XENAKIS – Combining tangible interaction with probability-based musical composition

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ABSTRACT
In this paper we present the table-based tangible interface application Xenakis which uses probability models in order to compose music in a way that can be strongly influenced by the user. Our musical sequencing application is based on a framework for tangible interfaces with an architecture that is strongly inspired by the model-view-controller pattern. In addition, we developed a hardware setup for tangible interfaces and used MatraX for tracking markers. The sequencer is the first implementation based on this framework. It allows users to create music simply by moving tangibles on the table. The graphics engine Horde3D is used to visualize the user-interaction and to show the relationships between the tangible objects on the table, creating an appealing audio-visual experience. An evaluation with 37 first time users was conducted in order to discover the strong and the weak points of such tangible user interfaces, especially in the context of our application.

Keywords
Xenakis, tangible interface, art, music, composition

ACM Classification Keywords
H.5.2 User Interfaces: Haptic I/O, Interaction styles

INTRODUCTION
Xenakis is an application which is designed to provide a simple and easily accessible interface to a complex automatic composition technique. It has only three different types of controls for rhythmic elements, tone pitches and instruments. The application's highly interactive way of composition generates notes from a musical model without using a fixed set of prepared patterns. The main goal was to create a tool which allows us to create diversified and harmonic music, and at the same time can intuitively be used like a "real" object rather than a computer. Much effort was put into developing an organic user interface with a unique combination of tactile interaction and appealing graphical representation. Primarily, we tried to emphasize the instrumental character of the table. Although the musical output is based on a stochastic model as will be described later on, the musician is still able to influence many aspects of the automatically composed music by modifying this model while it generates music. Tone, pitch and rhythm can be controlled by simply moving tangibles on the surface, like striking certain keys of a piano.

There are many other musical applications based on tactile interaction, for example Audiopad [8], which allows the spontaneous arrangement of sound samples and loops. Many applications have the character of an art performance, and music is generated from squeezable balls [11], spinning wheels [2] or building blocks [7]. Above all, the musical table reacTable [9] has reached a level of popularity far beyond the academic scope it originally came from. With a demo having been watched over a million times on YouTube, many people became aware of the potential of tangible interfaces. Xenakis is strongly inspired by reacTable, especially when it comes to the hardware setup. However, even though both are musical tables, there are major differences between Xenakis and reacTable: We focused on creating an algorithmic composition tool, which does not play sound directly, but generates a stream of MIDI notes driven by a probability model that can be built and modified dynamically while playing. We also considered using reacTable's tracking software reacTIVision [10], but soon decided to develop a new framework which does not only track markers but also provide much more additional functionality as we will show later.

In the next section, the concept underlying the sequencer is described. We then present the architecture of the software which is running the table. Afterwards we are going to describe the visualization and how it is used to support the user's experience. In order to identify strong and weak points of Xenakis, we conclude with the results of an evaluation we performed with 37 Xenakis users.

SEQUENCER
The musical concepts underlying the Xenakis application were inspired by Iannis Xenakis, an architect and composer, who used various mathematical techniques to create music. He was the founder of a new approach in composing music, the so called "stochastical music". For example, he composed music that catches the randomness of raindrops and transformed it into musical notes. Further readings and compositions can be found in [3].

Our idea of stochastical music was to divide a musical tone into its rhythm and its tone pitch and then have random transitions on both kinds of states independently. Fig.1 shows how a musical tone is split into a rhythmical and a pitch element.

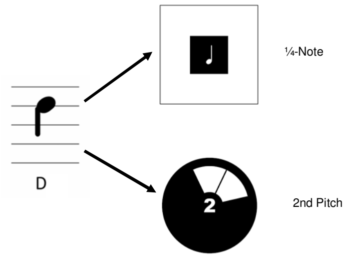

Figure 1. A note is divided into into its rhythm and tone pitch.

The forms on the right in the illustration represent tangible stones on the table. In this vein, a tangible stone corresponding to an instrument, influences rhythmic and pitch tangibles that are located next to it. As soon as an instrument is put on the table, it begins to play on the rhythmic and pitch stone that is closest. After playing the note, this stone searches for other tangibles in its range that could play the next note. The distance of a stone in range influences the possibility of being played next. Basically, two Markov models are built, one for rhythm and one for the pitch. Fig.2 shows an extract of an instrument that has played a tone and currently computes the next tone. For the sake of comprehensibility we use an instrument which is not concerned with tone pitches, but can only play rhythmic tones, like a drum.

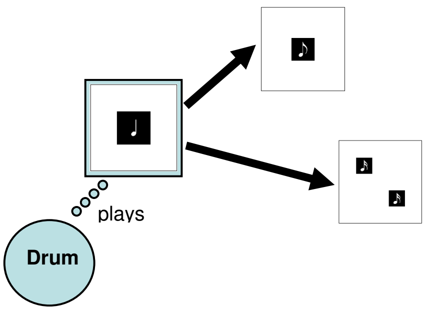

Figure 2. A drum instrument is playing the 1/4-rhythm and is searching for the next rhythm to play.

At first, the instrument plays on whichever rhythmic stone is closest, here the 1/4-tangible. After playing the tone, it has to find a transition to a rhythmic tangible on which the drum can play the next note. The distance to the 1/8-note is half as far as to the other one, so the possibility that the 1/8-note is played next is twice as high as the other stone. There is also a small chance that the 1/4-note makes a self-transition and is played again. The example shows that the music can be influenced by changing the distances of the stones, but there is also some randomness included.

As mentioned above, the basic concepts of this stochastically composition technique are Markov models. These models can be defined with a set of states S, a probability distribution $prob: S \times S \rightarrow [0..1]$ and a set of Events E. Every state holds one single event, unlike in Hidden Markov Models where states can also have more events. In our application, the purpose of those models is to generate random streams (Markov chains) of events according to the probabilities. Those chains are computed in real time over a dynamic model with continuously changing probabilities. As soon as a new event needs to be computed, a random transition is made from the current state to a new state according to the probability distribution. This state now becomes the chain's current state and its event can be processed. The probabilities are induced by the distances between the tangibles which represent states. Each state has also a given probability to make a transition to itself. We used a linear radial distribution to compute probabilities, which decrease until reaching a given distance ε. Tangibles with a distance greater than ε have a transition probability of 0. The probability is computed as $prob(s,t) = \max(0, \varepsilon - distance(s,t))$. Every tangible has a *total probability* p_{total}, which is the sum of all neighbor-probabilities and a *self-probability* p_{self}, which is the probability that there will be no transition to another tangible, but a self-transition.

$$p_{total}(t) := p_{self}(t) + \sum_{s \in \{Tangible\ s\ :\ distance(s,t) < \varepsilon\}} prob(s,t)$$

We do not need to normalize these probabilities since we are only interested in relative values. Notes can then be computed from two separate Markov models, a rhythmic and a tonal model. The rhythmic model's events are note lengths like 1/16 or 1/8, an event can also have multiple note lengths which are then played sequentially. The tonal events are tone pitches from 1 to 7 which are always interpreted in relation to a tonal scale. Given the base tonal scale C-major, the pitch value 2 is interpreted as the concrete tone pitch D. The actually played notes are then computed by combining a rhythmic and a tonal value.

FRAMEWORK-BASED ARCHITECTURE

Xenakis is the first application we developed for our table setup. During the development, it became evident that the possibilities of the table could be used best if the application developer can make use of a stable framework hiding the complexity of tracking tangibles or refreshing the user interface. So we decided to realize such a layer of abstraction (further referred to as the TWING framework, TWING being a made-up word of *Tangible* and the Java GUI widget toolkit *Swing*) right from the start and Xenakis as the first application based on this framework.

The framework is implemented with a classical model-view-controller pattern in mind, strongly inspired by the Graphical Editing Framework [1]. We tried to ensure that the model representing the domain of an application can be implemented independently and is as loosely coupled to the framework as possible. The framework is intended to offer a large set of controls and widgets, which can be used to build tangible user interfaces in the future. Until now, it contains a basic set like the representation of the table itself and the tangibles on it. These controls (Controller) provide a lifecycle for (de-)activating, moving and refreshing their graphical representation (View).

The coupling between the framework and a tracking system on the one hand and a render engine to create a view on the other hand is kept to a minimal interface, so different technologies can be adapted easily. For the realization of Xenakis we decided to use MatraX [6] and a 3D graphics engine called Horde3D [4]. For Xenakis, these two technologies seemed to satisfy our needs best. On the one hand we have achieved a stable tracking with MatraX and our hardware setup, on the other hand Horde3D offers a lot of possibilities we used to improve the user experience (see next chapter) and its developer supported us personally.

VISUALIZATION

The Xenakis interface was designed to enable multiple users to interact simultaneously with the table without requiring any training. To enhance the transparency of the system behaviour, we decided to provide the user with visual feedback in addition to the direct audio feedback. The decision for a tangible interaction interface for our application was driven by the idea to integrate a computer based instrument as smoothly in the user's physical environment as possible. To support this basic concept, we decided to create 3D representations of the generated music using Horde3D [4] conveying the impression that the animations reach into the table. By visualizing how the music evolves, Xenakis enables a multimodal experience integrating tactile, audio and visual feedback.

For displaying the visualization on the table surface, we placed a customary projector under the table and used a mirror to redirect the projected picture to the diffusing bottom of the glass table top. As shown in Fig. 3, the camera image is taken with infrared light to eliminate the projected image in the camera shots.

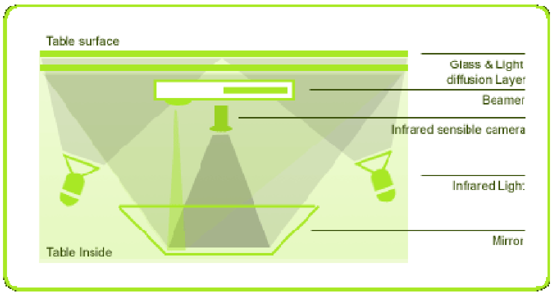

Figure 3. Tangible Interface Table Setup.

Tangibles representing instruments are displayed with different colored lights and emitting small instruments floating away from the tangibles. This visualization tries to capture the playing character of an instrument. Tangibles representing rhythms or notes are marked with corresponding emitters, e.g. note symbols. Each tangible played by an instrument is illuminated by the light of the playing instrument.

As the table continuously plays music, we display an emitter for the transitions between two note tangibles as well as two rhythmic tangibles. This emitter moves from one tangible to the other and produces a trail. The resulting visualization creates a vivid representation of the played music, its rhythm and tone.

USER EVALUATION

Participants and Procedure

Xenakis was presented to a larger audience, mostly students from computer science, together with their friends and family, at an Open Lab Party organized by the multimedia department-chairs. During this event, many people interacted with the Xenakis out of which 37 (27 males and 10 females, average age: 26 years old, 17 play an instrument) took part in an evaluation and filled out a questionnaire. The participants got an individual introduction to the tangible interface and the instrument, rhythm and tonal tangibles and then had the chance to create and play music on their own. After the experiment, all participants filled out an anonymous post-questionnaire.

Figure 4. Table at Open Lab Party.

Questionnaire

The questionnaire used 13 attitude statements with a 5-ary rating scale to evaluate how the participants perceived the music (appeal, controllability), the graphical visualization (appeal, helpfulness), the application as a whole (appeal, fun) and the interaction with the system (ease of use, evoked associations). The questionnaire also contained one question to test the participants' knowledge regarding the purpose of the stones used in Xenakis

Results and Discussion

To show that the mean value for rating was significantly below or above the neutral value of 3.0, we applied t-tests for one sample. In general, Xenakis was very positively received. The participants thought it was fun to interact with the music table and they liked the application and the interaction with the stones with mean values that were significantly above the neutral value of 3.0. In particular, the participants appreciated the graphical visualization with a mean value of 4.68 ($p < 0.001$). The generated music was less positively rated than the graphical visualization with a mean value of 3.38 ($p < 0.05$). Even though Xenakis uses a probabilistic approach to music composition, most of the subjects thought that they were able to control the music deliberately with a mean value of 3.86 ($p < 0.001$) and it was obvious to them what made the music change with a mean value of 4.03 ($p < 0.001$). They also found it not too difficult to use the system with a mean value of 4.03 ($p < 0.05$). Only 3 participants gave a wrong answer when being asked for the purpose of the stones used in Xenakis.

We were also interested in the associations the interaction with the music table elicited in the participants. In particular, we tested whether the participants rather felt reminded of a computer system, a musical instrument or an audio equipment or whether they had the feeling that they were laying out a pattern. Our study revealed that none of the options we presented to the participants reflected associations Xenakis might have invoked in them. Obviously, Xenakis was a completely new experience for them which we did not anticipate with our questionnaire. Definitely, Xenakis was not perceived as a computer system with a mean value of 2.22 ($p < 0.001$). The mean values for the other options were higher, but none of them was significantly above the neutral value of 3.0.

In this context, we noticed some interesting correlations which might provide some hints why the interface was not perceived as a musical instrument. The more the participants felt that they were able to control the music, the more they had the feeling to play an instrument (Pearson Product-Moment Correlation: $r=0.432$; $p < 0.01$) and the more they also liked the music (Pearson Product-Moment Correlation: $r= 0.538$; $p < 0.01$). We hypothesize that the participants consider complete controllability as an important feature of an instrument and that the probabilistic generation of music might be responsible for the fact that they did not perceive the interface as an instrument.

We aimed at creating a musical interface that is engaging to both musicians and non-musicians without requiring a lot of training or musical knowledge. Our analysis revealed that there were no significant differences for any of the attitude statements. Obviously, musicians do not have an advantage over non-musicians when using the interface - at least not as first time users. We take this as evidence that Xenakis has the potential to attract a broad range of people with different music background.

CONCLUSION AND FUTURE WORK

A great advantage of Xenakis over conventional sequencer applications is that the user is able to combine nearly any instruments simply by positioning tangible objects on a table whereby he gets immediate audio-visual feedback. The probability based tone creation helps to create amazing musical outcomes, even for beginners. Together with the 3D visualization it prevents the user from getting bored by monotonous sounds or continuously needed interaction to change the music.

The Open Lab Party and the conducted evaluation were very promising. Nevertheless, we should keep in mind that most participants had a technical background. In the next few months, we will acquire more experience with the table by opening it to a larger variety of potential user groups. By the end of October we will present our table at lab30, a three day media and art festival in Augsburg [5]. Here, we hope to get useful feedback especially from people with an artistic background. To evaluate our framework and to explore the general potential of table applications, small groups of students will develop their own applications based on the TWING framework within a practical multimedia course offered by the University of Augsburg for the winter term.

The way in which the table scales up is still an open question. New short throw projectors or the use of more than one projector will enable to overcome the current physical size limitations of the table. Most of the interviewed users said they would like to use the sequencer application together only with up to two other users, independent of the table size. However, there are definitely other applications which can be used by more people at the same time, and would then need a larger table.

We got very interesting feedback on the musical sequencer application which we will consider in future versions of it. In particular, we intend to develop a fast and robust tracking system that is specifically adjusted to table applications. With this new technology, we hope to enable the use of smaller tangibles and finger interaction and thus open up completely new possibilities for musical applications. The great challenge will be to improve the musical capabilities while keeping the interface as simple as it currently is.

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