SoundStrand: Composing with a Tangible Interface

Eyal Shahar
MIT Media Lab
75 Amherst Street
Cambridge, MA 02139
persones@media.mit.edu

ABSTRACT
SoundStrand is a tangible music composition tool. It demonstrates a paradigm developed to enable music composition through the use of tangible interfaces. This paradigm attempts to overcome the contrast between the relatively small of amount degrees of freedom usually demonstrated by tangible interfaces and the vast number of possibilities that musical composition presents.
SoundStrand is comprised of a set of physical objects called *cells*, each representing a musical phrase. Cells can be sequentially connected to each other to create a musical theme. Cells can also be physically manipulated to access a wide range of melodic, rhythmic and harmonic variations. The SoundStrand software assures that as the cells are manipulated, the melodic flow, harmonic transitions and rhythmic patterns of the theme remain musically plausible while preserving the user's intentions.

Keywords
Tangible, algorithmic, composition, computer assisted

1. INTRODUCTION
1.1 Motivation
It is well established that the benefits people get from engaging with music are substantial – it arouses creativity, provides means of deep expression and builds self-confidence [1][7]. The entry level for music composition, however, can be quite intimidating. Composing music requires extensive knowledge of music theory, developed aural skills, and often requires mastering a musical instrument. This prevents a large share of the population to take on composing, including young children and mentally or physically challenged people – those who need their self-confidence supported and their means of expression enhanced the most.
Therefore, it is not surprising that many endeavors have been made to lower the entry level for involvement in music composition. Software systems have been designed to enable music composition using abstract graphical input, with the software translating shapes, lines and colors to musically plausible compositions [5]. On the other hand, the use of tangible interfaces in music is mostly restricted to exploration and manipulation of pre-composed music due to their limited amount of degrees of freedom. SoundStrand demonstrates a hybrid approach that provides tangible interaction yet yields a complex, deliberate musical composition.

NIME'12, May 21-23, 2012, University of Michigan, Ann Arbor.

1.2 Distinction from Related Work
The body of work in the field of tangible interfaces for music creation is immense. Concentrating on interfaces for music composition, we can observe works such as the reacTable [6] and AudioCubes [8], in which objects represent musical elements that are constantly playing, bringing the interaction more similar to a performance, improvisation or composition in real time. Other interfaces such as the Tangible Sequencer [1] and Music Blocks [10] are, indeed, sequencers; however, the sequenced units are sampled, unchangeable segments of music, a fact that leaves the user highly limited in terms of composing. Finally, augmented reality projects, such as the Music Table [2], support detailed music composition, yet the objects with which the users interact take the role of commands or temporary representation of content, rather than embody the musical material and act as a consistent representation.
The SoundStrand cells not only represent their musical content but also the means to control it. Their individual manipulation controls rhythm, pitch and harmony, while their assembly is a high level description of the musical content arrangement. The finished strand is a mentally sustainable representation of a composed musical piece.

2. SOUNDSTRAND
SoundStrand is a set of cylindrical *cells*, each representing a musical one measure long musical *phrase*. Cells come in different types that represent different musical phrases. Cells can be attached to one another to create a musical theme, as shown in Figure 1. The skeletal mechanism of a cell allows it to be stretched or shrunk to shift the rhythmic center of mass, bent upwards or downwards to change melodic directionality and twisted along its axis to change the harmonic context.

Figure 1. Two SoundStrand configurations, demonstrating different manipulations of cells

The physical interface of SoundStrand is a set of cells. A cell is a cylindrical object with a 3D printed skeleton and stretchable fabric skin. The skeleton is designed so that the cell can be bent, elongated and twisted. Cells also include electrical circuitry that is used to digitally capture the cell's physical state and to communicate with neighboring cells. Cells connect to each other by a set of extrusions and holes on both their ends.

Electrical connectors are also located on the cells' ends. These are used to carry power and data between the cells. The first cell in a strand connects to a computer using an FTDI cable. The data that is received by the computer describes the complete current strand configuration.
The computer, in turn, is running dedicated software that reads the strand's configuration and translates the cells' order and individual cell manipulations to a musical composition.

3. MUSICAL APPROACH

3.1 Musical Paradigm

Currently SoundStrand is restricted to a single voice, single timbre theme accompanied by a harmony and a bass. It is recognized that a theme is the assembly of musical phrases, often repetitive with some modifications. It is then stressed that these variations are introduced to the timing of the notes, their pitches and the underlying harmony. Applying these variations using a tangible interface requires that a user will have access to the wide varieties of possible variations of one of these properties with a single parameter.
For rhythmic variations, a phrase can be viewed as having a *center of rhythmical mass*. If a phrase is one musical bar long and it is comprised of four consecutive quarter notes, it is said that its center of rhythmical mass is 0.5, i.e. in the middle of the measure. If notes are shifted towards the beginning of the measure it will have a smaller center of mass and a larger center of mass if notes are shifted towards the end. The suggested application will shift the notes to accommodate the desirable center of mass as expressed by the user.
For melodic variations, the notes comprising the phrase can be viewed as having *directionality*. Modifying the directionality of a phrase will shift the notes' pitches upwards or downwards.
Finally, when a harmonic variation is introduced to the phrase, the system not only changes the notes of the underlying harmony and bass, but also the melody notes in a manner that will be musically plausible.
It is also required that the system ensures that transitions from one phrase to the next are musical, mainly in respect to the harmonic transitions and the melody line.

3.2 Parameter Mapping

Assignment of the various degrees of freedom of the SoundStrand cell to the different types of phrase variation attempts to be as intuitive as possible.
As cells are connected sequentially to one another, it suggests that time moves along the trajectory connecting the cells, i.e. along the cells' lengths. Therefore the variation concerning the timing of the notes – their rhythmic distribution – is mapped to changes along that axis, which is the cell's elongation.
Pitch is commonly referred to as the axis perpendicular to time; therefore, the cell's bend is mapped to the phrase's melodic directionality.
Finally, the mapping of the cell's twist to harmonic tension seems natural as the act of twisting is often paired with physical tension, such as springs or lids of jars.
Table 1 shows a phrase along with one of the several results of the cell's manipulation along each degree of freedom.

4. DESIGN

4.1 Mechanical Design

The cells are cylindrical objects about 4" in length and 2" in diameter. They consist of a plastic skeleton, a skin and electronic circuitry.

Table 1. Example of a manipulated cell

Manipulation	Variation	Phrase
None	Original phrase	
Bend	Melodic directionality	
Elongation	Rhythmic distribution	
Twist	Harmonic tension	

4.1.1 Skeleton

The skeleton of a SoundStrand cell (Figure 2) is fabricated by 3D printing. It is designed to enable the cell to be bent, twisted and elongated, and to be connected to neighboring cells [9].
The center piece of the skeleton is the *frame*. It has a rail in which slides the *rack*. The rack can be moved back and forth to change the elongation. The frame has a niche to which the *pinion* fits. When the rack slides back and forth, the pinion turns, and by measuring a potentiometer attached to the pinion, the amount of elongation can be determined.

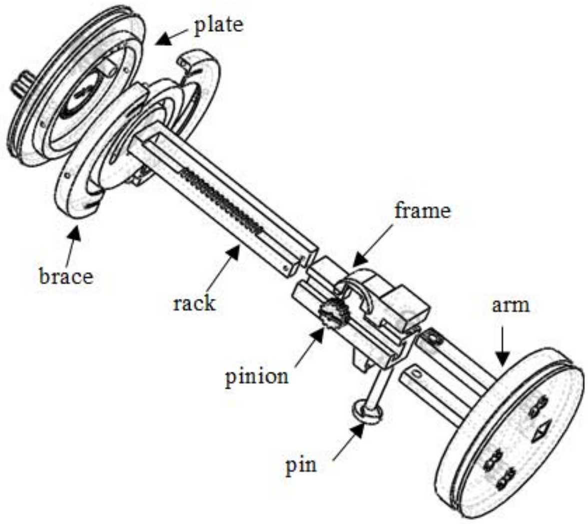

Figure 2. A disassembled cell skeleton

The *arm* serves as the bending mechanism of the cell. It extends from the frame to which it is connected with a *pin*, allowing the arm to turn around the pin's axis. The pin itself has an extrusion that fits into a niche in the arm, forcing them to move together. A potentiometer attached to the pin measures the angle between the arm and the frame, determining the cell's bend.
Finally, the twisting mechanism consists of the *plate* rotating against the rack's end. Two *braces* locked into each other and to the plate encapsulate the rack's end and hold the plate in contact with it. A potentiometer attached to the plate measures the amount of rotation between the plate and the rack's end in order to determine the cell's twist.

4.1.2 Skin

The cells are covered with an elastic fabric skin. The skin is sewn to a cylinder, and it keeps its shape with three plastic rings fastened to its interior. Two rubber rings are sewn to the ends of the skin and fit to grooves on the edge of both the skeleton's ends.

4.1.3 Connectors

Three cross-shaped extrusions are located on the face of the plate. These fit into corresponding cuts in the face of the connected cell's arm. In addition, the electrical connectors, which are a 2x2, 2.54mm pitch header-connector pair, not only provide power and communication but also support the mechanical connection between cells.

4.2 Electrical Design

In the center of every SoundStrand cell is an Atmel ATmega168 microcontroller. It measures the value of three potentiometers fixed to the cell's skeletal structure to determine the cell's elongation, bend and rotation.
Cells connect to each other electronically as described in section 4.1.3. The first cell in a strand is connected to the computer with a USB FTDI cable. This connection allows the computer to provide a 5V power line and a ground line for the entire strand and receive the strand's configuration, encoded as described in section 4.3. Two of the pins are used as a shared 5V power supply. A third pin is used to transfer data over a serial bus from a cell to the one preceding it. The fourth pin is reserved for future use.
The circuit features an RGB-LED that serves to indicate that the cell is working properly. The color of the LED is determined by the state of the potentiometers. The light is clearly visible to the user as it is diffracted by the cell's skin.

4.3 Communication Protocol

By design, data can flow between the cells in only one direction - from the end of the strand towards the computer. The last cell in the strand periodically initiates the data transfer with a packet that contains the cell's type and potentiometer values, followed by an "End of Transmission" (ETX) byte. The packet is passed to the preceding cell which adds its own type and potentiometer values to the beginning of the packet before passing it on. This process is illustrated in Figure 3.

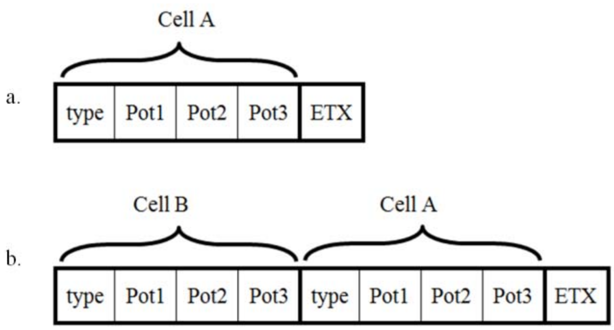

Figure 3. Packet formation. a) Cell A, the last in the strand, initiates a packet. b) Cell B adds its data to the packet.

Working in *tail* mode, a cell assumes it is the last one in the strand unless receiving a packet in its input port. While operating in this mode, it will initiate a data transfer every 250ms. Once a packet is received, the cell will no longer consider itself last and will enter *body mode*. Under this mode of operation, packets received will be promptly modified and passed on. If no packet is received for a period of 500ms, the cell will assume its subsequent cells have been removed and return to tail mode. The 500ms interval assures cells do not leave body mode prematurely.

4.4 Software

The software used to translate the strand's configuration to a musical theme is written in Java. When the software is started, it loads XML files describing the various cell types in terms of their musical content, which is the original pitches of the notes and a table of possible rhythmic distributions. Other XML files describing harmonic transition tables are also loaded.
The software then allows the user to select various harmonic models which are implemented through their respective transition table. The user can also select melodic models which determine how note pitches will be quantized, e.g. diatonic vs. pentatonic scales.
The software also features a transport bar, allowing playing, stopping and looping the strand or a particular cell and a piano-roll style visual representation of the theme.
Finally, the software allows the user to enter simulation mode in which connection to a physical interface is not necessary and cells are added, deleted and manipulated virtually.
Two additional software tools allow the user to program new harmonic transition tables and new phrases along with their possible rhythmic permutation. These will be described in section 5.4.

5. ALGORITHMS DESCRIPTION

5.1 Rhythmic Variation

Stretching and compressing a cell result in changes in the rhythmic distribution of its phrase's notes. Currently, a phrase is programmed with a predetermined list of possible rhythmic variations. The value of the cell's elongation potentiometer is quantized by the software which in turn selects the appropriate rhythmic permutation from the list.

5.2 Harmonic Variation

SoundStrand's harmony system is inspired by David Cope's SPEAC system [4]. A cell can have one of five possible tension functions: Statement, Preparation, Extension, Antecedent or Conclusion. Different states correspond to different degrees of twist introduced to the cell. A harmonic transition table determines the cell's chord based on its tension function and the preceding cell's chord. As an example, let us assume a SoundStrand playing in the C-Major key. If a cell is twisted to assume the *Extension* function and its preceding cell's harmony was an F-Major chord, the harmonic transition table might indicate that the cell's chord should be a D-Minor chord. Different harmonic transition tables can be applied to produce different musical modes, e.g. Minor or Phrygian, or various musical genres.

5.3 Melodic Variation

Bending a cell alters the melodic directionality of its phrase. The alteration of notes is done in several stages. First, if a cell is not the first one in a strand, the phrase is transposed so that its reference point, which is the middle C, is shifted to be the same as the last note of the preceding cell. This is done in order to achieve a natural melodic flow from cell to cell.
It is then that the direction and amount of bending are considered. Notes are transposed up or down depending on the direction of bending - notes that are closer to the end of the measure are transposed more than notes that are closer to the beginning. The notes' pitches are then quantized to pitch values that are on the strand's key, and the first and last notes are further quantized to pitch values which form the cell's chord.

5.4 Content Generation Tools

To achieve even greater flexibility using SoundStrand, advanced users can create their own content using two content generation tools. These define the melodic content, the rhythmic permutations and the harmonic behavior of SoundStrand.

5.4.1 Cell Content Editor

With the Cell Content Editor, the user can program cell phrases, along with the possible rhythmic permutations: in the piano-roll like *Pitch Area* the user defines the number of notes present in the phrase and their pitches when the cell is not bent. Although the timing of the events is also expressed in this editor, it is only for reference and for the initial setting of a new rhythmic pattern. The actual timing is specified in the *Rhythm Area*. The Rhythm Area allows the user to create the various rhythmic patterns accessible through modifying the elongation property. The pattern editing interface is a row of boxes representing the 1/16th note intervals in the measure. The user edits a pattern by marking the desired onset times.

5.4.2 Harmonic Transition Table Editor

The Harmonic Transition Table Editor allows the user to create a set of rules that determine SoundStrand's harmonic behavior. A rule, as a software entity, has two fields: state, which is a string expressing the harmonic function of the preceding cell; and transitions, which are an array of strings, each expressing the next function based on the degree of tensions as conveyed by the cell's twist. The user begins to create a new harmonic transition by starting with an empty table. When adding a new rule, the software prompts the user to determine the state of that rule. The user can choose any degree on the scale, i.e. I to VII, and has a choice between a major or minor chord. The user can then determine the different transitions of that rule. However, in order to use a harmonic function as a transition, it must first be defined as a state of another rule. This scheme prevents SoundStrand from reaching a harmonic function for which harmonic transitions are not defined.

6. SUMMARY AND FUTURE WORK

This work intends to demonstrate the feasibility of composition with tangible interfaces, a concept which allows users of various musical backgrounds to engage in creative musical activity. Additional work to develop this concept can take many forms.

Enhancement of SoundStrand interactivity can be explored in many paths. At present, auditioning cells, playing, stopping, and toggling the loop mode are all done from the computer GUI. A search for ways to execute these functions through tangible interaction will help to concentrate the user's engagement around the physical interface. Other sensors can be incorporated in the SoundStrand cells to detect the strand's location and orientation in space. This, for example, can be used once the piece is ready and is being performed by handling it in space. The research work to be done in this case will include the sensing technology, but even more importantly, the mapping of the data retrieved to musical parameters.

Visual feedback can also be greatly improved, perhaps by increasing the illumination of the currently playing cell or even the current playing position within the cell. In addition, a sturdier, more robust physical structure can be developed, both from the perspective of the mechanical design and the materials being used.

On a wider scope, the paradigm of composing by manipulation of pre-composed musical fragments can be implemented in other applications - the most obvious are a range of yet unexplored tangible interfaces for music composition that can take very different form from SoundStrand, use different mappings, but still utilize the same paradigm and algorithms.

Further research can be done regarding the algorithms themselves, allowing multiple harmonic changes within a measure, automatic generation of rhythmical permutations and key changes.

7. ACKNOWLEDGMENTS

I would like to thank Yan Shen and Kelsey Brigance for their key contribution in the mechanical design and Tod Machover for supporting this project.

8. REFERENCES

[1] Bernstein, J. T., *The Tangible Sequencer - a Simple Musical Instrument*, http://murderandcreate.com/tangiblesequencer, 2005

[2] Berry, R.,Makino, M., Hikawa, N., and Suzuki, M., The Augmented Composer Project: The Music Table, in *Proceedings of the 2003 International Symposium on Mixed and Augmented Reality*, Tokyo, Japan, 2003, pp. 338–339.

[3] Boulanger, A. *Music, Mind and Health: How Community Change, Diagnosis, and Neuro-Rehabilitation can be Targeted during Creative Tasks*. Ph.D. Thesis, Massachusetts Institute of Technology, 2010

[4] Cope, D., Computer and Musical Style, A-R Editions, Madison, WI, 1991

[5] Farbood, M., Kaufman, H., and Jennings, K. Composing with Hyperscore: An Intuitive Interface for Visualizing Musical Structure. In *Proceedings of the International Computer Music Conference*, Copenhagen, Denmark, 2007

[6] Jorda, S., Kaltenbrunner, M., Geiger, G. & Bencina, R., The reacTable*. In *Proceedings of the International Computer Music Conference*, Barcelona, Spain, 2005

[7] Machover, T. Shaping minds musically. *BT Technology Journal,* Kluwer Academic Publishers Hingham*, MA*, 2004, 22(4):171-179.

[8] Schiettecatte, B. and Vanderdonckt, J., "AudioCubes: a Distributed Cube Tangible Interface based," in *Proceedings of the Second International Conference on Tangible and Embedded Interaction*, Bonn, Germany, 2008, pp. 3-10.

[9] Shen, Y. Sound Strand Design: *Designing Mechanical Joints to Facilitate User Interaction within a Physical Representation of Digital Music.* B.S. Thesis. Massachusetts Institute of Technology, Cambridge, MA, 2011

[10] Sosoka, J., Abercrombie, B., Emerson, B. and Gerstein, A., *Educational Music Instrument for Children*, 6,353,168, March 5, 2002.

[11] Weinberg G. Playpens, Fireflies, and Squeezables – New Musical Instruments for Bridging the Thoughtful and the Joyful *Leonardo Music Journal*, MIT Press, 2003. Vol. 12, pp. 43-51