Tangible Scores: Shaping the Inherent Instrument Score

Enrique Tomás
Interface Culture Lab
Kunstuniversität Linz
Kollegiumgasse 2,4010 Linz, Austria
Enrique.Tomas@ufg.at

Martin Kaltenbrunner
Interface Culture Lab
Kunstuniversität Linz
Kollegiumgasse 2,4010 Linz, Austria
Martin.Kaltenbrunner@ufg.at

ABSTRACT

Tangible Scores are a new paradigm for musical instrument design with a physical configuration inspired by graphic scores. In this paper we will focus on the design aspects of this new interface as well as on some of the related technical details. Creating an intuitive, modular and expressive instrument for textural music was the primary driving force. Following these criteria, we literally incorporated a musical score onto the surface of the instrument as a way of continuously controlling several parameters of the sound synthesis. Tangible Scores are played with both hands and they can adopt multiple physical forms. Complex and expressive sound textures can be easily played over a variety of timbres, enabling precise control in a natural manner.

Keywords

NIME, Scores, Notation, Composition, Tangible Interface, Acoustic Interface.

1. INTRODUCTION

During the development process of a new digital instrument it is necessary to define an a priori set of musical applications and practices where performers can use it. This will determine many characteristics of the musical interface e.g. its gestural vocabulary, functionalities, ergonomics, visual aspect, etc.

Many NIMEs are not limited to a particular musical practice although some types of music will be more difficult to be played than others. For example, playing a classical music piece with a *Reactable* [10] can be quite tedious independently from the difficulty of the score. Other NIMEs are designed to constrain the playable musical elements at multiple levels. Max Mathews' *Radio Baton* [14] uses a complementary program called *Conductor* to automatize the selection of notes on a predefined score. Laurie Spiegel's *Music Mouse* [7] allowed only to interact with the ranges of change on the selection of frequencies. In both cases, the instruments require a predefined musical score. Therefore a NIME designer often also tends to develop a notation system for the new digital instrument and its performance practice.

Frequently we see performers who don't use scores because they prefer to improvise the composition during the very moment of a performance, interacting with the instrument and usually following some prior musical plan. For Chadabe [5] this practice transforms the act of composition into an interactive process that depends deeply on the system response. In these cases, the musical result can be completely different at every instance of a performance.

In this diversity of approaches to the problem of composing for new digital instruments, the traditional relations between composer, composition and performer are mediated by the *composed* nature of the instrument. In this paper we describe first the inherent compositional aspects of our digital instruments and their influence on the musical practice. Later, we extend the concept of *inherent score* to the physical layer of the interface, proposing a new family of instruments called *Tangible Scores*.

Figure 1: Playing a Tangible Score.

2. INHERENT INSTRUMENT SCORE

2.1 Composers and Digital Instruments

Composing for digital music instruments can be quite challenging. The decoupling between interface and the synthesized sound influences the whole process of composition. During the age of traditional acoustic musical instruments, the role of a composer was the encoding of musical ideas into standard musical notations. Reading those scores, players were able to decode the notation into physical movements, allowing the same music to be played with different instruments. But after the conception of electronic musical instruments, a composition often was not finished until the relation between sound and gesture was defined. And the definition of that relation can become a very complex process.

For the comprehension of this problem it is important to understand the origins of our contemporary practice with digital instruments. Nowadays composers are generally used to deal with gesture-based music. Many compositions after

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the 50s and 60s were increasingly understood as describing gestural information for the performer, rather than being notations of pitch organized in time [13]. We can say that during this period, the traditional notation system lost its predominant position since it was not able to embrace and reflect the new ideas of composers. The same problem later applied to the case of the more recent graphic scores, which often provided a rather subjective musical notation system. A graphic score is often generated from the need of a notation of sonic-facts that the performer will recreate in his imagination, an approach that anticipates the process of composing for electronic musical instruments.

But notably the last revolution in transforming the role of a score was achieved through the use of electronic circuits in musical language. Alvin Lucier [12] explains how within many of the works produced by the Sonic Arts Union "there were no scores to follow; the scores were inherent in the circuitry". Lucier describes the suppression of notation in its traditional form, where printed symbolic or graphic scores leave the stage to a new kind of *inherent score*. Circuits are configured in a specific way for their artistic use, containing enough structural elements to be used in a musical situation. The role of the composer, at an equidistant point among designers, composers and performers, starts with the configuration of the technical system behind the actual instrument. Performing became the creative exploration in freedom of the musical affordances, musical reactions or acoustic relations to the physical space performed, without the need of any kind of musical notation. It is important to remark that this historical moment is a bridge between the old traditional vision of the composer, and a new role that is more connected to the current practices with electronic instruments.

Now some decades later, our study field stays at the continuation of the cultural and technical evolution of all those pioneering works, developing a variety of alternative approaches [4] to composition, notation and performance. In the following section we discuss two compositional approaches for electronic musical instruments.

2.2 Composed & Self-Composed Instruments

The concept of an *inherent score* is important for understanding the mediated relationship between composers, performers and their instruments. In this section we introduce the phenomenological approach on performing with them.

Twelve years ago Schnell and Battier introduced the concept of *composed instruments* [17]. This term serves to explain that our digital instruments equally "carry the notion of an instrument as that of a score", in the sense of determining various aspects of a musical work itself. During the technical implementation of the instrument we often incorporate many ideas of composition into the programmed system.

In 1966, during the "Nine Evenings of Experiments in Art and Technology" the first composition of David Tudor was performed, marking his transition from a performer of many of John Cage's works to his new role of a composer. It was the premiere of *Bandoneon!*, a combine of programmed audio circuits, moving loudspeakers, TV images, and lighting, all controlled through the live sound of a bandoneon played by Tudor. From the program notes we read that *Bandoneon!* uses no compositional means, since it "composes itself out of its own composite instrumental nature". Kuivilar [11] asserts that we were in fact facing a new way of understanding instrumentality. In these self-composed instruments, Tudor acts as the interpreter and performer of a composition that composes itself out of these constituent parts. Or using Lucier's arguments, the composition is created from the *inherent scores* that can be found in the structural elements of a particular electronic configuration. This concept carries an extraordinary rendition: the acceptance that an electronic instrument is an entity that can display itself without the need of a composer or a composition.

Tudor's aesthetic of "composing inside electronics" anticipated the concepts found withing the contemporary practice of circuit bending, DIY builders and sound hackers. But more importantly, he founded the principles of a new musical practice that was continued up to the contemporary use of digital instruments and interfaces. Like in *Bandoneon!*, we should understand our contemporary digital music instruments as a more or less complex set of circuitry, software, logics and spatial relationships, exposing an inherent score that configures its nature, the source of inspiration for performing with them.

John Fulleman, a frequent collaborator of John Cage, attributes Tudor an "ability to assert just enough control over the equipment to get through a concert". The same methodology of composition can be advised to the composers of digital instruments. Navigating along the field of characteristics one could read from the instrument, not only as a mere catalog of potentials or affordances, but as an inherent score, that defines the sonic and musical possibilities that can be chosen by a performer every moment when it is played in real time.

Cook's principle [6] about musical controller design "better to make a piece, not an instrument", reinforces this vision of composing inherent scores. According to this, the design of a new instrument should be starting with a composition in mind. But just like in any traditional composition, many cultural, personal and idiosyncratic elements of the builder's personality impregnate each digital instrument design. Or as it is explained by Wanderley [22], if a composer decides to build or take part in the design of a certain instrument, the vocabulary of gestures of an instrument is often created with a subjective artistic reason in mind.

3. TANGIBLE SCORES

3.1 A Physical Layer for Musical Notation

Inspired by the mediated relation between musician, instrument and musical performance, we decided to design a new instrument that emphasizes the inherent scores. Hence our objective was the extension of the concept of inherent score and creating a new digital instrument that could incorporate some kind of musical notation within its very physical configuration. Our final goal is to study if we could conduct the way an instrument is played by adding a score to its physical layer, in addition to the overall affordances and functionalities that it offers. As a proof of concept we decided to build a tangible instrument that we called Tangible Score.

We define a tangible score as the physical layer that is incorporated into the configuration of a digital instrument with the intention of conducting the tactile gestures and movements. A composer could then conceive a musical idea and incorporate it to the instrument body encoding it in a physical manner. A performer can explore the tangible score and navigate through its materials as another element of the inherent score that it contains. A tangible score determines only the gestural constraints and as such does not define any sonic results. Therefore equally as a traditional score, it encodes a musical intention and delegates the decoding part to other agents. A tangible score can make use of any material and can extend to two- or three-dimensional artifacts.

In a tangible score the musical composition and its representation is integrated into the instrument at the physical layer. Making use of a physical score we can:

- Represent a compositional idea or a musical process to inspire or conduct a musical performance. As it is incorporated physically within the body of the instrument, a performer can be intimately inspired, conducted or constrained without looking at any other score.
- Define the gestures through the affordances of the instrument as a physical object. The instrumentalist will approach the performance in different ways depending on the physical configuration of the instrument.
- Modulate and design the control signal that feeds the sound synthesis. The tactile activity will be used as the expressive input for sound synthesis. The material qualities of the interface will define and modulate this flow of information.

On a technical level a tangible score can make use of different processes for the analysis of gestural behaviors of a performer. Although in our current implementation we took the approach of acoustic analysis of the gestural impact on the instruments surface, other additional or alternative techniques, such as computer vision, capacitive sensing and further sensing modalities may be incorporated.

3.2 Graphic Scores

During the process of finding a physical design language for a tangible score we got inspired by graphic scores. Graphic scores appeared in the musical avant-garde as a way to release composers from the constraints of writing their music using the notation of a traditional score. Consequently the representation of a musical idea opened to the personal and subjective selection of graphic figures that inspire new and imaginative ways of interpretation.

In the world of improvisation, graphic scores are often used for structuring the evolution of the performance. They are also useful for the analysis of electroacoustic music and as a parallel notation for composers. We can thus consider that graphic scores are living in the same musical environment as our new interfaces for musical expression. Graphic scores are useful when traditional notation fails, like complex or novel musical ideas including indetermination or extreme parameterization of the musical variables.

The importance of graphic scores is that we can sometimes have a closer approach to the original ideas or aesthetic intentions, although other representations are as well possible like using texts and symbols or even electronic circuits, as we have seen in previous sections. Graphic scores have been traditionally hand written or painted by their composers so we can extract valuable information about the work, just like from traditional music manuscripts. It is interesting to note that graphic scores can adopt any form and any dimension, although historically almost all of them have been published on paper, in an inexplicable conceptual analogy to the traditional format of the score. We had to wait until the advent of digital interfaces to see musical notations that can be interactive, dynamic, fragmented or non linear. Examples include the animated scores of Miyashita [15] or the Reactable's physical sound programming environment, and few three-dimensional scores such as in Berghaus [2].

With the aim of exploring and creatively extending the field of graphic scores, we decided to use them extensively in our first conceptual experiments towards tangible scores. Although our current implementations are therefore physical representations of graphic scores, this approach has to be understood as the further evolution of one possible score concept into the physical domain. Future implementations may extend to the idea of sculptural scores.

4. PHYSICAL EMBODIMENT

One of the core features within the genre of Tangible User Interfaces is the embodiment of digital information within physical artifacts, which can be shaped through the direct manipulation of the interactive object itself [9]. Our design approach for Tangible Scores borrows several concepts from this field and merges them with ideas from Graphic Scores and musical instrument design. As Verplank [21] has suggested an inverse relationship between Piaget's development psychology and the history of human computer interaction, we can equally observe a similar development in the history of musical score systems.

While a traditional score defines a highly symbolic notation language for the description of a musical system, a contemporary graphic score relies mainly on an iconic language that couples a rather versatile visual representation language with an according musical expression.

Therefore the analogy of a Tangible Score or a physical representation of a musical piece and performance practice seems to provide an appropriate method for an embodied musical encoding. This unification of score and instrument provides the representation and control within a single musical artifact, fully concentrating the performer's attention on the interaction with the musical composition in a physical form.

5. DESIGN ASPECTS

In order to facilitate the design process, we have established some prior constraints to our definition of Tangible Scores.

- Diversity. A Tangible Score design should promote a diversity of forms and materials. There is no unique identity for Tangible Scores and they can be designed in any color, form and material.
- Replicability. A Tangible Score should be easy to share, copy and replicate, transform or adapt. This suggests the use of rapid prototyping technologies such as 3D printers, CNC machines or Laser Cutters.
- Modularity. Traditional scores are modular, in order to allow to use them in parts. Tangible Scores should offer the possibility of being extended or reduced.
- Embodiment. The musical idea should be embodied into the instrument as its physical representation It should be defined through its materiality but not affected by the used technology.
- Discrete and Continuous Control. Our instrument should incorporate the qualities of an acoustic instrument, with discrete and continuous dimensions.
- Intimate Expression. The instrument design should promote an expressive performance, allowing a big dynamic range of gestures, from subtle tactile interactions to more energetic behaviors.

6. THE TANGIBLE SCORE INSTRUMENT

For the initial implementations of Tangible Scores we decided to create some ad-hoc surfaces and two-dimensional forms that could function as interfaces for tangible interaction and incorporate a physical score in its configuration.

This first set of instruments should be the proof of concept of our hypothesis of the physical representation of musical scores.

We chose wood as material since it is easy to manipulate and affordable, and is more importantly used commonly for the design of many acoustic instruments.

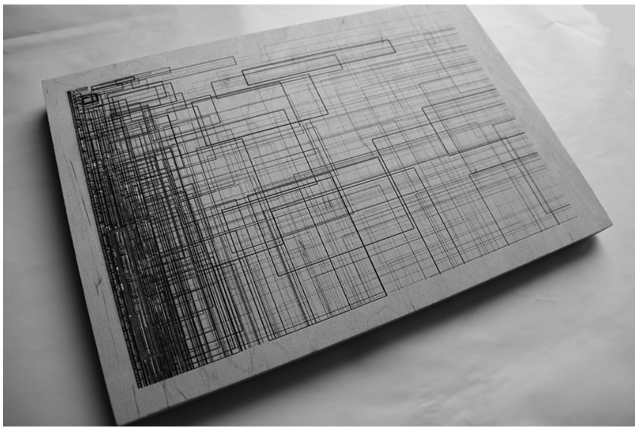

Figure 2: Engraved score used as a acoustic interface

Our first idea was the incorporation of a graphical design, therefore we were using a laser cutter to engrave graphic scores into the surface of the wood. This also allows the systematic production and easy replication of our designs.

For interfacing to the synthesis layer we decided to interpret these surfaces as tangible acoustic interfaces. The tangible interaction with the tactile footprint of the engraved score will produce vibrations on the surface that can be acquired through contact microphones. The variety of produced sounds provides an enormous vocabulary of signals that can be used for the direct sound synthesis and for extracting information that can be used for discrete or continuous control.

According to Crevoisser [16] tangible acoustic interfaces have the characteristic of recovering a clear correspondence between a physical gesture and the sound response produced by it. It is as well possible to conceive the interface according to a desired gesture instead of adapting the gesture to a given interface.

6.1 Sound Synthesis

After evaluating different types of synthesis, we decided to implement Corpus Based Concatenative Synthesis [18] (CBCS), since our objective was to facilitate creative musical expression. When CBCS is applied to a live input signal, it creates a very intimate relationship between the physical gesture created and the sonic gesture perceived. As Tanaka explained in [1] for the design of sonic affordances for new digital instruments, it is important to consider the tendency by audiences to describe sound production in terms of causality.

CBCS is a type of granular synthesis with the goal of imitating an input signal. Generally CBCS involves two processes. First the mathematical classification of a database of samples, extracting specific descriptors during small windows of time or grains. The objective of this first step is building what it is known as the space of sound characteristics, a comparative representation of descriptor values in the database. Second, for creating the synthesized sound, an input signal is analyzed with the same procedure and the grains of the corpus with similar descriptors are selected and concatenated. Usually there are multiple grains matching the input signal and the user defines the maximum number of audio snippets to be used in the synthesis.

The interest of using concatenative synthesis in digital music instruments was explained and discussed by Schwarz [19]. Playing a CBCS instrument consists in *navigating* along the space of descriptors, or in other words, projecting the input data on the multidimensional space of the descriptors. In theory, it is possible to pick single or multiple grains and play them back for creating different sonic gestures.

Schwarz introduced a taxonomy of controllers for concatenative synthesis: *positional control, audio driven or multifader controllers*. The first and third categories show a disconnection between physical gesture and sonic response. On the contrary, live audio control appears as a more natural way of creating sound gestures. As it is discussed in [16] using a live sound signal as input "the final objective seems to be the re-encounter of the acoustic energy of an excited surface with the synthesized sound generated". In other words, we can assume causal effects between tangible interaction and sound produced.

According to the online concatenative synthesis survey [20] we see that CBCS in combination with live input has not been explored enough. This motivates our present use of concatenative synthesis for the design of tangible acoustic interfaces, in particular after the promising results obtained in combination with acoustic interfaces [16] and scratch input [8].

6.2 An Engraved Graphic Score as Controller

Engraving the graphic score on the surface of a wooden panel, was influenced by artistic wood-carving techniques, known as xilography, where an image is carved into the surface of a wooden block. In our case this accomplishes the following feature set:

- It provides a direct representation of a musical score.
- It influences the quality of the input sound that feeds the synthesis. Tactile interaction on dedicated parts of the engraved surface produces different sounds and reinforces specific components of the control signal spectrum.
- It conducts and constrains the gestures of the player. Performers follow intuitively the visual contours of the engraved forms.

Therefore, the engraved score is designed to have an acoustic impact. It will determine the sound signal used in the concatenative synthesis. For example, if we scratch an engraved parallel line pattern, it will create a vibration with a component that depends on the distance between the lines. As shown in Figures 3 and 4, the engraved notches define different spectral envelopes of the signal for different parts of the surface. Thus, we can think of our engraved tangible score as a kind of complex Idiophone. Since it is played with our hands, these scratches and finger attacks are generally imperceptible outside of the material but can be easily acquired with contact microphones. We decided to make an exhaustive analysis of the sound signals produced in the wooden material. The first observation is the spectrum for each of the wooden pieces, was always centered around the same frequency, the actual resonant frequency of that particular piece of wood.

From another point of view, the spectral components are quite diverse, and different envelopes are easily observed. Therefore, in our synthesis we were going to listen always textures with grains centered in the same frequency, constraint that should be considered for the musical practice.

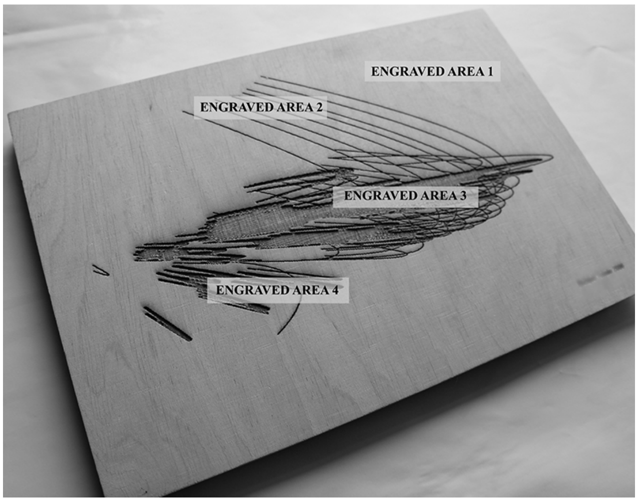

Figure 3: Engraved areas analyzed

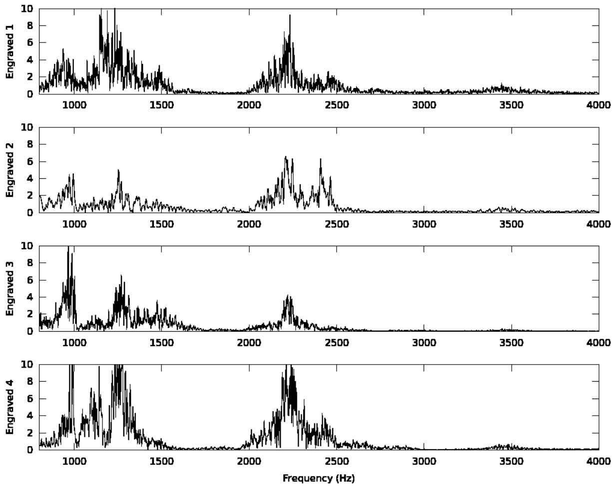

Figure 4: Frequency analysis for each of the areas

Different solutions can be worked out, like using the rest of the spectrum to create spectral music or developing mechanisms for shifting the frequency detected.

With a standard laser cutter we were able to create surface patterns with depths ranging from microns to 1mm. Once the first scores were engraved, we discovered that the physical gestures over the surface were naturally induced by the visual design that we had drawn and cut. After informally testing these engraved designs with several lab members, we noticed that almost all had a tendency to follow the printed design, through exploration with their fingertips. Although it needs to be studied more accurately in the future, our design triggered a kind of tangible attraction, which indicates an additional layer of tactile information apart from its visual content.

6.3 Technical Implementation

Our first series of instruments were built using 30x20 cm flat plywood panels with an attached piezo microphone. A preamplifier improved the audio signal sampled at 48KHz by an RME Fireface UCX. We programmed the system on a 2.3 GHz MacMini running OS X 10.8.5. After considering various CBCS implementations, we decided to use William Brent's library timbreID [3] for Pure Data (PD).

An important consideration with concatenative synthesis is the selection of the mathematical descriptor for the analysis. As Harrison explains in [8], natural gestures such as a fingernail dragged on a surface produce a specific spectral profile, while percussive gestures also contain significant information in a lower part of the spectrum. After analyzing the spectral components of multiple gestures, we decided to use the descriptor Mel Frequency Cepstral Coefficients (MFCC), which represents the spectral envelope of the live input signal through a bank of filters distributed along the spectrum. In particular we decided to use a version called Bark Frequency Cepstral Coefficients through the PD object bfcc∼ where the separation among the bank of filters is the Bark weighting parameter. Since it emphasizes the low frequency components, it achieves a better discrimination of percussive gestures.

As a starting point we engraved a series of seven designs: four generative based on parallel lines and another three graphic scores composed by one of the authors. We soon discovered that the sonic relation between the live input signal and its result is highly mediated by the selection of the sound corpus. Thus, some negotiation was needed between the database of samples and the engraved design, which also indicates a future investigation on alternative surface materials.

In a final design step we decided to include additional samples into our database, in order to reflect specific sound gestures that were not responding as expected in the initial synthesis experiments.

6.4 Performance Aspects

After having implemented a CBCS for our Tangible Scores we obtained the following subjective conclusions:

- In terms of expression, the produced sonic gestures are recognizable and suggest a causal relationship to the tactile input gestures. The instrument reacts to very subtle interactions, which makes the performance process very expressive and intimate.
- The sensation of playing was generally fluid. Latency is not an issue, since we chose an adequate buffer value of 32 samples. No glitches or dropouts were observed, the CPU was not used above 65 percent.

Those results show how using concatenative synthesis in combination with physical scores, is a promising way of creating expressive instruments. The main constraint of the acoustic nature of the interface is that the spectrum of the control signal is usually centered around the resonance frequency of the used material. Therefore we have assumed this sound characteristic, creating performances and compositions of spectral music, making use of the multiple parameters that concatenative synthesis offers to modulate sound, such as the range of the used corpus and the grain size.

6.5 Tangible Scores as a Discrete Controller

After having implemented Tangible Scores as an instrument for concatenative synthesis, we decided to complement its features using the same interface as a discrete controller. The objective was extracting specific information contained in the sound input for interpreting it as discrete parameters.

We decided to implement some simple machine learning system, with the objective of recognizing six percussive timbres in real time. For that we also used the timbreID library for Pure Data implementing the same descriptor, the Bark-frequency Cepstrum with an audio window of 2048 samples. The PD object bfcc∼ outputs a vector with 47 spectral components but only the first 20 were analyzed after noticing that our percussive gestures did not contain differentiable components above the spectral middle.

The process of selecting six candidates for robust recognition was more difficult than expected. Initially six different percussive hand gestures were chosen through listening, and the system was trained playing the same gesture twenty times. The extracted descriptors were later clustered in 6 sets. After testing the trained system only 40 percent were really robustly recognized. Therefore, we recorded around 20 different percussive gestures that were analyzed with the bark descriptor. From this process we extracted another six candidates with significant differences to all the others. Finally after another similar training process, the rate of recognition was higher than 90

As every engraved score reacts sonically different to the same physical gesture, we cannot interpolate our results to other surfaces. This fact makes the process of training the system quite tedious and indicates the need of a more systematic procedure.

7. EVALUATION IN LIVE PERFORMANCE

The first evaluation in a concert situation took place at the Linux Audio Conference 2013 in Graz. The performance, called "with intent to defraud" was an homage to Aaron Swartz. It was an improvisation for two performers of the ensemble Endphase, one playing a Tangible Score.

Therefore, we prepared an instrument with a specific design: an engraved text with a part of Aaron Swartz's indictment. The sound corpora for the synthesis were three recordings of English native speakers reading Swartz's indictment. The system was trained to recognize four percussive gestures that were used for changing parameters of the synthesis. Those recognized values were sent via OpenSoundControl (OSC) to the second performer, driving the algorithms in charge of creating a sonic counterpoint to the Tangible Score interface. All the sounds were spatialized in a studio equipped with an ambisonics dome of 24 speakers.

In this concert situation, playing the Tangible Score instrument was very intuitive, offering many expressive possibilities. The intimate connection between gesture and sound inspired the musical flow during the performance. It was quite easy to achieve a large dynamic range, from delicate grains to loud and dense textures. The rate of recognition of discrete gestures decreased to around 70 percent during the concert because the on-stage situation influenced the performer, who was not able to exactly repeat the trained gestures. Nevertheless the false detections didn't disturb the musical plan, since we prepared the improvisation for embracing that anticipated situation.

8. CONCLUSIONS & FUTURE RESEARCH

We have studied the mediated relation between composers and new digital instruments, proposing methodologies of work and approaches to the issues of composing for them. We have built a first series of instruments based on engraved designs and explained the possibilities of using these surfaces as acoustic interfaces. We have explored the perspectives that these intuitive, modular and expressive instruments can provide in combination with concatenative synthesis and machine learning. After having implemented and evaluated the instrument in a concert situation, several research questions emerged:

- What are the aesthetic, cultural and musical implications of using sculptural objects as scores?
- Which materials and shapes are most suitable for the design of Tangible Score instruments?
- Which other sensor and synthesis technologies can be used for the technical realization of Tangible Scores?

9. REFERENCES

[1] A. Altavilla, B. Caramiaux, A. Tanaka, "Towards Gestural Sonic Affordances". Proceedings of New Interfaces for Musical Expression, pp. 61-64, 2013.

[2] M. Berghaus, "Some Ideas for Three-Dimensional Musical Scores", Leonardo Music Journal Volume 21, pp. 7-8, 2011

[3] W. Brent, "A Timbre Analysis And Classification Toolkit For Pure Data", International Computer Music Conference Proceedings, 2010.

[4] M. Burtner, "Composing for the (dis)Embodied ensemble: notational systems in (dis)Appearances", Proc. of NIME Conference, Singapore, 2003.

[5] J. Chadabe, "Interactive Composing", Computer Music Journal, VIII:1, 1984. Republished in Curtis Roads, ed., The Music Machine. MIT Press, 1989.

[6] P. Cook "Principles for Designing Computer Music Controllers", ACM SIGCHI New Interfaces for Musical Expression (NIME) Workshop, Seattle, 2001.

[7] Gagne, C. "Interview with Laurie Spiegel". In Soundpieces 2: Interviews With American Composers. The Scarecrow Press, Inc. N.J., pp. 295-333. 1993.

[8] C. Harrison, S. E. Hudson, "Scratch Input: Creating Large, Inexpensive, Unpowered and Mobile finger Input Surfaces". Proceedings UIST '08. ACM, 2008.

[9] H. Ishii, B. Ullmer, "Tangible bits: towards seamless interfaces between people, bits and atoms". Proceedings of CHI'97 ACM SIGCHI, 1997.

[10] S. Jordà, M. Kaltenbrunner, G. Geiger, R. Bencina, "The reacTable", Proceedings of the International Computer Music Conference, 2005.

[11] R. Kuivila, "Open Sources: Words, Circuits, and the Notation/Realization Relation in the Music of David Tudor", Presented at the Getty Research Institute Symposium, "The Art of David Tudor", 2001.

[12] A. Lucier, "Origins of a Form: Acoustic Exploration, Science and Incessancy". Leonardo Music Journal 8, pp. 5-11, 1998.

[13] T. Magnusson, The musical score: the system and the interpreter In: Proceedings of ISEA, 2011.

[14] M. Mathews, "The Radio Baton and Conductor program, or: Pith, the most important and least expressive part of music", Computer Music Journal, 15:4, 37-46, 1991.

[15] H. Miyashita. Graphic Score Animation for Two Pianos, Feb. 28th, 2003. Toyama shimin plaza, Japan.

[16] P. Polotti, A. Crevoisier, "Acoustic Localization of Tactile Interactions for the Development of Novel Tangible Interfaces", Proc. of the 8th Int. Conference on Digital Audio Effects (DAFX-05), 2005.

[17] N. Schnell, M. Battier, Introducing Composed Instruments: Technical and Musicological Implications, Proceedings of NIME, 2002.

[18] D. Schwarz, "Concatenative Sound Synthesis: The Early Years", Journal of New Music Research, Mars 2006, Vol. 35, p.3-22, 2006.

[19] D. Schwarz, "The Sound Space as Musical Instrument: Playing Corpus-Based Concatenative Synthesis", New Interfaces for Musical Expression (NIME), 2012.

[20] D. Schwarz, "Corpus-Based Sound Synthesis Survey", IRCAM IMTR website, http://imtr.ircam.fr/imtr/

[21] B. Verplank, "Interaction Design Sketchbook", online publication 2009.

[22] M. M. Wanderley and N. Orio. "Evaluation of input devices for musical expression: Borrowing tools from HCI". Computer Music Journal, 62-76, 2002.