REXband: A Multi-User Interactive Exhibit for Exploring Medieval Music

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ABSTRACT

We present *REXband*, an interactive music exhibit for collaborative improvisation to medieval music. This audio-only system consists of three digitally augmented medieval instrument replicas: the hurdy gurdy, harp, and frame drum. The instruments communicate with software that provides users with both musical support and feedback on their performance using a "virtual audience" set in a medieval tavern. *REXband* builds upon previous work in interactive music exhibits by incorporating aspects of e-learning to educate, in addition to interaction design patterns to entertain; care was also taken to ensure historic authenticity. Feedback from user testing in both controlled (laboratory) and public (museum) environments has been extremely positive. *REXband* is part of the Regensburg Experience, an exhibition scheduled to open in July 2007 to showcase the rich history of Regensburg, Germany.

Keywords

interactive music exhibits, medieval music, augmented instruments, e-learning, education

1. INTRODUCTION

Music has been an integral part of our culture for millennia, and some historians believe music predates even spoken language. With music being such a popular medium of expression, it is not surprising that learning about the music from a certain time period can tell us a lot about that culture. With today's ubiquitous computer technology, it is possible for people to relive, personally, some of the experiences that could previously only be read about in history books.

REXband is an interactive musical exhibit we designed for the Regensburg Experience, an exhibition showcasing Regensburg, a city in southeast Germany with a rich medieval history. *REXband* is one of a family of exhibits, including REXplorer [2] and Minnesang [14]; it is, however, the only one that features music.

1.1 Concept and Goals

Anna and Nils are visiting the Regensburg Experience. As they enter, they hear the sounds of instruments from a semi-secluded corner of the room (see Figure 1). As Anna and Nils walk over, they see that the area has been decorated to resemble a medieval tavern; they hear shouts, glasses tinkling, and other sounds of merriment. In the center are three musical instruments on wooden stands, including a harp and a drum – the third instrument, however is unfamiliar: a wooden box with a crank on one side and a row of keys on another. "How about some music?" says a voice. Nils walks up to the harp and gently runs his fingers over the strings, creating a glissando*; accompanying music starts in response. Anna approaches the box-shaped instrument and turns the crank, creating a humming sound. By pressing the keys, she discovers that she can play melodies. As the pair continue playing, they are rewarded with sounds of tossed coins and encouraging shouts. When the music ends, they are rewarded with applause.*

Figure 1: A rendering of the *REXband* exhibit. Credit: Sarah Mennicken (sarah.mennicken@rwth-aachen.de).

REXband was created to explore a new approach of presenting medieval music and culture. As music is an important part of medieval history, we wanted to create an interactive medium for visitors. We had three main design goals:

- *Authentic*: Both the instruments and the musical material presented must be historically accurate.
- *Educational*: As a museum exhibit, the primary purpose of *REXband* is to educate the audience about medieval music.
- *Entertaining*: Users must be able to use the system without any prior training, and find the experience enjoyable.

Balancing these goals was one of our major design challenges for *REXband*, and we refer the interested reader to [17] for a more in-depth discussion of this aspect of *REXband*. We will focus on the technical aspects of the exhibit here, beginning with a brief overview of related literature, followed by a description of the design and implementation of *REXband*, and concluding with some results of evaluations with users in various settings.

2. RELATED WORK

REXband is one of many interactive music exhibits explored in recent years [1].

Jam-O-Drum, developed by Blaine and Perkis [3], is an interactive music exhibit focusing on collaborative rhythmic improvisation and visualization of musical cues. It consisted of a hexagonal table with electronic drum pads and a speaker at each of the six rounded corners. Using a projector, images and animations could be shown on the table. They experimented with several custom-made software applications, including "Call and Response", "Blispaint", and "HexaPong". The emphasis is on rhythmic (as opposed to *REXband*'s melodic) improvisation. *REXband* is also unique in its consideration of historical accuracy.

WorldBeat was an exhibit at the Ars Electronica Center in Linz, Austria [4], and showed how a wide variety of musical applications could be controlled with a relatively simple input device. Using a pair of Buchla Lightning II batons, users could conduct a synthesized piece of music, improvise on an "invisible xylophone", play a musical memory game, or use the baton as a selection device in a menu. Through *WorldBeat*, novices can explore various aspects of music using alternative interaction styles. There is no attempt to model specific instruments realistically.

Serafin et al.'s *Croaker* is a custom built controller based on Russolo's *Intonarumori* [13]. While it is not meant as an interactive exhibit, one of their goals, like *REXband*, was to preserve the knowledge of the historic instrument and the music it created. Their primary focus was to create an instrument to be used in composition and performance.

There is also a large body of work on augmenting traditional instruments with modern electronics. Brook (www.myspace.com/neilbrook), for example, modified a hurdy-gurdy with magnetic switches, and designed a custom controller to translate the output to MIDI. Mäki-Patola et al. [9] used a camera underneath the drumhead of an acoustic djembe drum to track players' hand positions. Finally, light harps (or laser harps) have become popular in recent years [7], although such instruments lack the haptic feedback of an acoustic harp. Kortier built a MIDI-enabled harp (www.kortier.com), using custom hardware to detect the string vibrations.

In contrast to these electronically augmented instruments, ours were made to resemble an acoustic instrument as much as possible by hiding the electronics; they were also designed to survive the use and abuse of being placed in a museum environment, rather than for performance.

Our system is thus unique through the following:

- it is historically accurate, and conveys to users historically accurate information
- it supports basic melodic improvisation
- it balances elements of authenticity, education, entertainment
- it contains electronically modified instruments that are robust and designed to resemble the original

[1] A more extensive literature review can be found in [16].

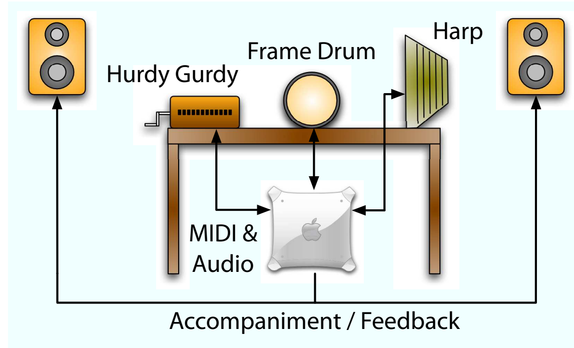

Figure 2: *REXband* system diagram. Three digitally augmented instruments communicate with host software using MIDI, which outputs the instrument sounds to speakers hidden by each instrument. Accompaniment and feedback are played on speakers mounted in the room.

3. SYSTEM DESIGN

Figure 2 shows the system diagram for *REXband*. The augmented instruments communicate to a computer running the *REXband* software using MIDI. The audio is produced using a combination of wavetable synthesis (for the instruments) and digitally sampled audio (accompaniment track, feedback). The musical piece for *REXband* was chosen after consulting with a medieval music historian at the University of Regensburg. It is a dance piece, with a relatively simple rhythm and compatible with the instruments we chose for the exhibit (instruments are typically not specified in these types of medieval music scores).

Interactive exhibit design raises some interesting questions that are not as pressing in other application areas of computer technology. An interactive museum exhibit is a "walk up and use" system where only very little training and instruction is possible. Other challenges include robustness, transitioning from visitor to visitor, and the selection/design of non-standard input devices. Much of the user experience design is based on our previous work on interactive exhibits [5, 8], and we refer the interested reader to this literature.

REXband is different from many interactive exhibits in that it is an audio-only exhibit. While printed (i.e., static) visuals are used to decorate the area to resemble a medieval tavern, feedback from the interaction with the system is primarily aural (there is some haptic feedback from users interacting with the physical instrument replicas). This is in contrast with other interactive exhibits [3, 4, 8], and was motivated by the fact that producing visuals that are both historically accurate and believable would be difficult (and expensive). More importantly, such visuals would distract from the instruments, which are the primary focus of the exhibit.

In addition to the sounds of the instruments, *REXband* provides feedback to the user using a "virtual audience". When the system is idle, users can hear the sounds of glasses tinkling, shouts, and other sounds of merriment, creating the ambiance of a medieval tavern. Users assume the role of a band playing in this tavern; the system rates users' performances, rewarding them with the sounds of tossed coins and cheering shouts.

The feedback mechanism is based on a rhythmic analysis of the users' input: it checks the rhythmic accuracy of the users' input relative to the rhythm of the accompanying track. The rhythmic pattern of the music was prepared offline by musical experts, and is stored as metadata in the system. We compute a relative differ-

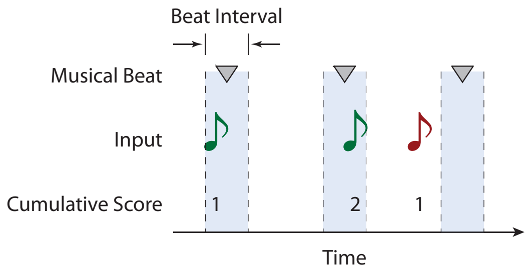

Figure 3: Rating mechanism based on users' rhythmic accuracy. The first two notes played by the user falls within a predefined interval around the beat, increasing the rating; the last note falls outside this region, decreasing the rating. The rating can never fall below zero.

ence between this rhythm metadata with user input, which is used to accumulate a rating of the "rhythmic accuracy" (see Figure 3). If this rating exceeds a threshold, then users are rewarded with cheering, encouraging shouts, or the tinkling of tossed coins, and then reset. The average rating over the entire piece also influences the intensity of the applause when users finish playing.

Aspects of e-learning and psychology also influenced our design of the virtual audience to help make our system *educational* and *entertaining*. Reeves and Nass, for example, have shown that people respond more positively when users receive praise from the system [11]; moreover, there is no perceived difference between unwarranted and sincere praise (although the same is not true for criticism). Thus, we decided against including any negative feedback in the system (even though it would have been possible for us to do so).

4. INSTRUMENT DESIGN

As a musical installation, the instruments played a central role in the design of *REXband*. The physical shell of the three instruments (hurdy gurdy, harp and frame drum) were built by a professional instrument builder from Regensburg. We then digitally augmented these replicas with sensors to send MIDI signals to a computer running the *REXband* software when they are played.

4.1 Hurdy Gurdy

The hurdy gurdy, also known as the wheel fiddle, is the most complex of the three instruments we incorporated into *REXband*. While the body shaping and keyboards have changed through the centuries, the basic mechanics for sound generation rely on the same principles. A set of strings is pulled over a wooden wheel covered with rosin. The wheel is turned using a crank, causing the strings to vibrate. Melodies are played using a small keyboard on the side of the instrument (see Figure 4). The strings can be divided into three categories:

Drone Strings: These strings sound while the crank is turned. They always play the same note, and are not affected by the turning speed of the crank. Drone strings can be tuned to different notes, and can be switched on and off as needed for accompaniment.

Melody Strings: The melody strings are shortened at certain fixed positions using the keyboard, resulting in notes with various pitches. Because of the position of the wooden wheel, only one melody note can be played at the same time, with higher pitch notes taking precedence since they are closer to the wheel. This property can be used to create a warbler-like sound when playing. Like the drone strings, the melody strings are not affected by the turning speed of the crank and can be tuned as needed.

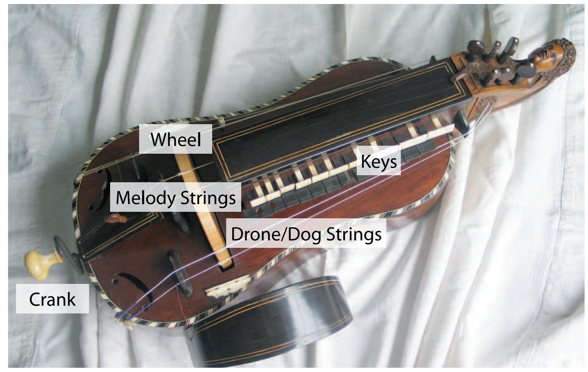

Figure 4: Hurdy gurdy. Credit: Wikimedia Commons (commons.wikimedia.org).

Dog Strings: A dog string is a drone string held by a loose bridge. When the crank is turned slowly, the dog string behaves like a normal drone string. When the crank is given a stronger impulse, however, the dog string causes the loose bridge to vibrate. Experienced players often use this feature to add a percussive element to their play, especially in dance pieces.

For our electronic hurdy gurdy, we tried to maintain as many of the acoustic properties described above while still making it usable by a novice musician:

- Only one note can be played at a time. When two or more keys are pressed, only the note with the highest pitch (the one closest to the crank) is played.
- The hurdy gurdy produces sound only while the crank is turned.
- The pre-recorded drone and dog strings play continuously while the crank is turned.
- The range of playable notes is restricted to ensure the output is harmonious with the accompaniment.

We decided not to allow the users to create their own rhythmic accents using the dog string. Based on early user tests, we found that few people knew about this subtle detail, and decided that it would only confuse people who were not familiar with the instrument.

We used a Doepfer CMT64 (www.doepfer.de) board to generate the MIDI signals sent to the computer. We equipped the wooden bars attached to the keys with Marquardt snap action switches. When one of the keys is pressed, the switch is pushed against the inner wall of the hurdy gurdy, triggering a note on-message (see Figure 5).

Crank rotation is detected using a light reflector consisting of an infrared LED and a photo sensor. Operating the crank also turns a small wooden wheel inside the hurdy gurdy with alternating light and dark regions. The light from the LED is reflected by this wheel and creates a different output from the photo sensor depending on whether it hit a light or dark region (see Figure 5). Using a small electric circuit, we were able to detect the wheel rotation as a pitch wheel controller-message in MIDI.

4.2 Harp

Our harp replica consists of a wooden frame with 12 nylon guitar strings. The sensors are housed inside the resonant body, which is stuffed with Styrofoam to minimize the acoustic sound from the

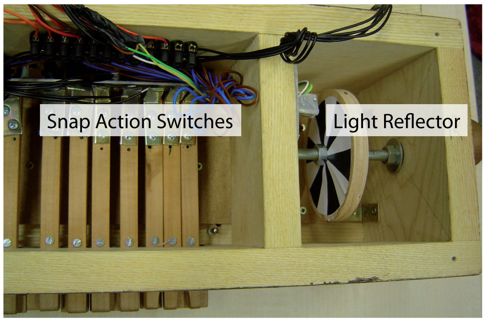

Figure 5: Electronically augmented hurdy gurdy. Snap action switches detect key presses, and a light reflector with alternating black and white regions detect when the crank is turned.

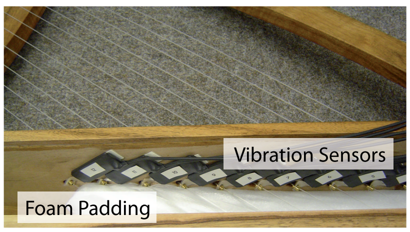

Figure 6: Harp augmented with string vibration sensors. The resonant body is stuffed with Styrofoam to minimize acoustic sounds when the strings are plucked.

strings. We use i-CubeX Vibe sensors (one for each string) to detect the string vibrations; each string is mapped to a different note, and the intensity of the vibration to the velocity. We implemented an algorithm to detect sudden increases in the string vibration, similar to a rising edge trigger. The first velocity value of a peak is used as the note's velocity. While a peak detection algorithm would be more "correct", we found it also results in unacceptably large response times as the falling edge of the peak must be detected before the note is recognized.

In earlier prototypes, we also experimented with a "glissando" support mechanism, whereby a glissando sample would be triggered when multiple neighboring strings were plucked in succession. However, we found in user tests that such a feature was unnecessary – most users were able to create glissandos without this additional support.

4.3 Frame Drum

Our frame drum consists of a wooden body and a leather drumhead (see Figure 7). A Roland drum trigger sensor coupled with a Roland TMC 6 trigger MIDI converter sends MIDI messages from the drum to the computer. We used a rubber foam cone to prevent the sensor from coming into direct contact with the drumhead (see Figure 7). The body is stuffed with Styrofoam to minimize acoustic sound, and the bottom of the drum is sealed.

The intensity of the detected hit is mapped to the velocity parameter of the MIDI message. This setup, while simple, unfortunately means that we are also unable to distinguish a soft hit at the center of the drum from a hard hit at the rim. We hope to address this shortcoming in future work.

5. MUSICAL SUPPORT

As an interactive exhibit targeted to a wide audience, musical support is an essential feature for *REXband*. During the iterative design process, which included frequent evaluations of prototypes with users, we examined two aspects of musical support: melodic and rhythmic.

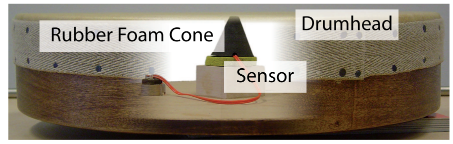

Figure 7: Drum trigger mechanism. A rubber foam cone sits between the sensor and the drumhead to prevent direct contact.

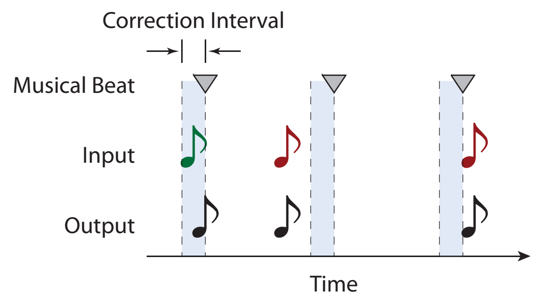

Figure 8: Experimental rhythmic correction scheme. The first note arrives within 110 ms of the beat, and is delayed until the beat. The second and third notes are not modified.

5.1 Melodic Support

The musical piece we chose for *REXband* has a scale of C-major, and we mapped the keys of the C-major scale to the keys on the hurdy gurdy and strings on the harp, to ensure the user cannot play "wrong" notes. This scheme, while simple, is effective and has been used successfully in some of our previous systems [4].

5.2 Rhythmic Support

Based on evaluations of early prototypes of *REXband*, we found that many users have trouble following the rhythm of the music, despite our choice of a piece with a relatively simple rhythmic structure (according to an expert in medieval music). Thus, we decided to experiment with rhythmic correction of users' input. Rhythmic correction has been explored in the past, most notably by Blaine and Perkis [3] in *Jam-O-Drum*. They found rhythmic quantization to be undesirable primarily because hitting is a gesture that requires immediate feedback. However, melody is a primary component in *REXband*, and we hypothesized that users may perceive their input not as single, isolated events, but as part of a larger melodic structure. If so, minor adjustments to timing improve the perceptual quality of the resulting music, but still not affect users' sense of causality. Moreover, rather than quantizing *all* input from the user, we only selectively modify user input, by delaying any notes that are played by the user only when they are within a certain time interval before a marked rhythm beat. If a note is not within that interval, it will be played without any delay (see Figure 8).

We tested our hypothesis by running thresholding experiments with users. We found that more than two-thirds of our users were not able to detect latencies below 110 ms (roughly one-sixth of a beat). However, correcting user input within this time window did not significantly improve the quality of the performance, and in the end, we decided to use a more natural rhythmic support mechanism – an optional audio track with the sound of hands clapping to the beat of the music.

6. PHYSICAL SETUP

The software was implemented in Objective-C using Apple's Core Audio and Core MIDI software libraries. Our software renders the audio as a multi-channel audio stream. In the exhibit, the ambient sounds and accompaniment are wired to a stereo stream, and each of the three instruments to a mono stream. We hid a small speaker next to each instrument; we found in early user evaluations that this addition significantly improves the user experience. Not only does having the sound source co-located with the instrument more realistically imitate the real instrument, the vibrations emanating from the speaker also provide subtle haptic feedback to the user.

This result is not entirely surprising – previous research in human-computer interaction (HCI), for example, has shown that co-location of audio output has an effect on users' memory and comprehension in video conferences [1]. Rowan and Hayward [12], and O'Modhrain [10] have also studied the importance of haptic feedback in musical instruments – our physical instruments already provide some tangible feedback when users hit press the buttons on the hurdy gurdy, pluck the strings of the harp, or hit the surface of the drum. The additional haptic feedback from the speaker vibrations reproduce the haptic feedback that is normally obtained when the instrument itself is the sound generator.

7. EVALUATION

In additional to user testing throughout the design process, we performed extensive user testing of the finished system. We performed user evaluations in both a controlled environment where we could observe and interview users, and also a public setting similar to the planned Regensburg Experience. Our main goals were to see if *REXband* provides users with an enjoyable experience while still conveying to them some new information about medieval music.

7.1 Controlled Test

We performed an observation study with a retrospective interview at the end of each session. Instructions for the 18 participants divided into groups of 2 or 3 were kept simple: we asked the members of each test group to pick one instrument and play it until the end of the accompaniment piece. Users would then move to another instrument, and repeated the test four times, so that each user played each instrument at least once. The interview included questions to quantify how well we met our goals, and more general questions about participants' musical background. Users were also encouraged to offer suggestions on how to improve the exhibit.

During the experiment, we did not interrupt users and kept any answers to their questions short, so as to not disturb the interaction. We observed some recurring patterns in users' behaviors. Most users playing the harp or the hurdy gurdy for the first time approached them curiously, but carefully. Some users were not sure how to hold and play the hurdy gurdy properly, and some did not even find the keys on the backside of the instrument at first. Fortunately, this was usually corrected by the other users in their group. For the harp, we observed a learning effect when users had the chance to play it more than once during the four trials. One user only plucked single strings in his first trial and tried multiple strings in his second one. Another user started with glissandos, but played more single notes later, which apparently sounded better to her. With the frame drum, users experimented with both single and double-handed playing styles, as well as drumming with just their fingers.

When asked afterwards, only three of our 18 participants reported to have seen a hurdy gurdy before, and none had ever played one. The harp and drum were more familiar: all of our test users had seen or heard of these instruments before. Only one user had ever played a harp before, but did not see himself as an experienced player.

Figure 9: *REXband* setup at the Couven Museum in Aachen, Germany.

When asked for characteristics of the hurdy gurdy, responses varied greatly. Two users confused it with a barrel organ, and no single user was able to fully explain the hurdy gurdy. Each group together, however, was able to successfully identify many of the characteristics (e.g., connection between crank and sound production, drone sound, ability to play only single notes). For the harp, playing glissandos and plucking single strings were the most common playing techniques. Only four users experimented with plucking two or more strings simultaneously.

7.2 Public Test

REXband was installed as a temporary exhibit for one evening at the Couven Museum (www.couven-museum.de) in Aachen, Germany (see Figure 9). A few hundred visitors were exposed to *REXband* that evening. We had initially planned to only observe people use the system, but soon found this to be difficult due to that specific environment: most of the other exhibits in the museum were old and valuable, and visitors were not permitted to touch them (ours was the only interactive one). Upon realizing this, we began approaching visitors directly, inviting them to try it out, which encouraged other visitors to try it out without further intervention.

Feedback from the visitors was very positive. Many of them told us that they liked the idea very much, and that it was fun to play on the instruments. One visitor told us that she had always wanted to play the harp, but never actually took lessons and was very happy to have the chance to try one. Many visitors asked questions about the hurdy gurdy, both about the original instrument as well as our modified version. No visitor appeared to be familiar with this instrument, and this also led to some users standing on the wrong side of the hurdy gurdy; we corrected this by placing a photo of the correct standing position close to the instrument.

Before trying out the system, some visitors were hesitant about playing the instruments; lack of musical ability was an often-used excuse, but users were encouraged enough to try the exhibit when told that they are "easier" to play than the original instruments. The hurdy gurdy and harp were the most popular instruments, but visitors with less confidence in their musical abilities often started with the drum first.

8. FUTURE WORK

We have identified the following areas for future work:

Both the instruments, and the system in general, were created for robustness and ease of use, not for depth of artistic expression. A system with a focus on artistic expression could allow melodic correction to be disabled. The melodic correction algorithm used for *REXband* is fairly simple and relies on a static mapping of incoming to outgoing notes. Systems like *coJIVE* [6] and *Band-out-of-the-Box* [15] follow a more complex approach that could provide interesting results when coupled with modified instruments such as the ones used for *REXband*.

Our experiments with rhythmic correction and our literature review in this context showed that the perception of rhythm and latency is not yet fully understood. More experiments in that direction could show how people with varying level of musical experience perceive rhythm and latency, and how a computer music system could provide support.

While *REXband* is a collaborative system, the psychology of collaboratively playing music has only been touched on in this work. Further research could provide knowledge about interaction patterns in this context and show how a system can support players in collaboratively playing music.

9. CONCLUSIONS

REXband is an interactive music exhibit featuring replicas of three medieval instruments augmented with electronics: a hurdy gurdy, harp, and frame drum. Our design incorporates elements of e-learning (interactivity, collaboration, and flattery) in addition to interaction design principles to make the system fun to use, while still conveying little-known facts about medieval music and its instruments. Moreover, we sought to maintain historic authenticity by including experts in medieval music and history in our design process. Our digitally enhanced replicas are designed to resemble the original instruments, with the electronics hidden from users' view. A virtual audience provides both ambiance and a mechanism for feedback on users' performance. We experimented with both melodic and rhythmic support in software to enhance the user experience; we found that while rhythmic support by adjusting the timing of user input by up to one-sixth of a beat is possible, it does not significantly improve a user's performance. Results of user evaluations showed that we were able to satisfy our original goals of creating a system that provides both an entertaining and educating experience.

We hope that our experiences with *REXband* can serve as both a reference and inspiration for future work in using technology to create interesting and novel systems for promoting musical culture.

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