Kinéphone: Exploring the Musical Potential of an Actuated Pin-Based Shape Display

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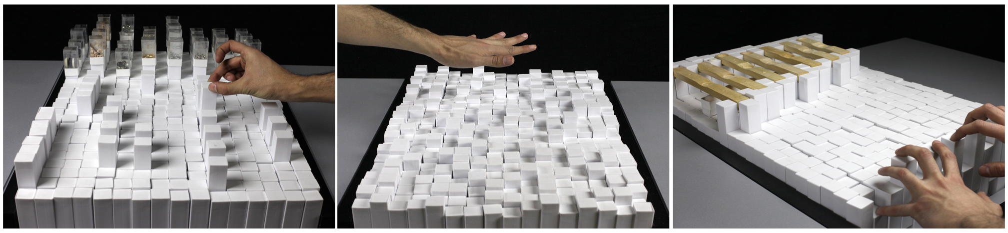

ABSTRACT

This paper explores how an actuated pin-based shape display may serve as a platform on which to build musical instruments and controllers. We designed and prototyped three new instruments that use the shape display not only as an input device, but also as a source of acoustic sound. These cover a range of interaction paradigms to generate ambient textures, polyrhythms, and melodies. This paper first presents existing work from which we drew interactions and metaphors for our designs. We then introduce each of our instruments and the back-end software we used to prototype them. Finally, we offer reflections on some central themes of NIME, including the relationship between musician and machine.

Author Keywords

Shape Display, Radical Atoms, Shape Changing Interfaces, Sequencer, Gesture, Bricolage

ACM Classification

H.5.5 [Information Interfaces and Presentation] Sound and Music Computing, H.5.2 [Information Interfaces and Presentation] User Interfaces—Haptic I/O, I.2.9 Robotics

1. INTRODUCTION

In recent years we have seen a growing trend in dynamic, physical actuation of matter in diverse domains, from architecture to biology [36, 9]. Looking into the future, researchers have envisioned a world where physical atoms may be just as dynamic and malleable as bits [11]. To design for this future, HCI researchers have used currently available "enabling" technologies to build novel interactions and applications, following Alan Kay's idea that "the best way to predict the future is to invent it" [17]. One popular enabling technology is the pin-based, actuated shape display. Originally designed to render shape content for haptic feedback [13], the shape display has become a platform on which to imagine future interactions in applications including computer-aided design, data visualization, and telepresence [7, 19].

Our work explores how the pin-based shape display may become a generalized platform for creating custom acoustic musical instruments. Additionally, we also demonstrate how the pins may serve as input interface (musical controller) and sound producing object. Though the shape display was not designed expressly for music, this research follows a long history where innovative technologies are adapted for musical purposes. This practice not only opens creative avenues for music-making, but also helps to push forward the technologies themselves. Moreover, probing the musical properties of the shape display offers novel perspectives on major themes of NIME, such as the relationship between the physical and digital, the control and output, the performer and instrument-maker, as well as the musician and machine.

As a first step of exploring the musical potential of the shape display, we designed and prototyped three instruments on TRANSFORM, a state-of-the-art shape display [10]. This paper begins with a background that describes TRANSFORM and presents examples of existing instruments and interfaces which inspired our designs. We then describe each of our new instruments as well as the software system that drives them. We conclude with a set of reflections on key themes of NIME, closing with a vision for the future of the shape display as a musical platform.

2. BACKGROUND

TRANSFORM comprises three separate shape displays of 16x24 pins. Each pin measures approximately 1'x1' and extends 100mm from the surface. Based on the same hardware as inForm, TRANSFORM features custom Arduino boards running a PID controller to control the position of polystyrene pins through motorized slide potentiometers [7, 10]. Actuation speed is 0.0655 m/s, with up to 1.08 Newtons of force. TRANSFORM can detect user input from each

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pin based on changes in position and includes an overhead Kinect to detect users' gesture and movement. A program written in C++/OpenFrameworks acts as the main software interface for TRANSFORM, which updates pin positions at 30fps. For more information, see [7, 10].

TRANSFORM was originally built as an interactive art installation and featured 3 modes: a wave generator responsive to visitors' movements, an abstract animated narrative, and a kinectic sculpture where pins guide the movement of passive red balls. The pleasing variety of natural sounds of the machine itself and the interplay between the machine and passive objects became our first inspiration to use TRANSFORM as a platform to build *acoustic* instruments. For insights on shaping our new instruments, we look to existing work on mechatronics, tabletop tangible interfaces, and gestural control applied to music.

2.1 Mechatronic Music

Works done by Zimoun, Pe Lang and Zareei et al., demonstrate the potential in using mechatronic noises themselves as the source of musical sounds [25, 44]. Many of Zimoun and Pe Lang's work incorporate a large number of DC motors to create sound-emitting mechanisms with and without other objects. Mutor is a mechatronic sound art that uses the sonic artifacts of DC motors. The continuous humming sounds from DC motors is aesthetically modulated to create a drone chorus. We may apply a similar principle to repurpose the sounds of TRANSFORM's motorized slide potentiometers.

Instruments using mechanisms to actuate passive sound-producing objects have existed since the dawn of the machine age in the 18th century [8]. Sometimes, as in the case of the harpsicord and the pianoforte, these instruments require human actuation of the mechanism. Other times, as with the music box and player piano, these instruments mechanically imitate how humans play music, such as plucking, bowing, hammering, and blowing [3].

More recently, works within the NIME community have used robotic actuation to empower humans to create acoustic music never possible before [34]. A popular approach uses robotic actuation to create percussion instruments with greater speed and accuracy than a human player [15]. These instruments may be controlled digitally, as in the case of the Machine Orchestra, an ensemble of human laptop performers and robotic musical instruments [16]. The field of robotic musicianship embodies another approach where the robot acts as an intelligent agent capable of higher level musical exchange with a human player [41].

2.2 Tabletop Tangible Interface for Music

The notion of tangible interfaces has been applied to the control of digital music, to offer physical affordances and constraints not present in purely digital controllers [12]. The core mechanics of this interaction model is the mapping between the tangible controls and the resulting digital sounds. One lineage of works [[31, 14, 20]] is based on the tabletop metaphor, where the configuration of physical tokens dictates the synthesis of digital sounds and rhythmic patterns .

A core idea of Tangible Interfaces is to leverage the rich relationships people already have with everyday objects in interactions with the computer [12]. This idea has been applied to music in projects such as Drumtop, which invites the user to discover the acoustic properties of everyday objects [38].

Another family of peudo-tabletop interfaces, such as the Tenori-on and the Monome, features a grid of back-lit LED buttons, which allow user input and act as visual feedback for the digitally synthesized sounds [27, 1]. The form factor of the grid make these devices ideal for layered, rhythmic compositions, a model to apply for music on the pin-grid of the shape display.

2.3 Gesture Control of Music

Research on gesture is complex, with varying definition across disciplines [24]. To contexualize related works, we follow Wanderley's definition of gesture—the characteristic actions of music instrumentalists during performance [40]. To further specify our scope, we focus on free-handed gestures—gestures that do not have physical contact with an object—and their control of musical parameters. We are interested in both discrete event and continuous control of gestures, both of which are powerful expressive tools [42].

The analysis of free-hand gestures is an on-going active research and a significant amount of effort has been made both in music and in HCI using a variety of input technologies. Two common approaches include capacitive sensing and electric field sensing, demonstrated respectively by Max Matthew's Radio Baton [23] and the Sensor Chair used in the Brain Opera [30]. Another technique uses wearable systems, including handheld devices [39] as well as bio signals [35].

As the TRANSFORM system includes a Kinect camera, we look more to related work on using computer vision systems to detect and process gestures for musical performance. EyesWeb is a camera-based system for the real-time analysis of body movement and gesture [4]. Similar approaches to EyeWeb may be seen in several camera-based musical systems [43, 33, 28]. In addition, machine learning techniques in conjuction with computer vision have become a popular approach to analyze and classify gestures for music performances [26].

3. SHAPE DISPLAY INSTRUMENTS

Drawing from the works described in the previous section, we designed and prototyped three new musical instruments on the shape display. Each instrument uses one 16x24 module of TRANSFORM and can be played alone, with the others, or with any other musical instrument. All three feature tangible and gestural controls and output entirely acoustic sounds.

Our goal in creating these instruments is to demonstrate the versatility of the shape display as a general music-making platform. Thus, these instruments are designed to cover a variety of input and output paradigms to suggest a larger space of possible designs. Some elements of our designs have been dictated by by the existing hardware constraints of TRANSFORM. These constraints are mentioned where relevant along with suggestions of improvement to facilitate music-making on future versions of shape displays.

3.1 Gestural Wave

The first instrument uses free-hand gestures to control ambient textural noises generated by the the acoustic sounds of TRANSFORM's actuation. We implemented three types of waves: a sinusoid wave, a Perlin noise wave [32] and a vertical cross wave. All three were inspired by patterns from TRANSFORM's original applications and were selected based on the distinct sounds they produced. The sinusoid wave outputs a smooth, "undulating" sound. Due to more surface contact between adjacent pins, the cross wave produces a louder "rustling" noise. The Perlin wave features the most "jumps" in the pins and is much noisier and "chaotic" sounding than the other two.

For more variation in sound, all three waves were re-coded to expose parameters targeted for modulating sound (figure

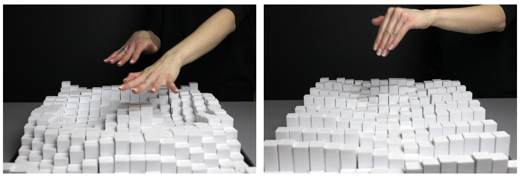

Figure 1: Sinusoid (left) and cross wave (right)

5). Based on extensive experimentation, we identified four parameters of each wave and describe how they change the acoustic properties of the sound output:

- **Amplitude:** Controls the height of the pins which corresponds to the overall volume.
- **Ordinary frequency:** Adjusts the repetition of the acoustic waveform shape. More repetition increases friction between adjacent pins.
- **Phase:** Determines the speed of the pins, which also controls volume.
- **Center:** Positions of the center of waves, which changes the directional focus of the sound.

For real-time performance, we detect the position and shape of a user's hands with the overhead Kinect. The depth image from the Kinect is used to process a threshold distance image which then is passed to OpenCV for blob detection (see figure 2).

By default, the vertical position of one hand controls the amplitude of the selected wave, which corresponds to the overall volume and heights of the pins. This gives users the most immediately noticeable change in sound in response to their movement. With a second hand, the user may modulate the frequency of the physical wave, which changes its texture. The opening and closing of the hand may be used to switch between the selected wave and a random pattern of pins, which adds an instantaneous accent to the sound. With this, it is possible to create *staccato* rhythms to punctuate the more ambient waves. Currently, a GUI is used to switch between the three different waveforms. A logical future extension would be to use gesture (e.g. holding out different numbers of fingers) for mode-switching.

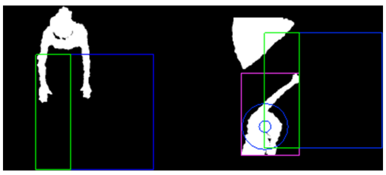

Figure 2: Threshold image with area of detection (left) and blob detection (right)

3.2 Step Sequencer

Our second instrument uses the shape display to sequence and play layered rhythms, inspired by interfaces like the Tenori-on [27]. It features up to 8 simultaneous tracks, each mapped to every other column on one TRANSFORM module. Within each column, the pins are divided into 2 regions. Four pins in of the top portion act as actuators, and each is augmented with a "shaker" cap made from clear polyester film. Selected for both visual appeal and its acoustic properties, the film is cut and folded to form a box of 1'x1'x2", with a 1/2" extension at the bottom to fit over a pin. The cap is secured with a small piece of double-sided tape. To differentiate between tracks, the caps of each column are filled with different materials (e.g. beads, bells, wood scraps, buttons, nails).

The actuators of each row take turns making sounds based on the sequence given by the 16 pins directly below, which represent a repeating pattern of 16 steps. These pins may be set to an *up* or *down* state to program the pattern. Pushing on a pin in the *down* position sets it to *up* while pulling on an *up* pin returns it to *down*. The very last pin at the bottom of each column acts as a button that toggles whether that sequence plays or pauses.

On the far right edge of the display is a column of 16 pins with a "cursor" shown by a slightly raised pin that indicates the current position in the sequence of 16 steps. Based on the position of the "cursor", the top pins for each column move given a step set to *up* and rest when the step is set to *down*. The very last pin on the cursor column controls pause for the entire sequencer.

The four actuators take turns making sounds to compensate for a limitation in the shape display hardware. Even though the pins have a refresh rate of 30fps, we found that successive movements of large distances ($>$ 0.5 of the maximum position change) occur at a much slower rate due to friction. Additionally, our prototype treats the a shaker pin's up motion and down motion as equivalent sounds even though down is much louder than up. This decision is due to another limitation in the system. To only use the downwards movement for sound production, we must reset the pin after each movement. Because pins contain sound-producing objects, we are limited to a slow, gradual reset to prevent extraneous noise. However, slowly resetting all the shaker pins interferes with our touch detection. These experiences reveal limitation with the shape display hardware that previous applications had not encountered.

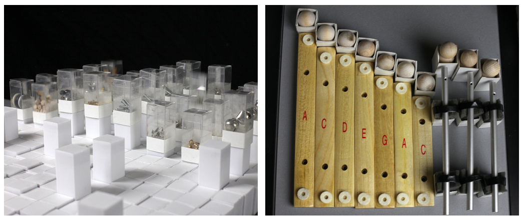

Figure 3: Objects for the sequencer (left) and keyboard (right)

3.3 Modular Keyboard

Our third instrument uses TRANSFORM's pins to strike sound-producing objects, inspired by Drumtop [38] and by the piano. Since textures and rhythms have been explored by our two other instruments, we focused on objects that emit pitched tones for playing melodies though striking objects may also produce sound effects and rhythms.

Our prototype plays tones of two different timbres, taken from a disassembled wooden xylophone and a set of metallic chimes. Pins in the top portion of one TRANSFORM module are raised to hold the objects in place. The xylophone bars are attached with foam feet on each end and placed directly in their holders. For the chimes, caps fitted with foam are placed on the hold pins to help with resonance. Currently, our prototype supports 7 slots for the bars and chimes. Under each slot is a pin with a cap that contains a wooden ball which acts as a hammer. The order of bars and chimes could be customized at will to correspond to different intervals and scales.

The bottom row of pins acts as a "keyboard" interface, with raised pins in the same column as the hammers which act as "keys". Pressing on each key activates its corresponding hammer to strike. Holding down a key triggers multiple successive strikes. Hammers may also be played through a computer keyboard, where the computer keys trigger both the striking of the hammer and the depression of its coupled shape display key. Sequences of melodies may also be programmed on the computer to play and loop on our modular keyboard.

Due to the existing implementation of touch detection on TRANSFORM, there is an approximately 200ms latency for touch events to register. The delay arises from the touch detection algorithm which tries to prevent false positives since touch is currently detected from reading the positions of pins from their backdriven motors. This same latency is present for the Step Sequencer, but it does not pose a major problem since sequence setting and actuation are not not directly coupled.

Though 200ms is a significant delay considering studies done in network music [5], we found that a player may compensate for it if they imagine hammer strikes to be mapped to key up rather than key down. Players may also use the computer keyboard for latency-free playing. Latency in touch detection is an important issue to address in future iterations of shape display hardware and software. Future implementations will also delve more into the passive haptic feedback from the pins to design interfaces for more expressive control.

4. SOFTWARE IMPLEMENTATION

Prior interactive applications for TRANSFORM [10] have all been implemented in OpenFrameworks, where heights are represented by a 2D pixel map shown in a runtime GUI. To enable faster development, we built a software architecture that allows external applications to control the shape display. A Node.js application acts as a middleware server between external applications and OpenFrameworks. Using OSC over UDP, the Node server passes height messages from external applications to TRANSFORM and input messages (touch and Kinect) from TRANSFORM to external applications.

Within OpenFrameworks, all three modules of TRANSFORM are indexed together like one large shape display. The Node server allows external applications to control one module of TRANSFORM at a time. Our main external development environment is xForm, a JavaScript client application served by Node over http that runs on localhost. xForm offers a 3D preview of TRANSFORM written with 3js and includes live scripting using the Ace editor. This allows a developer to try out shapes and movements virtually before sending to TRANSFORM. The xForm UI includes a toggle to connect the virtual model to the physical machine. When on, it sends heights and receives input. Both the sequencer and the keyboard are written using this environment.

Our architecture also allows developers to code for the shape display in any language of their choice, as long as they pass OSC messages in the proper format. The Gestural Wave instrument was written in Processing. We were also able to interface with TRANSFORM using Cinder while prototyping our instruments.

5. DISCUSSION

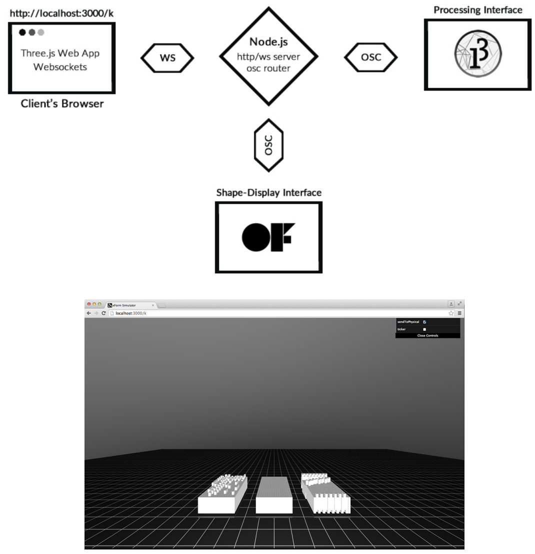

Figure 4: (top) Software architecture, (bottom) xForm simulator for the TRANSFORM

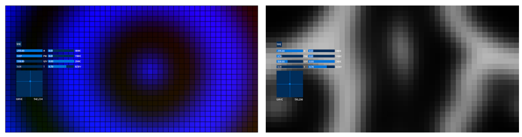

Figure 5: Processing GUI to control parameters of the sinusoid (left) and Perlin wave (right)

We first summarize the overall space of musical possibilities of instruments on the shape display as suggested by our three prototypes. We then offer reflections on key topics in NIME relating to the machine and the musician.

5.1 Musical Possibilities

5.1.1 Parameters of Music

Our three instruments give the player control of all four basic parameters of music: pitch, loudness, timbre, and duration [18]. The Gestural Wave controls loudness, timbre, and duration of sound; the Step Sequencer explores timbre; and the Modular Keyboard covers pitch and timbre. While the Sequencer and the Keyboard do not control the duration of individual tones, they do allow control of timing—in other words, the duration of silence.

5.1.2 Control Paradigms

Our prototypes demonstrate 3 different control paradigms based on metaphors from existing instruments and interfaces, but they are by no means the only way to control each instrument. For example, the "shaker" pins of the Step Sequencer could also be played the same way as the keyboard and sequenced based on the playing. In this input model, we may introduce the equivalent of a looper pedal, where pin movement based on user input is repeated and layered. Free-hand gestures and movement could also be used to control patterns of scales and arpeggios on the keyboard. Additionally, all three instruments could be played via live coding in their respective software environments.

5.1.3 Interface to the Digital

Though this paper focused on acoustic sound production, the shape display could also serve as an interface for digital music. In that scenario, all the interaction paradigms that we discussed would still apply. The same movement of the physical pins to generate sound would then serve as visual and haptic feedback on the state of the digital music.

When used as a digital controller, the sounds of the pins should be minimized in order not to interfere with the digital sounds. Amplification of the digital sounds could also hide the noise of the physical sounds. Additionally, the shape display could be used in the context of remote musical performances. For instance, the gestures of remote performers could be rendered on the shape display, as envisions by [19]

5.2 Machine and Musician

5.2.1 Player, Controller & Sound Producing Object

Within the NIME community, one common way of describing instruments is through the paradigm of the player, the controller (or interface), and the sound-producing object [6]. In traditional acoustic instruments, such as the violin, the "interface" and sound-producing object are intimately connected. Thus, there is no latency, and the player receives subtle feedback through both sound and haptics [22]

In electronic and digital instruments, the controller and sound-producing object (synthesizer) are connected by mappings created by the designer. While these instruments offer more flexibility in both interaction and sound synthesis, the lack of tight coupling between controller and synthesizer poses problems. Perry Cook points out 3 major flaws of the paradigm: (1) the lack of haptic feedback from the controller to the player, (2) the introduction of distortions/delays between the controller and the sound-producer, and (3) the lack of any sense that sound comes from the instrument [6].

In our instruments, the tangibility and actuation of the shape display serve as haptic feedback, taking care of (1). Moreover, all of our sounds are acoustically produced by the physical instrument, taking care of (3). Noticeable latency only arises for one of our instruments, but it is due to the implementation of the platform and could conceivably be removed in the future. Our prototype instruments represent a hybrid of physical and digital, where a digital layer connects the two physical sides of controller and sound-producer. While physicality imposes constraints on the potential space of controller and sound design, it offers advantages of purely physical instruments with the flexibility to design digital mappings [22]

5.2.2 Beginner & Expert

Another key question of NIME is how to support a low-floor-high-ceiling usage on new musical instruments [29]. A core feature of shape displays is their capacity for dynamic affordances and constraints, which may help beginners to make sense of a new interface [7, 21]. For players with more experience, musical interfaces on the shape display could be designed to mimic existing instruments, as our prototypes have demonstrated. This allows allowing players to adapt their existing technique and musical understanding to new instruments.

Additionally, the shape display's flexibility and ease of programmability make it an ideal platform for music pedagogy. Part of learning to play music is the reconciliation of musical understanding with embodied actions on the instrument [2]. The shape display allows users an easy way to physically encode their own evolving musical understanding in the controller's form and function. It also encourages bricolage in both instrument design and music-making, promoting playful learning [37].

6. FUTURE WORK

Based on the explorations of this project, we now look far into the future to imagine how people may interact with music in a world where shape displays have become an essential part of everyday computing. Just as the computer has become a standard way of interfacing with digital music, shape displays may also become a standard platform for a new genre of hybrid physical/digital musical instruments.

Musicians around the world will be able to quickly share their designs and prototypes of new instruments, which may be downloaded and simulated on any standard shape display. A culture akin to today's open source movement may arise for new musical instruments on this platform. To popularize their designs, instrument builders may share tutorials and encourage other musicians to download, try out, and ultimately "fork" their designs, much like code on Github.

Similar to how digital instruments coexist happily with traditional instruments today, the shape display will not take the place of existing instruments. Nor will it prevent designers from building custom digital instruments and controllers. Rather, it will provide an additional means of musical expression for musicians of across genres, roles, and levels.

7. CONCLUSIONS

We began this research to assess the versatility of the shape display as a platform for music making, focusing our efforts on the physical nature of both control and sound production. A state-of-the-art pin-based shape display was used as an enabling technology. We first studied its properties and looked to several types of existing instruments and controller for inspiration. We then prototyped three designs that demonstrate a variety of controller paradigms and methods of sound production. These cover a range of musical parameters and suggest a wider space of possible instruments on the shape display. Finally, we discuss the themes of musician and machine, ending with a vision of the shape display as a general platform for future music-making.

On a meta-level, this paper has followed the approach of Vision-Based Research advocated by Prof. Hiroshi Ishii [11]. In this approach, existing technologies become vehicles for prototyping an envisioned future, allowing designers to look beyond current technical constraints to invent radically new interactions and applications. While constructing functional instrument for today will always be important, we encourage the NIME community to try out this approach to re-invent musical instruments for the future.

8. ACKNOWLEDGMENTS

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