relationships between events (for example all duration values are even multiples of the two shortest duration values). The attention of the performers is pushed away from precise control of musical elements, and onto the ordering of events in the stream — and thus into the realm of the collaborative control between performers. In a sense, the form of collaboration between performers is not only determined by the composer but also is privileged by the constraints given by the composer.

4 - Physical Computing Ensemble

> The laptop orchestra presents a challenging field of opportunity to both explore the appeals of making music in large numbers – people and their relationships are front and centre in this ensemble – and see what might be possible with new technologies. – Dan Trueman, *Why a Laptop Orchestra?* (Trueman, 2007)

I co-founded the Physical Computing Ensemble (or PCE) in order to explore computer music performance in the spirit of Trueman's quote above, and also to explore music-making using the principles of *physical computing*. Tom Igoe is a professor in NYU's Interactive Telecommunications Program (ITP) and co-author of the book *Physical Computing: Sensing and Controlling the Physical World with Computers*. Igoe describes physical computing as "an approach to learning how humans communicate through computers that starts by considering how humans express themselves physically." (Igoe, 2011) This statement encapsulates several key aspects of the PCE. Considering how humans express themselves physically refers to more than just the use of expressive gestures such as hand movements. It also includes the ways in which we position ourselves in space — whether we face each other, move closer and further away from each other — as well as the ways in which we use eye contact and subtle physical cues. These physical expressions are then used as the conceptual frameworks for computer-mediated forms of human communication. In particular I want to emphasize that in physical computing the focus moves away from human-computer interaction and towards human interaction as mediated by a computer, which is a subtle but meaningful shift.

There are many reasons why I chose physical computing as the framework for a digital music ensemble. By focusing on performer action and placement in the physical world, the PCE attempts to honor the sentiments of many computer musicians who feel that the correlation between visible performer gesture and sonic result is an important part of audience experience. Chris Dobrian states “the expressivity of an instrument is dependent on the transparency of the mapping for both the player and the audience.” (Dobrian, 2006) John Croft has also noted the importance of this consideration in his *Theses on Liveness*. Croft states that in order for live performance of electronic music to be meaningful there must be a “causal link between the performer’s action and the computer’s response.” (Croft, 2007)

The PCE also takes advantage of wireless technology to free performers from a fixed location onstage. This allows for forms of physical expression that aren’t possible for performers tied to an immoveable instrument, both in terms of types of gestures available as well as shifting physical relationships between ensemble members. Both of these elements are important aspects of the Physical Computing Ensemble performance described below.

The sole performance interface used by the PCE in this performance is the Nintendo Wiimote, a wireless video game controller developed for the Nintendo Wii gaming system. The Wiimote is a handheld device with many integrated sensors, including a three axis accelerometer, a four position directional pad, trigger button and 7 additional buttons, and an infrared signal detector. While I experimented with numerous ways of using the sensors built into the Wiimote, in the end I chose to use only the accelerometer and two pushbuttons. The two buttons used are the button Nintendo labeled as “A” which is on the top of the Wiimote and pressed with the thumb, and the button labeled “B” which is designed as a trigger pressed by the index finger.

PLOrk was a huge inspiration during the development of the Physical Computing Ensemble. From PLOrk I drew the concept of a performance system where each performer uses the same hardware configuration while the software is developed in tandem with a composition. The idea of the composition and the instrument being co-developed was particularly important. The PCE also borrowed many other concepts from PLOrk including the use of sonic localization of individual performers and network-based conducting. There were also elements of PLOrk that I actively tried to avoid, notably the fixed physical location of individual performers and the use of the standard HCI interface of computer keyboard and trackpad.

As the Physical Computing Ensemble took shape it developed the following attributes:

- The performer interface should rely on gestures which would be meaningful to the performer, fellow musicians, and audience. In the performance described below, the Nintendo Wiimote was used as the primary interface.
- Performers would each have their own speaker, which would be positioned on stage as to localize each performers' sound in a different place. However, the performers themselves would not be tied down to a specific location. One corollary of this decision is that performers must not be tied down with reading sheet music, as this would tie them to a location on stage.
- The performers' attention should be on their fellow performers, with interaction being the focus. Therefore there would be no central conductor and again there must not be sheet music to attract the musician's gaze (including any kind of visual projection or conduction). The performer's instruments should not require visual feedback.
- The role of the computer, and its actual physical presence, should be minimized in order to direct attention to the performers.
- Each composition should use a different software instrument which is tailored to give the composition a unique identity.

Before describing the actual PCE compositions and performance I would like to reflect on the assumptions and implications of the points described above. The most important assumption underlying all of the points above is that the focus is on the interaction of the performers. This interaction is dependent upon the clear communication of the performer's intent. This communication takes the form of the performer's physical actions and the sonic result of these actions, and there must be a clear connection between action and sound. The performer must be confident in their command of their instrument; therefore, they must not be burdened with an overly complex instrument or with complex compositions (in practice this was one of the most difficult elements). The physical location and relationship of performers is an important element which must be addressed. The individual expressivity of the performers as well as the compositional complexity must be subservient to human interaction.

Perhaps the most important point to be made here is that the performers should feel confident of their command of their instrument and of their ability to contribute to the musical experience. This confidence will be communicated both aurally and visually to the audience as well as the other performers. The end result should be a shared experience, one where each performer's meaningful contributions are witnessed and validated by others' responses. The hope, then, is that this will translate into a meaningful musical experience for everyone involved.

5 - Physical Computing Ensemble Compositions and Modes of Interaction

Behind each PCE composition is a different concept of interactivity. The concepts in the compositions examined below are: the parameterization of musical elements, where different musicians are in control of different elements of the same musical event; turn-based collaborative control of sound, where performers share control of a sonic element sequentially rather than simultaneously; and systems interaction, whereby systems set in place by each performer interact over time. These three forms of interactivity are notable because they rely upon a property inherent to computer based music systems, i.e. network-based information sharing. The latter form of interactivity relies less upon a network (although in practice a global tempo is an essential element) than the other two; instead each performer initiates self-sustaining systems whose starting parameters are controlled by the performer.

To the degree which these forms of interaction depend upon the capabilities of a computer they are unique to a Digital Music Ensemble. There are other more traditional forms of interaction in these compositions as well[9], but the success of each piece is dependent upon the quality of the forms of interaction described above.

Triangulation

Triangulation is a composition for the PCE which explores the parameterization of musical elements. The concept of parameterization comes from the DMI world, in which the control interface is connected to the sound generator by mapping strategies. This allows for a musician to use a control interface which is mapped to only control rhythm, while a separate musician has a control interface mapped to only control pitch.

[9] Including but not limited to shared control of tempo and dynamics, conducted passages, and free improvisation.

Illustration 2: Parameterization of musical elements

acceleration in each axis is written into a wavetable. When the B button is released, the wavetables are read independently to generate three waveforms which are mixed together and fed to the audio output of the computer.

The rhythm musician has a system which is oriented towards rhythmic events. The acceleration in the x- and y- axes of the rhythm musician's Wiimote is read at fixed intervals (generally 16th notes at 120 beats per minute). Rhythmic events are generated at each interval whose maximum amplitude and duration are derived from the accelerometer values. The rhythm musician thus does not determine where the beat is located but rather determines the characteristics of rhythmic events located on the beats. The data from the x-axis is used to create a percussive gated noise sound, while the data from the y-axis is used to control the amplitude of the pitch musicians sound in those sections where the pitch and rhythm musicians are linked.

The first two major sections of *Triangulation* consist of rhythm and pitch musicians working independently. In these sections the pitch musicians generate sustained tones and the rhythm musicians generate simple rhythmic patterns. In the later sections of the piece each pair of pitch and rhythm musicians are linked. When this happens there are three elements to the sound generated by each pair. The first element is the rhythm musician's basic percussive sound which is controlled by the x-axis of their accelerometer. This is unchanged from the sections where the pitch and rhythm musicians work independently. The second element is the sound generated by the pitch musicians. This sound is also unchanged from the sections where the pitch musicians are independent; however, once the musicians are linked the amplitude of the pitch musician's sound is controlled by the rhythm musician's y-axis movements. This works similarly to the way the rhythm musicians generate their basic percussive sound — at fixed intervals the y-axis acceleration is read and this value used to determine the amplitude and duration of a rhythmic event. This rhythmic event is then used to control a gate through which the pitch musician's sound is fed. When the y-axis reading is very small or zero the pitch musician's sound is effectively silent. The third sonic element generated by each pair is the ring modulation of the pitch musician's sound by a sine wave whose amplitude is controlled by the rhythm musician's x-axis. The frequency of the sine wave is randomly selected from {0.5, 0.75, 1.5, or 2} times the frequency of the pitch musician's sound.

The pairs of pitch and rhythm musicians are linked in the third and fourth sections of *Triangulation*. The third section consists of a free improvisation where each pair of musicians are given very basic instructions for an overall musical shape (see the performance instructions included in the Addendum). The fourth section consists of the three pairs of musicians playing in tempo while the pitch musician's pitches, which are determined by a computer controlled sequence, change every two bars.

Just Continue to Move

Originally entitled *Catch, Just Continue to Move* is a composition in which musicians share control over a sonic event sequentially. This is in contrast to *Autopoetics I*, in which musicians share simultaneous control over the sequencing of musical events. *Just Continue to Move* uses the motions of throwing a ball back and forth as its primary control. The concept of playing catch has many associations. Cooperative play between friends, interaction / exploration with the environment (bouncing balls off of walls), knowledge of physical laws (gravity effects, characteristics of the ball, knowledge of the arc of a ball, characteristics of surfaces we bounce the ball off of, et cetera). In a way, tossing a ball into space and throwing it between different people is a very complex act — one that is taken for granted but has room for virtuosity. There is a common desire for a form of computer musicianship that is easy for the beginner to grasp but that rewards expert performance; perhaps catch can be an example of this.

Throwing a ball is an expressive act with an infinite number of variations. To throw a ball to a specific destination one has to choose the speed and trajectory. To determine the destination we need to know the location of the catcher and evaluate what kind of relationship we would like to establish — playful, aggressive, cooperative. One then has to execute the throw based on these mental calculations. An embodied knowledge of physics is required along with an aesthetic sense for what kind of throw is appropriate. More virtuosic ball throwing incorporates topspin, curve balls, etc.

Playing catch can be seen to satisfy William Buxton's criteria for expressivity in that it enables one "to articulate subtle nuances of gesture and intent." (Wandeley, 2000) Subtle nuances of gesture determine the course of the ball; our intent is guided by aesthetic issues of timing and visualization of the ball's trajectory, as well the relationship we wish to establish with the catcher. Buxton also notes expressivity is "largely tied to the ability to capture and amplify human motor skill potential." In this context we can see human motor skill potential as an expression of embodied knowledge.

The PCE has implemented catch using Wiimotes and Max/MSP. With the Wiimote we grasp a virtual ball using a pushbutton and are able to measure the forces on the ball while it is in our possession, as well as extrapolate the physical motion of the ball once it is released. If the ball is represented by a sound there are certain intuitive acoustic properties we can assign to the ball's motion — pitch being relative to the speed of the ball as well as its vertical position and spatialization relating to the ball's position.

Once the metaphor of catch is established, it can be used in many different ways. The mapping of speed and height to pitch is a powerful one, evocative of the doppler effect; however its characteristics can also be transferred to other parameters. A pseudo-doppler effect can be used to portray the movement of the ball in physical space (bouncing off of the floor for example). It can also be used to portray the ball defying the laws of physics — speeding up or slowing down for part of its trajectory, freezing in mid-air, or reversing the effects of gravity. The spin of the ball can be used to control a shorter internal process within the larger process of a toss.

The sound which is passed can be part of a phrase. As the phrase is passed each musician may be able to change the phrase, or add to it. When the ball is released, the most recent part of the phrase may be looped with the speed of the loop dependent upon the velocity of the throw. The musician may pass the ball to themselves, allowing them to loop part of the phrase they are creating. They may toss multiple phrases into the air, with the speed at which they are tossed determining how many times they repeat.

The power of the catch metaphor lies in our embodied knowledge of the process of throwing a ball and the physics which act upon the ball once it is in motion. This knowledge allows us to determine whether the sonic characteristics of a throw match our expectations. The fact that this knowledge consists of the interaction of many physical attributes allows us a rich source of possibilities for musical control. Once the metaphor is established, we are able to take our knowledge and expectations and intuitively map them to new parameters. These new mappings can be fairly abstract as long as the metaphor is still clear.

The catch metaphor has been utilized in several compositions for the PCE. The composition included in the performance discussed below is entitled *Just Continue to Move*. The main focus of this piece is two musicians passing a recording of Cesar Chavez talking about childhood back and forth. In order to 'grab' the phrase, the musicians press the B trigger button. As long as the button is pressed the phrase plays back normally. When the phrase is tossed to the other musician, a short snippet of the phrase is repeated until the other musicians 'catches' it, at which point the phrase begins to play back normally until it is thrown again.

Skipping Stones

In *Skipping Stones* individual musicians create musical events whose qualities are derived from the metaphor of skipping stones on a lake. The musician makes a single motion — picking up a stone by pressing the B trigger button, throwing the stone by moving their hand perpendicularly to the ground, releasing the stone at the proper place in the throw by letting go of the B button. This single motion, however, creates a miniature musical system whose characteristics are determined by the acceleration of the performer's hand at the moment of the stone's release — how hard the stone is thrown determines the speed, amplitude, and number of repetitions, or 'skips', of a note. In this piece there is a metric pulse and each skip is some rhythmic subdivision of the basic pulse, from a 32nd note to a half note.

While a computer is not strictly necessary in order to create self-sustaining musical systems, these kinds of systems are very common in computer music. *Autopoetics I* is an example of a composition in which musicians collaborate to create a sequence which, once created, will play through indefinitely with no further input from the musicians. Algorithmically generated computer music, as seen in the works of composers such as David Cope, is commonly created by systems that require the definition of a set of initial parameters, which are fed into computer algorithms to generate musical compositions. *Skipping Stones* can be regarded as an incredibly simple example of such a system, one which takes a single initial condition, acceleration at the moment of release, which is then used to determine the evolution of a miniature musical system. Due to its simple nature, these systems can be created in a single motion, and in fact performers in *Skipping Stones* can have up to four of these systems active at a single time.[10]

The primary form of interaction in this composition is in the creation of systems with different rhythmic subdivisions. Depending on how many musicians are playing at once this can take the form of a duet with easily discernible interlocking rhythms or it can take the form of a complex composite of many different rhythms.

How Quickly Infinite Becomes Eight

While the performance of the PCE and exploration of interaction in a Digital Music Ensemble is the core of this paper, there was another piece on the performance discussed below which is relevant to the issues under discussion. *How Quickly Infinite Becomes Eight* is an octet for chamber ensemble and electric guitar. There are two main concepts explored in this composition — bridging the gap between a highly individual style of electric guitar performance and composition and transferring concepts of interaction in a DME to an acoustic ensemble.

Focusing on the interactive concepts, there are two main approaches taken in *How Quickly Infinite Becomes Eight.* The first is exploring parameterization of musical elements in an acoustic ensemble. To achieve this effect the ensemble is split into parameter 'groups,' with the guitar playing a sustained 'f' pitch while the Bb clarinet plays a rhythmic motif on 'e.' The effect is dissonant chord clusters which occur at the intersection of the guitar and clarinet parts. The second interactive concept that is explored is the idea of playing catch. In *Just Continue to Move* the musicians grab the phrase by pressing the B trigger button. As long as the button is pressed the phrase plays

[10] Which in practice is difficult to achieve since the sound of each systems fades out over time, and relatively quickly (i.e. over the course of 1-2 seconds).

back normally. When the phrase is tossed to another musician, a short snippet of the phrase is repeated until the other musicians ‘catches’ it, at which point the phrase begins to play back normally until it is thrown again. This effect is transferred to *How Quickly Infinite Becomes Eight* by having the violin play a melody, the last few notes of which are repeated indefinitely until the flute comes in and picks the phrase up where the violin left it. The intention with exploring these ideas is to demonstrate that new kinds of interaction that leverage computer mediation can also be transferred to acoustic ensembles in modified form. This kind of cross-pollination can be very stimulating, and can lead to unexpected and promising results.

Illustration 3: Passing control from the violin to the flute

6 - Tangible Relationships

The first indications that the initial performance of the works described above was going to be successful was the feedback from the PCE performers during rehearsals. While the instruments which they were using were individually very simple, the performers' immediate responses were that the instruments felt intuitive and expressive. Since the focus of the compositions was interaction (in order to highlight this interaction the ensemble was often broken down into smaller units of 2 or 3) we began PCE rehearsals with smaller groups. Once we began these rehearsals it became apparent that the instrument's ease of use translated quickly into freedom to experiment and have fun interacting. The most challenging part of rehearsals was the process of memorizing the parts. Since each composition is very simple, and each performer plays in only part of each composition, I created grid-based scores for the musicians that showed them the overall form of the piece as well as laid out what their contribution would be. Most of the musicians, upon being confronted with these scores, immediately expressed doubt that they would be able to memorize their parts in time for the concert. Several of them asked for individual sheets that contained only the information they needed to know in order to perform. A selection of these individual parts as well as photos of the original scores are included in Addendum A. By the time the final two group rehearsals came around, which took place the day before and the day of the concert, many of the musicians had succeeded in memorizing their parts; however, several musicians, afraid that they would forget, wrote cheat sheets on their palms which they could consult during the performance. This was the one part of the performance that qualitatively differed from my original intentions — I feel confident that with only a few more rehearsals this could have been avoided, but in any event it only made a slight impact on the course of the performance. Certainly the occasional glance of a performer at their palm was a better solution than having actual sheet music in front of them, as most performers, even if they have a piece memorized, are unable to not look at music on a page when it is presented to them.

One of the most enjoyable aspects of developing the catch paradigm with the PCE was the free-spirited pantomime that accompanied the actions — performers running across the stage in order to ‘catch’ the ball, or playing tricks with one another by ‘faking’ a throw. I had hopes that this spirit would carry over into the performance, and I am glad that it did. In fact, several times during rehearsals I had to encourage the musicians to focus on the musical results of their actions rather than the actions themselves. Happily, the gusto with which the performers threw themselves into the performance was perhaps the biggest factor in its success. A side result of this gusto was that correlation between the performers actions and the audible result carried over beautifully both to the other performers and to the audience as well. There were several ‘laugh-out-loud’ moments during the performance as well as a general sense of musical confidence that helped to engage everyone involved.

The audience for the performance was a mix of musicians trained in various styles and non-musicians. After the show it was gratifying to hear audience members express their enjoyment of the performance. The most telling conversation I had immediately after was with two non-musicians who have very little experience with computer music or contemporary classical music. Both of these audience members expressed their appreciation for the concert — and one of them remarked upon how much the music differed from what she normally listened to. Yet, faced with music in a radically different style, she still enjoyed the concert. To me, this represents the success of the physical computing concept, that the performers were able to make the music meaningful by their actions in performance.

7 - Conclusion

The goal while preparing the music presented in my MFA performance and described in this paper was to build meaningful, perceivable relationships between the music and musicians, and between the musicians themselves. The three modes of interaction — the parameterization of musical elements, turn-based collaborative control of sound, and systems interaction — were developed in order to clearly focus on these relationships. At the same time care was taken to let the relationships develop on their own terms and not to force too many of my own opinions onto the performers. The musicians for this performance were chosen for their musical and performative sensibilities.

Concepts drawn from the physical computing community were extremely important in the development of the performance systems used in these compositions. The use of wireless controllers in performance allowed the performers to use a wide range of physical gestures, while also preventing the technology involved from drawing attention to itself. The performers' gestures became meaningful on many levels: they provided the necessary information to the computer in order to generate a musical result; their embodied nature allowed the performers to self-monitor their performance and evaluate the connection between action and musical result; the performers were able to see each other's intents and actions in order to respond and interact appropriately; and the audience was able to see the relationship between the performers and the music. It was imperative that the performance systems used by the Physical Computing Ensemble were able to satisfy each of these conditions. The fact that the performers and audience were able to perceive all of these meanings and relationships while the Wiimotes and computers faded into the background made for a successful performance, underscoring the theme and intent for this project from its outset – highlighting technology-mediated human-to-human interaction.

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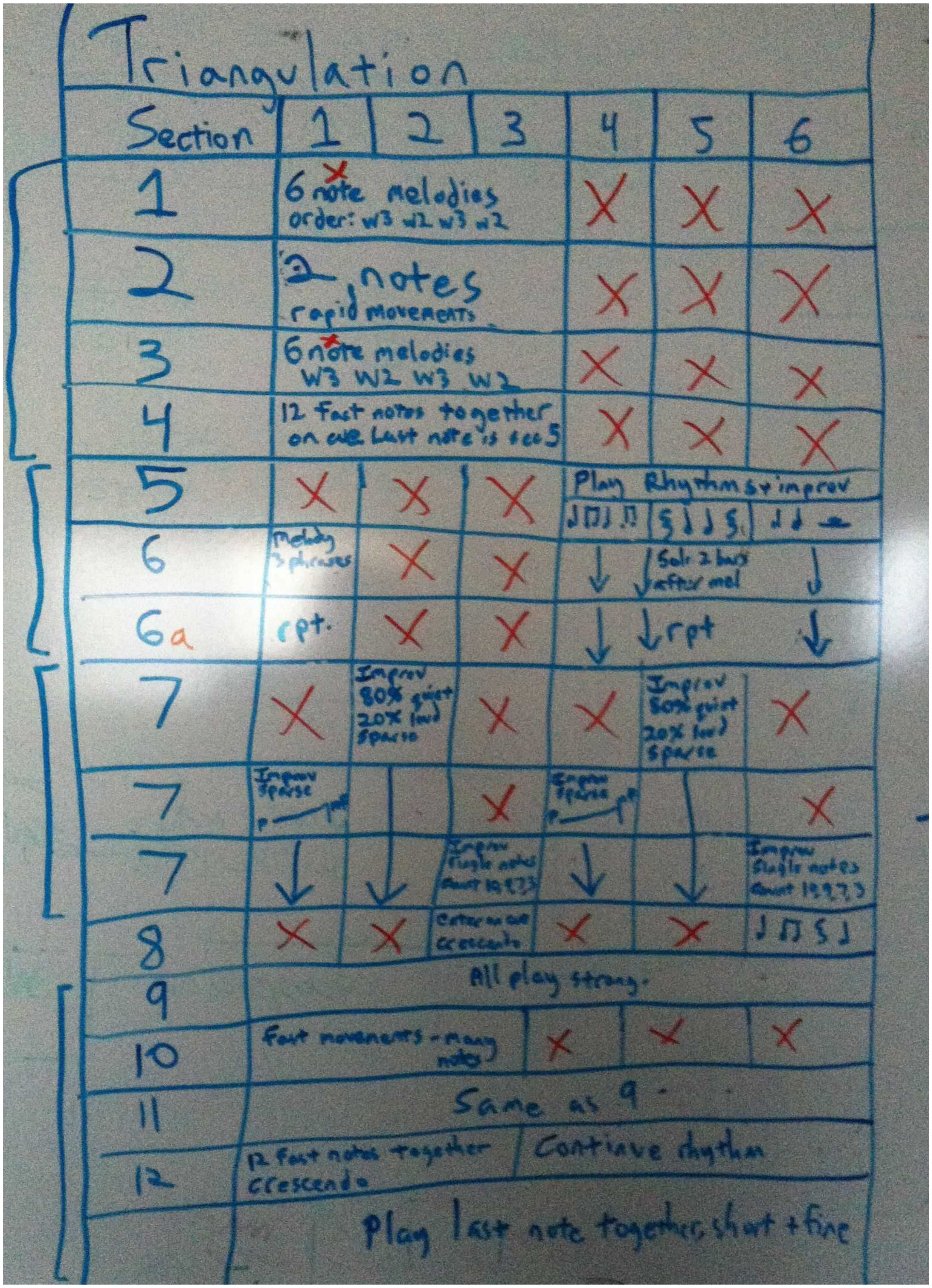
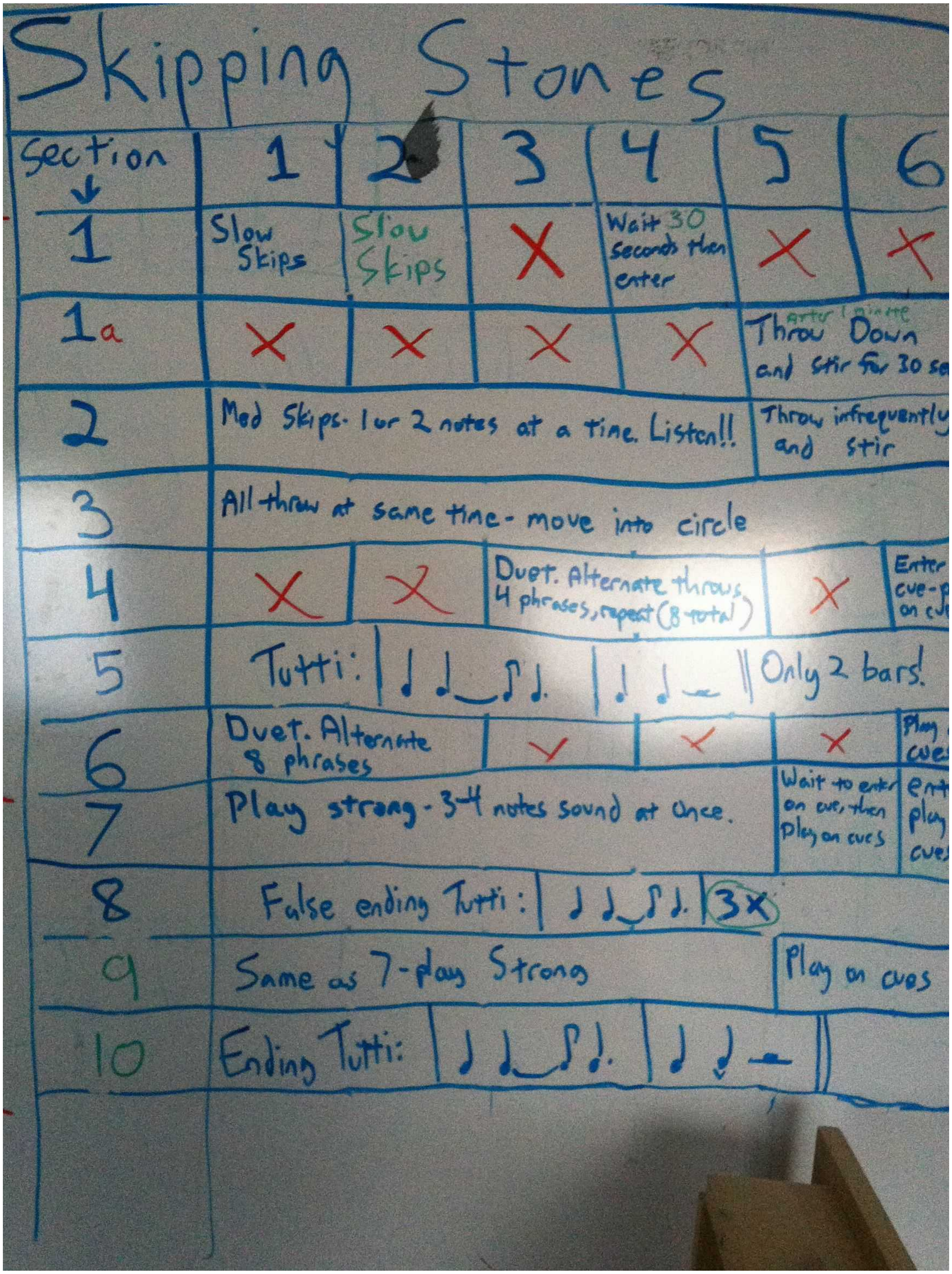
Addendum

Rehearsal Score for *Triangulation*



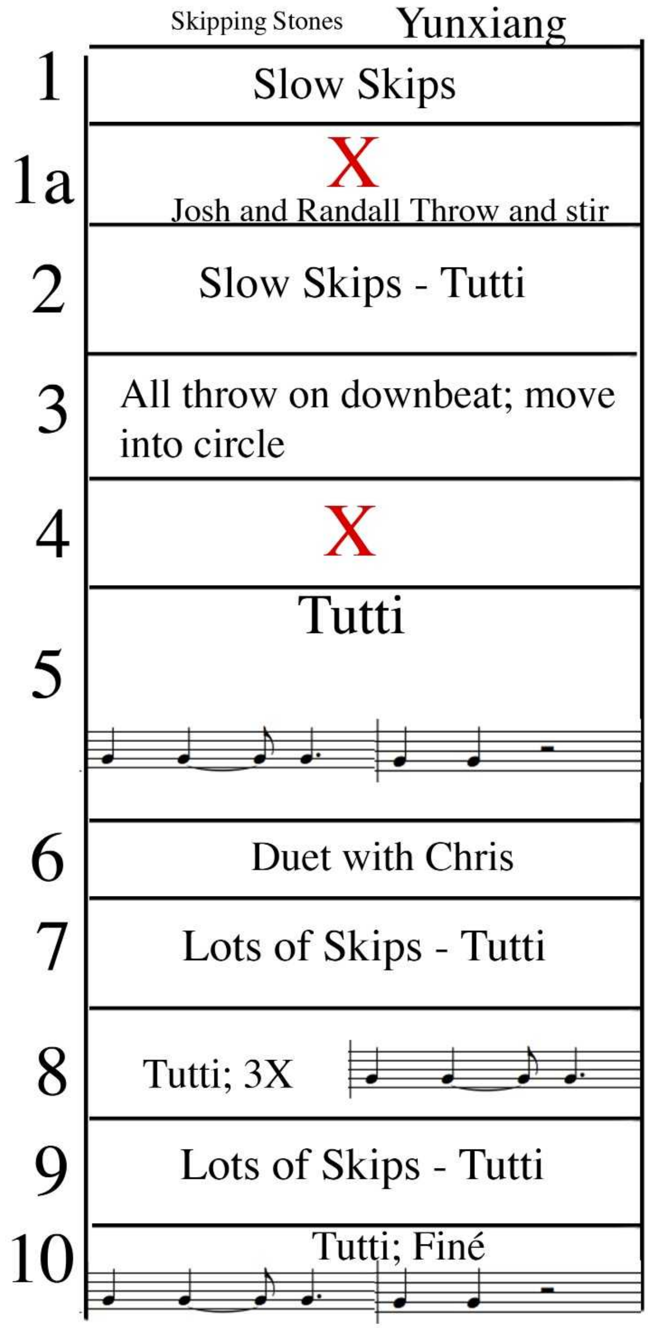
Rehearsal Score for *Skipping Stones*



Individual Part for *Triangulation*

Triangulation	Chris
1	X
2	X
3	X
4	X
5	Play rhythms - improvise
6	Play rhythm - after 30 seconds, break on cue repeat section 6 (with break at end)
7	Enter after 45 sec Improv with Yunxiang pp mf
8	X
9	Tutti; Work with Yungxiang
10	X
11	Tutti; Work with Yunxiang
12	Continue playing rhythm Yunxiang cues ending finé

Individual Part for *Skipping Stones*



¡MANO-A-MANO!

IAN HATTWICK'S MFA RECITAL

FRIDAY, APRIL 22 8PM
WINIFRED SMITH HALL, UC IRVINE

How Quickly Infinite Becomes Eight

for chamber ensemble and electric guitar

Rachel Bittner, flute
Dexter Stevens, clarinet
Pierre Flores, violin
Nick Neel, violin
Andy Chen, viola
Evyn Barb Mingo, cello
Mikael Hastrup, bass
Ian Hattwick, electric guitar

". . . each deed you do, each act, binds you to itself and to its consequences, and makes you act, and [act] yet again." - Ursula K. LeGuin, *The Farthest Shore*[1]

How Quickly Infinite Becomes Eight grew out of my desire to create a chamber work which reflects my personal approach to playing the electric guitar, as well as my interest in ensemble interaction. Various techniques from my work developing the Physical Computing Ensemble are explored as well. These include the distribution of musical elements between musicians as well as a shared responsibility for texture.

The title reflects on how our acts and decisions take form in the world, limiting our future decisions and actions as well as focusing our energy in specific directions. It can also be seen as a play on the physical forms of 8 and ∞. As Kojiro Umezaki, my thesis advisor, aptly points out: "Infinity is a sleepy form of eight; eight is an upstanding, focused form of infinity."

The Physical Computing Ensemble

Yunxiang Gao, Chris Lavender, Josh Ottum,
David Resnick, Randall Smith, Kevin Zhang

Physical computing is "an approach to learning how humans communicate through computers that starts by considering how humans express themselves physically." — Tom Igoe[2]

The idea of a Physical Computing Ensemble (or PCE) took shape during several conversations I had with Chris Lavender last summer. I was interested in two ideas — creating music built around the movements and physical relationships of an ensemble, and thinking about possibilities for human interaction mediated by computer music systems. I was particularly inspired by the Princeton Laptop Orkestra (PLOrk) and its director Dan Trueman.

It was while watching video of PLOrk performances that I found myself wondering what would happen if we were to take away the screen and computer keyboard, and instead focus the performer's attention on each other rather than on the computer.

The PCE first met in the fall, and the three pieces performed at this concert grew out of those early experimentations. Each piece contains different implementations of my original ideas. The most fun part of this whole experience has been the way in which the performers have embraced the spirit of these concepts and have brought them into the physical world.

Skipping Stones

When we play at skipping stones over a still lake we are creating miniature systems — systems which we create with a single action but which persist over a short duration of time. In this piece, these systems interact to create interlocking rhythms and textures to which each performer contributes an essential part.

Just Continue To Move[3]

One of the earliest PCE experiments was with playing catch — tossing a sound from one musician to another. In this piece, two musicians share in the act of telling a story drawn from Cesar Chavez's recollections of his childhood. It is also a meditation on the fact that Cesar Chavez's story, although unique to him, is but one in an ocean of human experience.

Triangulation

Early computer music ensemble *The Hub* experimented with distributing control of musical parameters between different ensemble members. In *Triangulation* the ensemble is split into two groups, one which determines pitch and timbre, while the other group determines rhythm. The collaboration of members from both of these groups form the central focus for the composition.

Thanks to: My Thesis Committee — Kojiro Umezaki, Chris Dobrian, and Amy Bauer; Michael Dessen, Kei Akagi, Matias Vellutini, and everyone at ICIT; Simon Penny and everyone at ACE; Paula McMath, Michael and Barbara Hattwick and the rest of my family; The Infinite Octet and Maggie Parkins; Matt Jackson, Ross Whitney, and the UCI Music Department; and Dan Trueman, Perry Cook, and PLOrk; and thanks to you for coming.

[1] Leguin, Ursula K. *The Farthest Shore*. Bantam Books,:NY,1984, p. 34.
[2] http://tigoe.net/pcomp/blog/archives/notes/000169.shtml, accessed 3/31/11.
[3] *Just Continue to Move* uses samples from the gamelan orchestra Marsudi Raras and recordings of interviews by Studs Terkel.