Musical Interfaces: Design and Construction of Physical Manipulatives for Musical Composition

by

Elysa Wan

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Submitted to the department Mechanical Engineering on May 11, 2007 in partial fulfillment of the requirements for the Degree of Bachelor of Science in Engineering as recommended by the Department of Mechanical Engineering.

ABSTRACT

Currently, musical composition is considered to be a high-level skill that is inaccessible to young children. There is a "high floor" for children who want to create a piece of music because they must learn a way of recording and remembering the notes, their sequence, etc, such as musical notation.

Our project explores tangible designs that will make music composition simple to learn and practice while also building an intuition about complex musical concepts. Three original designs of tangible interfaces for musical composition are introduced and the merits and limitations of each are explored using non-functional form models. Audio processing is performed on a peripheral computer running an audio program written specifically for each system. A "Wizard of Oz" approach was used to study user interactions with each design.

Music Blocks are designed to be physical representations of inherently intangible musical notes. Each block represents a single note, and the user can modify its pitch and duration by changing the physical shape of the block. They resemble wooden building blocks and suggest the parallels between building structures and the organization of musical compositions and its melody.

The Music Glove introduced the idea of using a sound recording instead of a musical note as the musical unit in a composition. This introduced rich ideas about nesting and recursion. At the same time the glove interface highlights the role of personal expression, interaction and affect in musical composition and performance. Here physical inputs of the system were related to the rhythms, tempos, and the tone of the composition. The system was more gestural, performance-oriented and more suited to spontaneous improvising.

The Musical Leaves interface is a melding of the concepts for the Music Blocks and Glove. The individual Leaves reflect the modular structure and organization of the composition. At the same time, the Leaves can be manipulated in real-time to change pitch and volume and as a result are deeply expressive and flexible.

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1. Introduction & Background:

Musical exploration is a fundamental part of children's play activities. Children often explore musically, using both toys that were deigned as instruments as well as found objects to create sounds. They also hum tunes or create melodies that relate to a storyline. Unfortunately these melodies are usually lost and forgotten immediately after they are conceived. How can we make it easier for children to create and explore melodies?

Learning the art of music composition often takes years of music theory and training. Traditional music training is often rigid, without much opportunity for beginners to improvise and explore. Additionally, while the process of playing musical instruments is inherently physical, the process of learning, creating and playing compositions is typically cerebral. Most traditional music composition occurs on sheet music that does not lend itself to physical manipulation. If you want to change a note, or move a phrase these changes occur on paper – there is no tangible counterpart for the elements of a musical composition.

Our project explores physical interfaces for music composition using the physical vocabulary of common play activities. Our design draws on the theory of using digital manipulatives to apply a kindergarten approach [RESNICK, 1998] that enables users to study advanced concepts through the direct manipulation of enhanced physical objects. The kindergarten approach assumes that physical interactions with simple play objects will develop into an intuition when learning complex concepts later. One example is the Pattern Blocks that are accessible to very young children, but can be used to teach complex geometric principles about the shapes of the blocks later on.

Digital manipulatives apply this learning technique by embedding computational elements into familiar objects such as traditional toys. For example, PicoCrickets [RESNICK, 2006], are small, programmable bricks allow children to design projects with light, sound, music and motion. PicoCricket creations complement traditional craft activities, while also introducing users to complex ideas such as programming logic and feedback cycles. Furthermore, users can use PicoCrickets to design original creations to investigate different scientific and mathematical concepts such as energy transfers in Rube Goldberg machines, or engineering an automatic bird feeder.

We hope to leverage a similar approach to teaching an exploring musical composition. A successful design would introduce users to meaningful musical concepts, while also giving them the ability to design their own creations to explore further.

Another guiding design principle is a low floor-high ceiling approach for the manipulatives. While translating music to the physical world this system should be easy to learn and use for people with little or no musical or technical experience. The system's physical design should be intuitive so it implies metaphors for manipulating audio music in the new physical form. At the same time, the system should be dynamic enough to create complicated pieces, without sacrificing its ease of use.

Within the large body of existing research on tangible interfaces for music composition, some of the most relevant projects include Sony Block Jam, [NEWTON-DUNN, 2002], Lady's Gloves [SONAMI, 1991] and the Music Table [BERRY, 2003]. While these projects have many design principles in common with our research, the existing approach that influenced us the most was Hyperscore [Farbood et. al, 2004].

Hyperscore is a revolutionary tool for music composition that allows children to "compose-by-drawing." The software uses a series of lines that can represent chords, melodic motives, timbres or sounds-each color-coded – which are then annotated along the spine of the narrative line. Finally, the HyperScore system automatically realizes a full composition integrating the specific musical material into the overall formal shape represented by the narrative line.

Although Hyperscore is not a physical manipulative, our research was heavily informed by the way Hyperscore represented music using specific visual and dynamic elements. Nonetheless, we wanted to build a system that did not require the use of a computer or any amount of technical ability. We hoped to make a system that is accessible to users of all skill levels. Also, Hyperscore compositions often look like drawings, but they do not emphasize the structural approach or the tactile influence of a building system. While Hyperscore represents musical elements in a novel way, the notes are still two-dimensional, abstract and intaangible.

This project hopes to remove music composition from this intangible realm by transforming musical elements into manipulatives that a user can interact with physically. A tangible interface encourages users to engage and experiment with the system as they would with with familiar objects such as building blocks or other toys. [ISHII, 1997] We hope to take advantage of the physical language of the to emphasize the parallels between conventional physical play and music composition.

2. Music Blocks

Music Blocks Functionality

Figure 1: Musical blocks make music tangible and manipulable. Pulling the blocks lengthwise changes the duration of the note that is associated with the block.

Music Blocks are designed to resemble wooden building blocks, with block representing a single note. A telescoping frame allows the block to expand and retract in vertically and horizontally. The user can change the pitch and duration of a block by changing its shape. To set the pitch of the block, pull the block vertically, making it taller or shorter. The block will expand in fixed increments corresponding to a tonal scale. Similarly, determine how long the note will play for by pulling the block horizontally, as shown in Fig. 1.

In a composition, each block must be arranging in a continuous linear sequence, so every block is touching the next. The composition is played from left to right; so two blocks next to each other will play one after another. Blocks that are stacked on top of each other will play at the same time. If the two blocks are stacked but not aligned the left-most block will begin to play and the other block joins in later. To be part of the composition, each block must be physically touching the one before it – there can be no empty space between any two blocks in a composition. For this reason, there exist special "silent" blocks which denote a rest. The "silent" blocks are identifiable by their color and can change duration similar to other Music Blocks.

Music Blocks: Physical Embodiment of a Musical Composition

Music Blocks is based on the idea that a melody is simply a combination of several notes. Yet musical notes are often intangible – they are transient, disappearing after they are played. On sheet music they are inaccessible, black dots on a page that you cannot touch, move or manipulate. *Music Blocks' crucial contribution is to give notes a physical form, one that users can use to experiment, compose and design.*

Music Blocks uses the vocabulary of building blocks to emphasize the modular design and structure within a musical composition, similar to a physical structure.

We hope that this system will make it easy for amateur users to experiment with tempo, harmony, dissonance and other advanced musical concepts. Furthermore, the shape of the blocks is designed to emphasize some fundamental musical principles. For example, a change in pitch is recognized in the varied shape of a series of blocks.

Rhythms can be recognized from the distance between blocks or a chord progression can be recognized from the shape of the stacked blocks.

A Composition's Design Process

This system is not designed to be a performance-oriented tool similar to a musical instrument. Rather, it supports an intentional and often recursive design process. After assembling a composition, users can go back and improve or build on that work. This system considers blocks as elements of a more complicated melody, not just temporary sounds.

Additionally, Music Blocks are designed to incorporate the collaborative nature of traditional wooden blocks. This would allow users to work together on creating a melody.

Early Implementation

Several experimental prototypes were built to assess the validity of our initial design for Music Blocks. The computation for these prototypes used PicoCrickets. A PicoCricket is a circuit board that can be programmed to respond to various sensors. We used the resistive sensors, LED displays, and speakers to put together several examples.

We experimented with different materials and forms for the Musical Block, and specifically different ways of controlling the pitch and duration. The materials used including clay, sliders and wooden blocks.

The Music Block made out of clay was very malleable and flexible. Needles were used to measure the resistance between to points in a piece of clay. That resistance was used to determine the pitch of the Music Block at that time. Because this mapping relationship was not obvious it was more difficult for the user to control the pitch. The user was able to be more creative with the shape of a clay Music Block, but it also required more experimentation to achieve a desired pitch.

Figure 2: Cricket prototypes for playing music with a piece of clay.

When the slider was tested as a Music Block, a linear relationship was established between the slider position and the block's pitch. In this design, the relationship between the slider and the pitch was more obvious to the user. As a result, the user can predict the Music Block's not by simply looking at the position the slider – this was not possible with the clay prototype.

Our studies with these prototypes was limited by the number of Crickets available so each prototype simulated a single block, and did not explore the interactions when multiple blocks are used. From this study the most intuitive design was a slider, because it is linear similar to a piano keyboard and other classical instruments. The clay prototypes had difficulty controlling pitch consistently. Nonetheless, there is something attractive about the act of molding a melody, or a clay sculpture that represents a note.

Wizard-of-Oz studies

We made modular wooden blocks for mockups and conducted a Wizard-of-Oz experiment for studying how the expected implementation works. Our wooden block mockups work with a pianist playing the notes from behind the scenes. A user moves the blocks, experimenting with the physical shapes while the pianist plays the corresponding notes.

During our Wizard-of-Oz experiment with the wooden blocks, as shown in Figure 4, the users were interested in the different geometries implicit in the system. For example, if two blocks stacked together are the same height as another block, what is the relationship between the chord and that other note? Also, the user expected a stack of blocks to produce a sound that was higher in pitch. Furthermore users would sometimes stack two identical notes together, which would not produce the expected results. Also, users were interested in chords where the two notes had different durations.

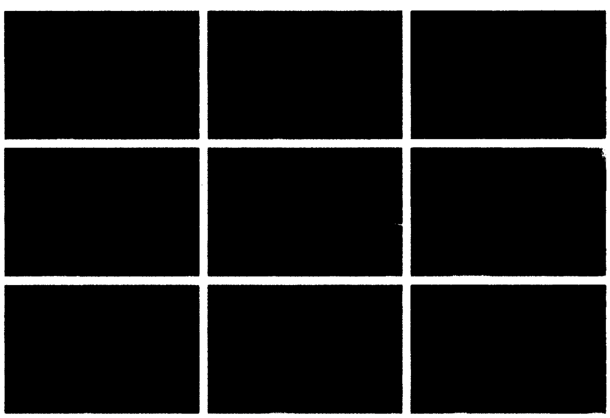

Figure 3: A Wizard-of-Oz setup used solid wooden blocks to simulate the notes while a piano plays the composition.

Limitations: Intuition and Rigidity

The Wizard-of-Oz evaluation illuminated a key weakness in our design. Mapping pitch to the height of a block may be intuitive when the user considers a single block, but for a stack of Blocks, the mapping breaks down. Two stacks of the same height most often are completely unrelated, contrary to what you might expect. As a result, the shape of block structure is not intuitive or natural when composing chords.

In this respect, the system requires users to learn a new "language" before they can begin composing. While the language of our system may be simpler than learning musical composition, Music Blocks is still not acceptably intuitive or simple to learn.

Another disadvantage of the system is its rigidity. The current design requires the Blocks to be arranged in straight rows, taking away the intrinsically free form and spontaneous nature present in building blocks and playing music. As a result, the system appears boxy and too linear. Additionally, because of the size of each Music Block, the entire system is large and sprawling. A vast number of blocks are needed to create a complex melody. As a result, the number of blocks and the space available quickly limits the design.

Some of the shortcomings related to the rigid structure, and impractical size can be addressed by the use of sound recordings. For example, instead of a single note each Block could be a sound sample which the user records. This way, an entire composition can be contained in a single block. While this simplifies size and logistics of the system, a Music Block loses its ability to manipulate and customize the pitch or duration of every individual note. This loss of function diminishes the original purpose of the Music Blocks as a physical manipulative that represent often-intangible musical notes.

3. Music Glove

Music Glove Functionality

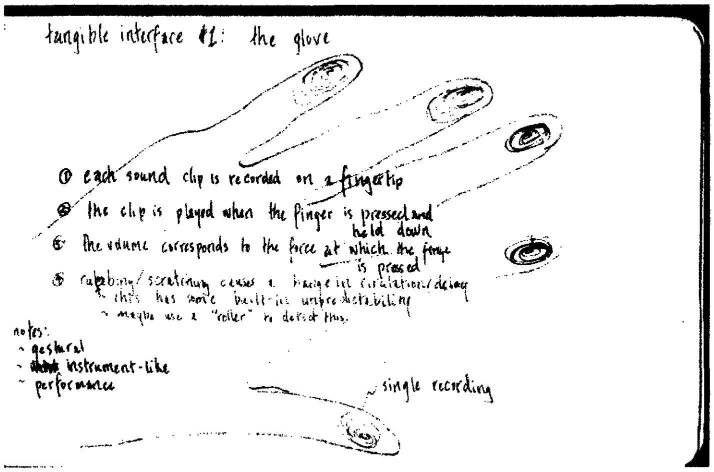

Figure 4: Original design sketch for the Music Glove

The Music Glove concept is an interface that records sound clips on its fingertips and then plays the clip when the finger is tapped. To record a sound onto a finger, hold down the black button on the knuckle of that finger, and hold the fingertip towards the sound like a microphone. The finger will stop recording when the black button is released.

To play a sound clip, simply press down on the fingertip. The clip will play once, and only once. You must lift up the fingertip and press it down again each time you want to play the sound clip.

The sound of the audio clip will change depending on the way it is pressed. Press the fingertip lightly to play the clip at a lower volume, and apply more pressure to play the clip more loudly. If the finger pad is pressed and dragged, the sound clip will change pitch depending on the direction it is moved.

Music Glove: Nesting & Expression

The design of the Music Glove was inspired by the criticisms of the Music Blocks system. The two critical features of the Music Glove is a direct response to the Music Block design. *First, the Music Glove uses sound recordings to introduce nesting and recursion into the system. Secondly, the glove interface is used because of its physical flexibility and expressiveness.*

In response to the limitations of using discrete, single notes, the system uses audio recordings as the compositional unit. This means that a user can create a composition with the glove, and then record the entire composition onto a single finger. The user can repeat this process by adding onto the composition or create another composition and rerecording all the compositions back to a single sound sample. This concept of nesting and recursion, allows the system can create infinitely complex compositions using just five sound recordings.

This approach also recognizes that children already create music by humming and playing with found objects. By allowing children to collect sounds from their environment, this simplifies the structure of the system as well as making the system more similar to natural play-patterns.

Music Blocks was best suited for creating and playing melodies, while it did not make use of repeating rhythms patterns and looping sequences. The static structure of the Music Blocks discourages an improvisational approach to composition. The Music Glove addresses these issues by creating an interface that is deeply interactive and expressive. It is better suited to rhythmic compositions, similar to the way people often drum on surfaces with their fingers.

While the Music Blocks utilized the system's physical structure to highlight the process of building a composition, the Music Glove explores the physical and gestural vocabulary as a form of musical expression. The movement of a user's hand in the glove represents a more visceral connection to the music. As a result the movement and development of a composition is deeply affected by the way the user plays the Glove.

Prototype and Evaluation Methods

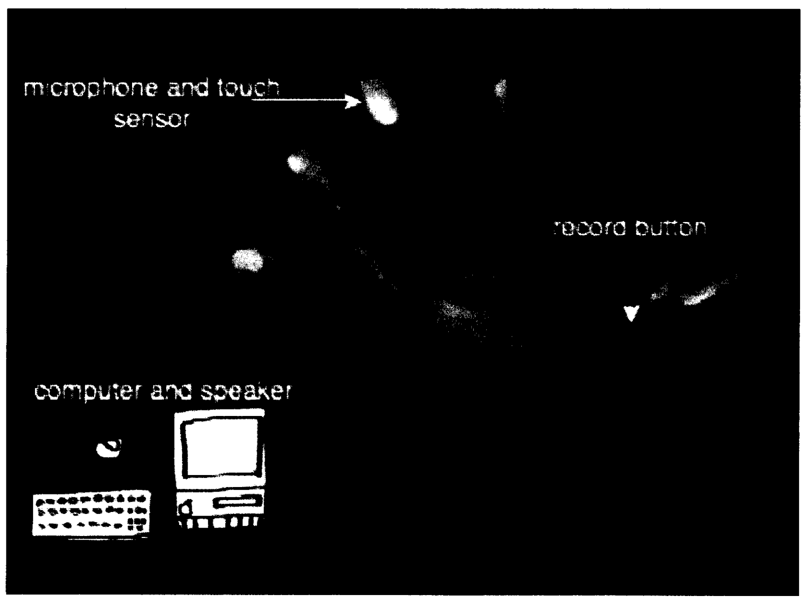

Fig. 5: The prototype used for the "Wizard of Oz" experiment is shown. If built, the glove would require a record button on each finger, a microphone, and touch sensor located on each finger pad. All audio and control computation would be performed on a peripheral computer. Audio would be played from the peripheral computer.

The current prototype is a standard glove with adhesive patches that simulate the record button and touch sensor. The recordings were captured using an external microphone, and processed on a peripheral computer. The record, playback and manipulation of the sound clips were processed using a Pure Data program written specifically for the Music Glove.

The system was evaluated using a series of "Wizard of Oz" experiments. The glove prototype was used to simulate a working glove while the audio processing occurred on a peripheral computer. These studies investigated the novelty, ease-of-use and the effectiveness of the design without requiring a working model.

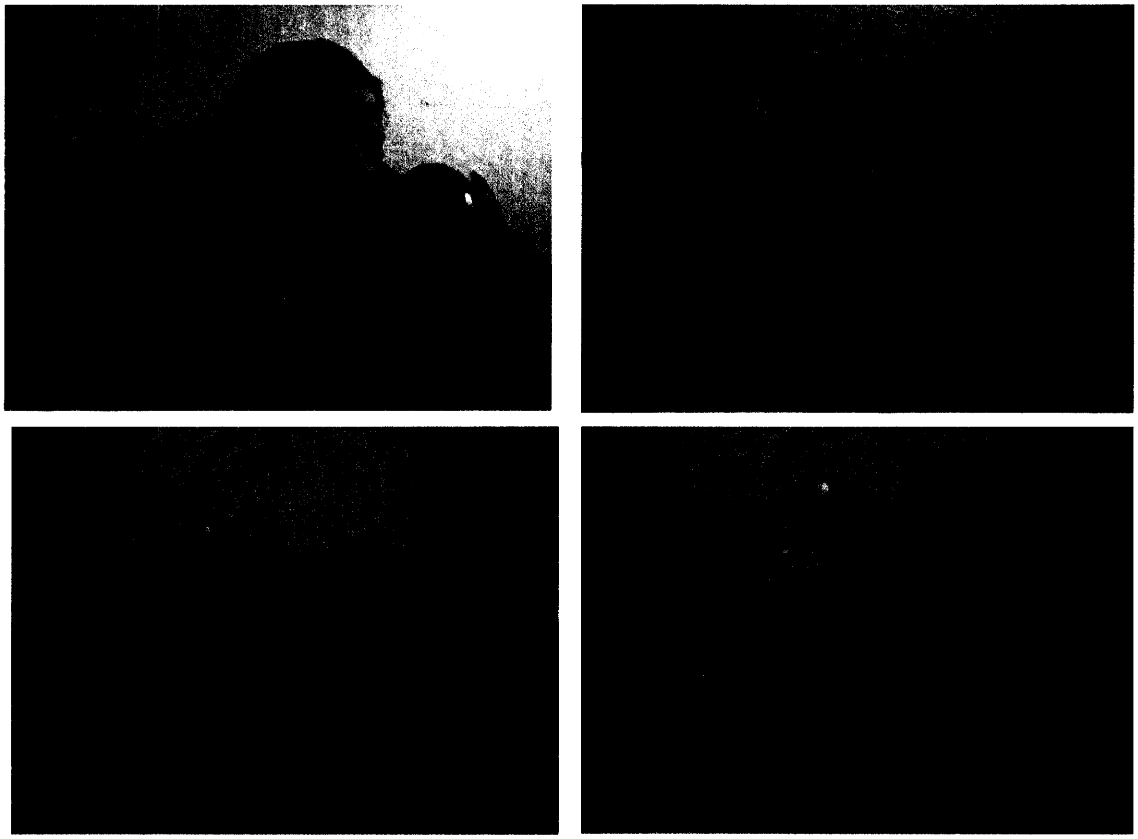

Fig 6: The upper pictures show two sound recordings being collected. To the left, a vocal sound effect is recorded. To the left, a snap is recorded. The lower pictures illustrate the glove as it a recording is played. To the left, the recording is played back without any change. The image to the right shows the Music Glove as the touch pad is being dragged, transforming the pitch.

Keyboard Metaphor and Classical Music

During the Wizard of Oz simulations, the type of sound recorded was critical in determining the dynamics of the system and the nature of the composition.

An early approach was to record short, note-based melodies played on different instruments. These discrete melodies were then played on top of each other to create a larger arrangement. This approach drew inspiration from the structure of fugues, rounds and point-counterpoint compositions popular in Classical music.

This approach was doubly attractive because the way the Music Glove can be played the way one plays a keyboard. As a result, the Music Glove evokes a parallel to a musical keyboard. On the keyboard, tapping a finger produces a single note. In the Music Glove, the tapping motion produces a sound that was recorded. Theoretically, tapping a single finger can play an entire concerto. Consequently, if melodies or musical "modules" are recorded onto the Music Glove, the glove can arrange these melodies and modules into a "customized concerto".

Both the theoretical and practical defects of the keyboard metaphor emerge quickly. Because there are only five sound recording stored on a single glove, the elements available for the glove's composition are much more limited than those used in many classical arrangements which rely on a great number of small variation on a theme to prevent repetition.

Additionally, the selection of appropriate modules to record onto the Music glove is complicated. To create a coherent composition, the individual recordings must complement each other in tempo, pitch, scale, timbre etc. This selection process required foresight that was simply impractical for users with little knowledge of music. Also, many users will not have access to recordings of Western scale instruments. This approach was ill suited for the Music Glove interface and unreasonably complex for beginning musicians.

Percussive Recordings and Electronic Music

Responding to the difficulty creating compositions in the Classical style, we began making recordings, made from non-instrumental objects. These recordings were simulated recordings that a beginning user may use – spoken words, banging sounds, vocal sound effects, snaps, claps etc. In general, the new recordings were short, simple and percussive.

Because the simple nature of these new recordings the structure of the composition relied more heavily on rhythmic techniques, volume and pitch shifting. The resulting composition resembled sound and structure of electronic and ambient music styles.

Characteristics and Limitations of the Music Glove

While the glove interface succeeded in creating a system that was gestural in nature, dynamic and performance-oriented, it introduced many limitations to the compositions created. Because every note must be initiated by pressing a button, the complexity of the composition is limited by the mobility of the human hand. Additionally, this requires users to acquire a level of finger dexterity in order to master this system. This is similar to the criticism of the Music Blocks that requires the user to learn a new "language" before creating compositions. The Music Glove requires users to develop a specific skill before creating complex compositions.

Additionally, the Music Glove study emphasized the way short audio recordings are well suited for looping and nesting arrangements. Although the design purported to use rhythmic manipulations rather than melodic manipulations, its use of rhythms was complicated and difficult to manipulate.

4. Musical Leaves

Functionality of Musical Leaves

Musical Leaves are a collection of flat leave-shaped modules that can record, and playback a sound clip. To record a sound clip, hold down the black record on one side of the leaf. The leaf will stop recording when the black button is released. To play the sound clip, press the large silver button on the other side of the leaf. If the play button is held down, the clip will play on a loop.

The leaf is flexible and can be "scrunched" like a caterpillar and twisted like a bow tie. If the leaf is scrunched, then played the sound clip will be played at a lower volume. If the leaf is twisted, then played, the sound clip will be played at a transformed pitch.

Importantly, if the play button is held down while the leaf is twisted and/or scrunched, the audio clip will play on a loop, undergoing real-time pitch and/or volume transformations.

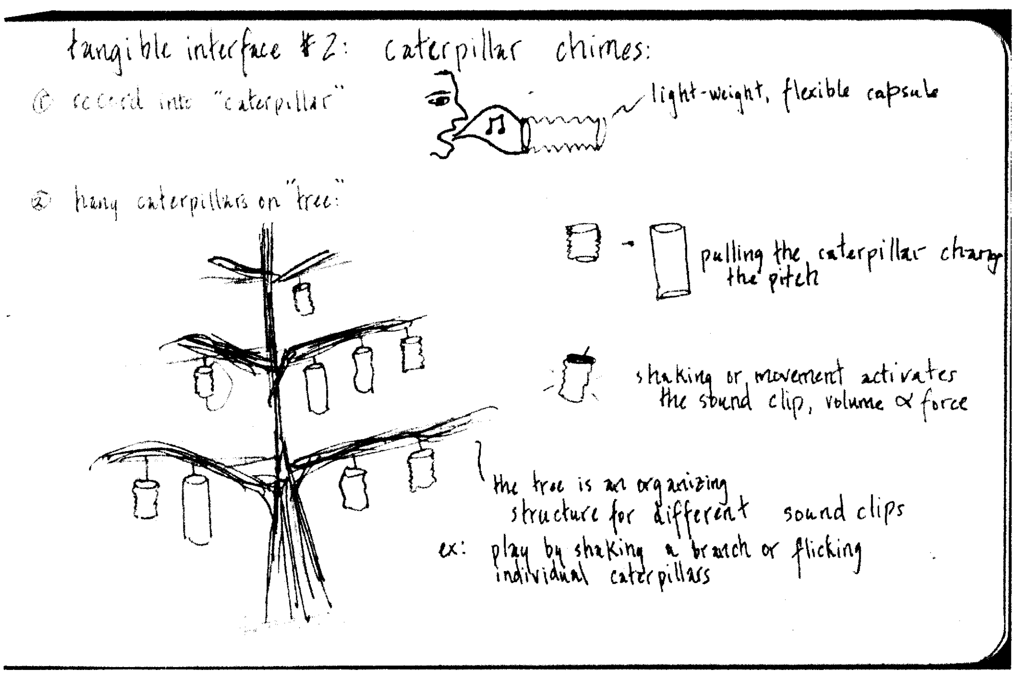

Figure 7: Initial design sketch for Music Leaves, including a tree-like structure for organizing the leaves.

Expression and Organization

The Music Blocks aimed to develop a physical representation for musical notes that could then be manipulated and organized into a composition. Next, the Music Glove emphasized the power of nesting and recursion as well as the importance of flexibility and expression when playing music.

The Musical Leaves interface combines defining qualities from both of the previous projects. *Like the Music Blocks, this system makes use of physical and spatial relationships to organize a composition. Similar to the Glove, this system uses sound recordings to apply nesting and recursion. The interface is also flexible, allowing the user to apply personalized expression while performing.*

Experimentation and Sample Composition

Similar to the Music glove, the prototype of Musical Leaves is a non-working form model of the system. All audio processing is performed on a peripheral computer running a Pure Data program written specifically for the Music Leaves. The same "Wizard of Oz" approach was used to evaluate the design of the system.

The most successful compositions were created using percussive recordings. Fig. 8 below shows the creation composition using ordinary sounds. This composition collected audio samples from brushing teeth, a soda can popping, running water from a faucet and an alarm clock.

Figure 8: Four samples were collected from everyday life for the composition.

Figure 9 shows a composition being played using the four sounds collected above. Notice the ***deliberate*** way the leaves are organized. Users find it useful to organize the leaves spatially according to their position in the composition (i.e. which sounds are introduced first, which ones are used rarely.) Here the soda can leaf and the teeth brushing leaf are placed next to each other because they are played at a similar rhythm, provided the underlying beat for the composition. The alarm clock leaf was positioned in the periphery because it is used only occasionally as an accent.

The water faucet leaf was played while being twisted at the same time. This change in pitch provided a continuous melody – important in a system often dominated by percussion and rhythmic elements. Eventually, the leaves were scrunched one at a time, and the piece decrescendoed to the ending.

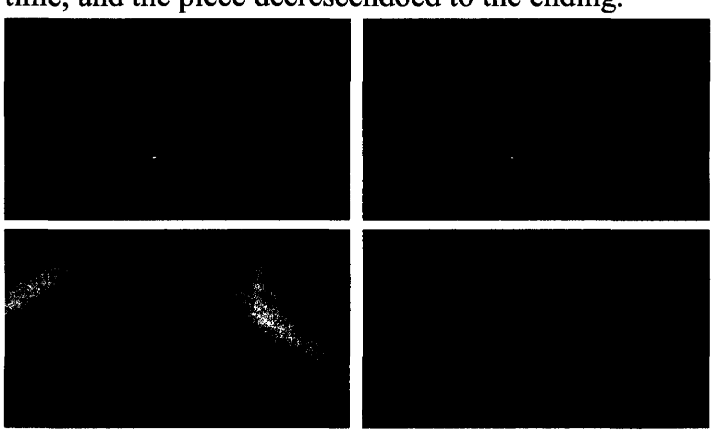

Figure 9: Music Leaves in use.

Return to the Keyboard Interface

In fact, Music Leaves can act as a fully functioning keyboard if the notes of a keyboard are recorded onto each finger. As a result, the Music Glove can be seen as a customizable keyboard. Instead of playing notes on a musical scale, the Music Glove plays sounds that are selected by the user.

Yet another departure from the keyboard metaphor is the ability of the user to move and arrange the leaves as he wishes. The spatial relationship between the leaves can help to organize the composition as well as allowing the user to reflect the relationship or progression between audio samples.

While this physical interface is less restrictive than the glove interface, it suffers from similar limitations because there is a one-to-one relationship between input and output. That is, each sound played requires a certain action by the user. Similar to the Music Glove, the complexity of the compositions is limited by the manual dexterity of the user.

5. Conclusions

Three tangible interfaces for musical composition are explored and evaluated. All interfaces aimed to use their physical structure to represent and/or affect musical elements within the resulting composition. These interfaces aim to develop in users a certain intuition about complex musical concepts from the physical manipulatives used in the system.

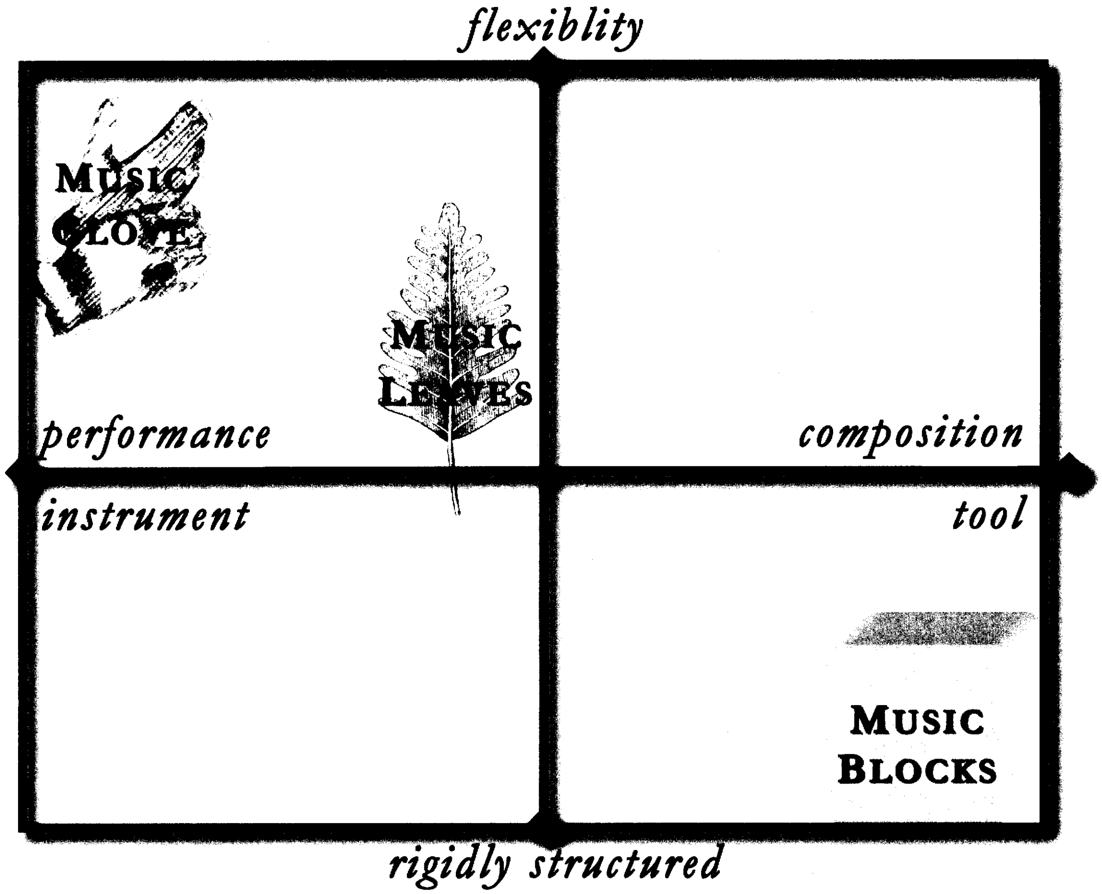

Figure 10: The above graph illustrates the relative position of interfaces on a design plane. The horizontal axis spans the spectrum between performance-oriented instruments to tools for composition. The vertical axis describes how expressive or spontaneous the design is.

Music Blocks, is designed as a direct physical representation of discrete notes, which are arranged to make up a composition. Here, each block is mapped to a single note, and the configuration of the modular blocks in a larger structure suggests the organization of musical compositions. Additionally, the user can pull the block to change its shape, consequently changing the pitch or duration of the note. These manipulations of the blocks allowed the user to design the melody in a recursive way.

This design is geared towards highly designed compositions that can be edited and replayed over and over again. On the other hand, compositions evolve slowly so Music Blocks are poorly suited for spontaneous performances or improvisation.

The system is described as "rigid" because it is a highly structured method mode of operation and there is very little user interaction while the music is playing. In this design, each block must be in contact with its neighbors in a linear fashion, so there is not much flexibility in the composition structure. A the same time, the composition does not require user input while it is playing so there is no room for artistic expression during the performance.

The Music Glove departed from the use of discrete notes as a compositional unit and relied on user-recorded audio samples instead. The audio samples were then played as fingertips were tapped. This system introduced important new concepts about nesting and the role of artistic expression in music composition. The Music Glove is performance-oriented, so its compositions were not so easily repeatable. Here the physical nature of the system is related to the rhythms and tempos of the composition in real-time. Music Gloves was a more performance-oriented system, relying on gestures and manual dexterity.

The Musical Leaves interface melds principles of the Music Blocks and Glove. Like the Blocks, it is a system of modular units that can be organized to reflect the structure of the musical composition. But it is not rigid like the Blocks – the modules do not have to be arranged in a system-defined order to be played. At the same time the Leaves apply the critical concepts of the Glove. Each Leaf module holds an audio recording that can be used to nest compositions recursively. Also, the Leaves can be manipulated in real-time so you can adjust the pitch or volume continuously.

In this way, Music Leaves are highly flexible and suited for live performances, while they can also be organized in a highly structured way for planned compositions.

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