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The Squeezables: Toward an Expressive and Interdependent Multi-player Musical Instrument

The Squeezables is a computer music instrument that allows a group of players to perform and improvise musical compositions by using a set of squeezing and pulling gestures. The instrument, comprised of six squeezable and retractable gel balls mounted on a small podium, addresses a number of hardware and software challenges in electronic music interface design. It is designed to provide an alternative to asynchronous and discursive interactions with discrete musical controllers by allowing multiple channels of high-level simultaneous input. The instrument also addresses new challenges in interconnected group playing by providing an infrastructure for the development of interdependent, yet coherent, multi-player interactions. As a test case for a particular high-level control and interdependent mapping scheme, a short musical composition was written for the instrument and was performed by three players. This article presents a critical evaluation of the composition, the performance, and the mapping design, which leads toward a number of suggestions for improvements and future research.

Goals and Challenges

Electronic musical instruments that use controllers such as keys, buttons, knobs, and menus tend to favor sequential operations by the performer that promote a discursive manipulation of musical parameters. While serving an effective and practical function, such asynchronous interactions might also impair flow and musical expressivity when they are not supported by a more immersive, large-scale musical approach (Langer 1942; Weinberg 1999). Previous solutions for these shortcomings focused on digital modifications and enhancements of traditional acoustic instruments (Chadabe 1997), as well as utilizing novel sensing techniques, such as electric field sensing, for musical applications (see, for example, Paradiso and Gershenfeld 1997). These approaches, while serving their goals, usually fail to provide an immediately responsive malleable interface that can offer both novices and professionals a tactile and immersive musical experience. The main challenge in designing the Squeezables, therefore, was to address these drawbacks by providing "organic"-feeling control (using soft squeezable materials like fabric, foam, and gel), and by sensing multiple axes of synchronous and continuous hand gestures. The instrument is also designed to provide an alternative to the low-level analytical reasoning that is often required by asynchronous and discursive controllers. By mapping the sensed gestures to algorithmic imitation of high-level musical concepts such as stability (Dibben 1999), contour (Schmuckler 1999), or tension (Lerdahl 1996), the instrument can offer expressive and intuitive musical experiences without requiring a long learning process, virtuosic performance skills, or an analytical knowledge of music theory. Such an approach can be used to introduce young musicians and novices to expressive aspects of music playing.

As a synchronous multi-player instrument, the Squeezables can also provide an infrastructure for addressing challenges in the field of interdependent group playing (see, for example, Jorda 1999; Burk 2000; Blaine 2000; Pazel et al. 2000). Wired and wireless communication systems as well as

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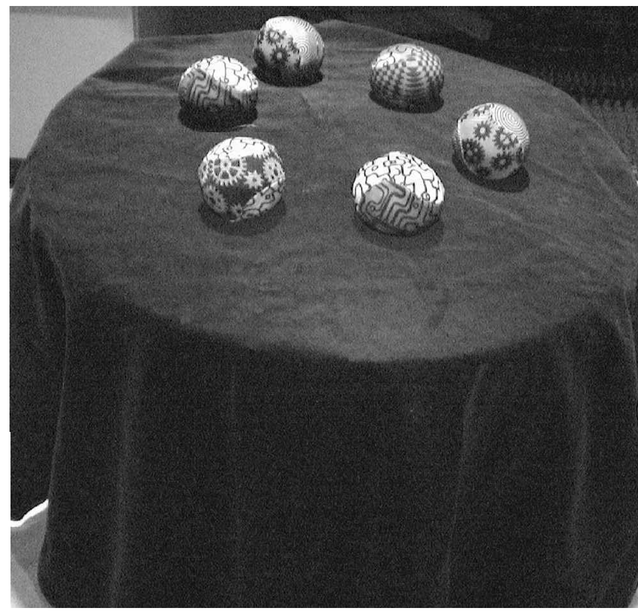
Figure 1. The Squeezables.



Internet-mediated interactions can enhance the traditional experience of musical group playing by providing players with new ways of manipulating each other's music in real time. For example, one player can continuously manipulate the timbre of another player's instrument while controlling the pitch of his or her own instrument. This manipulation will probably lead the second player to modify his or her gestures in response to the new timbre received from the first player. These new gestures can also be transmitted back to a third player and influence that person's playing in a reciprocal loop. Such an enhanced interaction can lead to new creative and expressive experiences that may give a new perspective to the prospect of group collaboration. It is important to note, however, that high levels of interdependency might lead to uncertainties regarding the control of participants over their specific roles. On the other hand, simple one-to-one mappings might obscure the immersive interdependent experience from beginners who are not yet skilled enough to construct such a collaborative sensation on their own. An important challenge in this regard is to develop a coherent scheme, using the appropriate musical parameters, that would provide enhanced yet controllable musical experiences for novices as well as professionals. This will potentially lead to a well-balanced equilibrium between full autonomy on the one hand and complex interdependency on the other. Several previous works have explored different locations along this axis of interdependency (Bischoff, Gold, and Horton 1978; Gresham-Lancaster 1998; Goto et al. 1996; Duckworth 1999). The Squeezables demonstrates an idiosyncratic algorithmic mapping scheme that offers a new approach to this challenge.

The Instrument Design

Both hardware- and software-oriented issues were considered when addressing these goals and challenges. The hardware design centers on developing sensing techniques that provide soft, malleable, and synchronous interaction, whereas the software design focuses on developing mappings for high-level musical control and interdependency.

Hardware and Sensing

The Squeezables is comprised of six squeezable and retractable gel balls that are mounted on a small podium, as shown in Figure 1. Each player around the podium can simultaneously squeeze and pull the balls (one ball per palm) and control a set of musical parameters based on the algorithms described below. The combination of pulling and squeezing allows players to employ familiar and expressive gestures to manipulate multiple synchronous and continuous musical channels. As a whole, the Squeezables instrument supports up to twelve simultaneous input channels of squeezing and pulling. Several materials have been tested to provide a soft, organic, and expressive control for these continuous gestures. The first versions of the instrument used a cluster of soft foam balls that flaked easily and lost their responsiveness over time. For the final prototype, soft gel balls were chosen. These proved to be robust and responsive, providing a compelling sense of force feedback control owing to the elastic qualities of the gel.

Buried inside each ball is a 0.5×2.0 cm plastic block covered with five pressure sensors that are protected from the gel by an elastic membrane (see

Figure 2. The sensor block. The combined signal from five force-sensing resistor (FSR) pressure sensors indicates the level of squeezing around the ball.

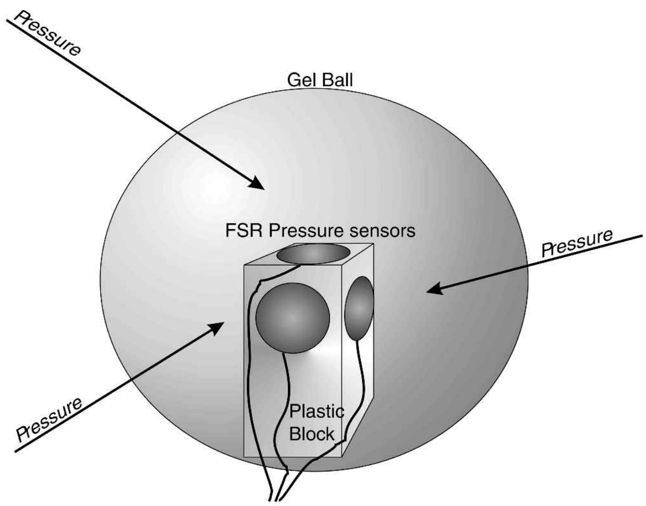


Figure 3. Playing the instrument requires a combination of squeezing and pulling gestures.

Figure 2). The analog pressure values from these sensors are transmitted to an Infusion Systems I-Cube digitizer and converted into MIDI format. The pulling actions are sensed by a set of six variable resistors that are installed under the table. An elastic band connected to each ball adds opposing force to the pulling gesture and helps retract the ball back onto the tabletop (see Figure 3). Here, too, a digitizer converts the analog signal to MIDI and transmits it to the computer.

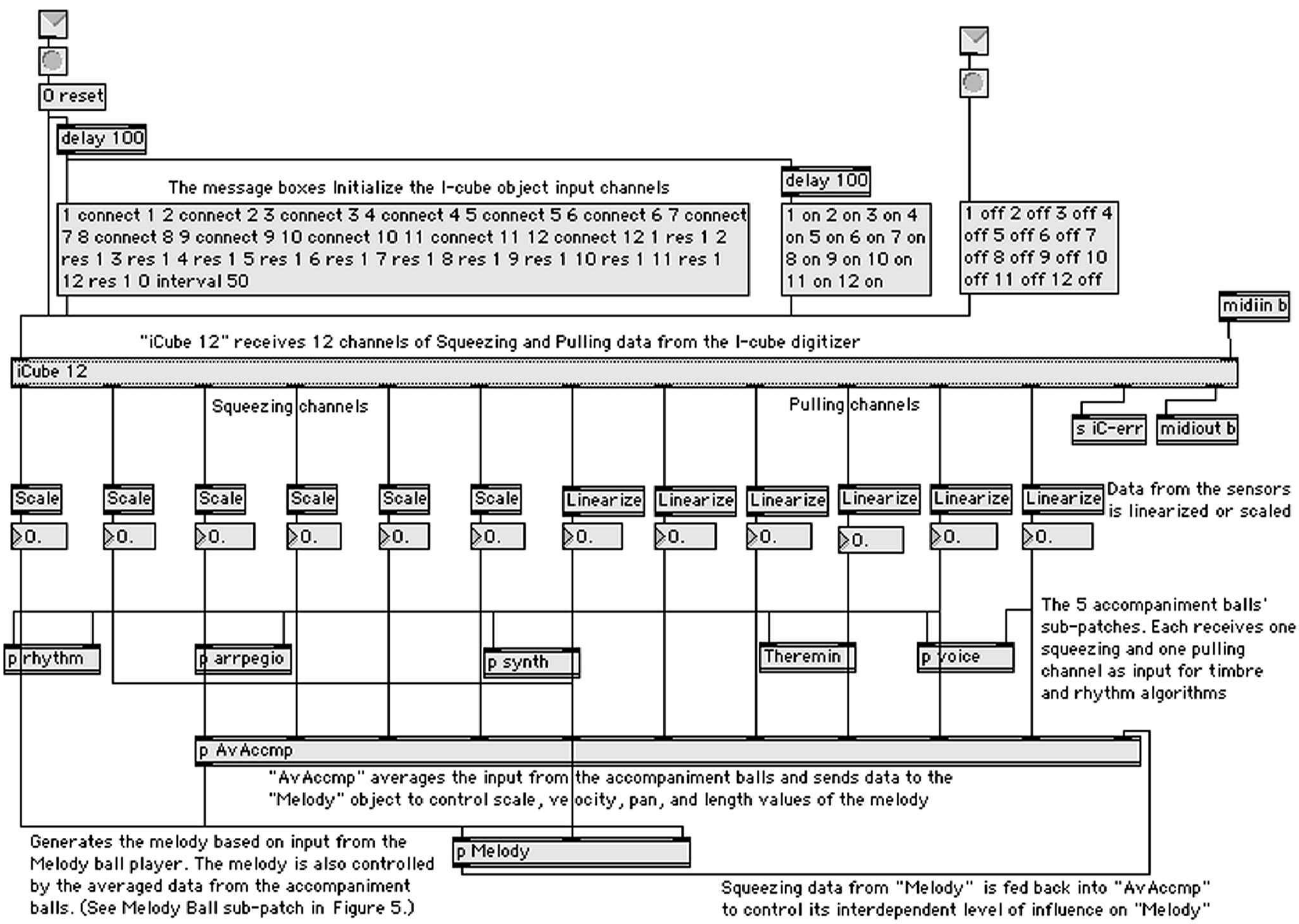
Software Mapping Principles

The digitized data that represents players' pulling and squeezing gestures is transmitted to a Macintosh computer running a Max patch that maps the digitized data into musical output. In an effort to explore the concepts of expressive high-level control and interdependency, our particular Max patch was constructed with two main goals. The first was to provide a mixture of low-level and high-level control that would allow an intuitive and expressive interaction with the instrument. The second goal was to create a setup that allowed a well-balanced interdependent collaboration among a group of players to enhance their interaction while maintaining the system's coherency.

To better evaluate the instrument's high-level control implementation, we decided that some of the mapping algorithms should control relatively low-level musical parameters. For example, the Synth ball employs a one-to-one mapping between the squeezing and pulling of the ball and the modulation rate and range of two low frequency oscillators, respectively. In other balls, higher-level algorithms such as musical "stability" were used. Psychoacoustic studies have shown how the perception of musical stability is influenced by musical parameters such as tempo, pitch commonality, dissonance, or rhythmic variation (Dibben 1999). These parameters were chosen to be manipulated by pulling and squeezing the Arpeggio ball, so that the more it is squeezed and pulled, the more "unstable" the arpeggiated sequence becomes (see below). Other studies show the perceptual significance of melodic contour (see Schmuckler 1999). For example, it has been shown that the ability to retain melodic contour of a melody is much better than the ability to retain specific pitches (Sloboda 1985). These phenomena suggest that melody contour can serve as an intuitive high-level control where the player only manipulates the pitch curve and not the actual pitches. Such an algorithm was implemented in the "Melody" ball. (A detailed mapping description is given below.)

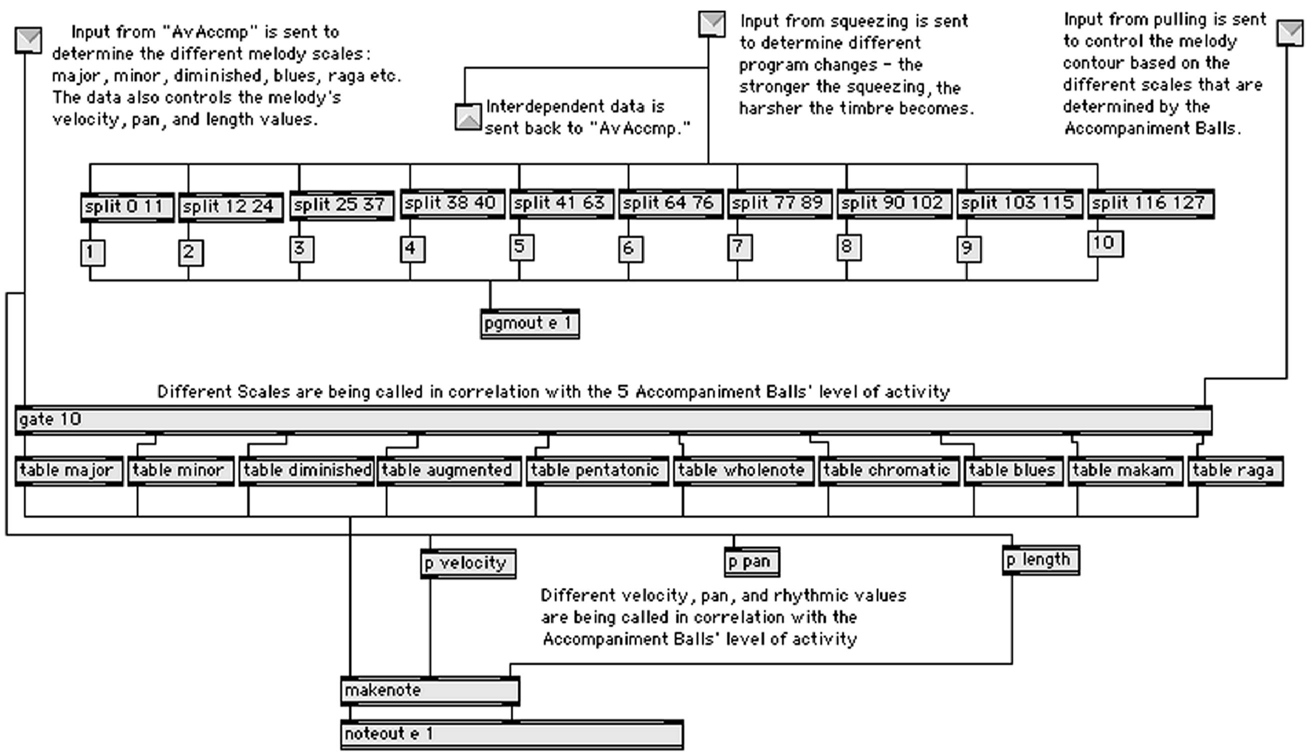
The development of the interdependent mapping scheme for the instrument is informed by previous efforts which indicate that high levels of

Figure 4. The Squeezables main Max patch. Data from squeezing and pulling the balls is sent to six different sub-patches (one for each ball). The output of the five accompaniment balls is also sent to the Melody ball sub-patch through the AvAccmp object. Input from the Melody ball is sent to manipulate AvAccmp in an interdependent loop.



interdependency can create uncertainty about the individual control of each player (Weinberg et al. 2000). On the other hand, too little interdependency might impair the immersive interdependent experience for children and novices. Our approach for this tension involves an automatic system that provides different kinds and levels of interdependency to the different players based on their musical role. The balls, therefore, are divided into five accompaniment balls and one melodic soloist ball. The accompaniment players are provided with fully autonomous control so that input from other balls cannot influence their output. However, their output is not only mapped to the accompaniment parameters (described later) but also significantly influences the sixth Melody ball. While pulling the melody ball controls the pitch contour of the melody so that the higher it is pulled, the higher the melody becomes, the actual pitches—as well as the key velocity, duration, and pan values—are determined by the level of pulling and squeezing of the accompaniment balls. This allows the accompaniment balls to affect the character of the melody while maintaining a coherent scheme of interaction among themselves. In addition, squeezing the Melody ball controls its own timbre and manipulates the accompaniment balls' weights of influence over their own output in an interdependent reciprocal loop (see Figures 4 and 5).

Figure 5. The Melody ball Max Patch. Data from the AvAccmp object is mapped to different scales as well as key velocity, pan, and length values, which are then applied to the melody. The Melody ball player merely controls the melody's contour and timbre.



Mapping Details

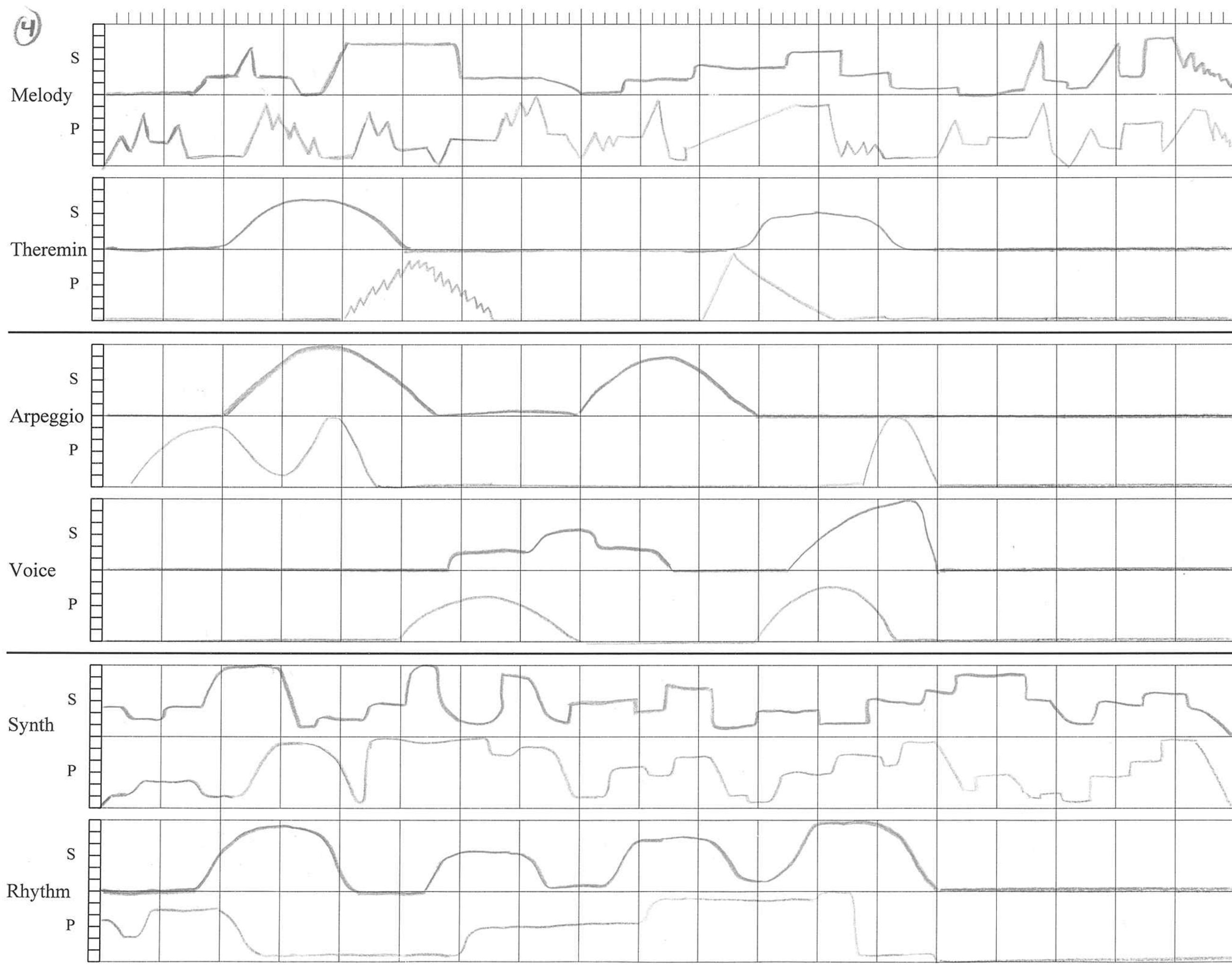
Three of the accompaniment balls, named "Synth," "Voice," and "Theremin," mainly control timbre-oriented parameters on a Clavia Nord Lead 2 Virtual Analog synthesizer. These balls highlight low-level one-to-one control and serve as a balance to the other higher-level control accompaniment balls, named "Arpeggio" and "Rhythm," which are mapped to control intervals and rhythmic parameters in Steinberg's Rebirth software program. The Melody ball controls contour and timbre parameters on an E-mu Ultra-Proteus sound module.

Each ball employs a separate mapping scheme, each of which we now describe in greater detail. The Synth ball manipulates the timbre of a sound that was digitally programmed to imitate the quality of an analog synthesizer. Pulling the ball controls the range of a low-frequency oscillator mapped to amplitude, while squeezing the ball controls the oscillator's frequency. The higher the ball is pulled and the harder it is squeezed, the higher the oscillator's range and rate become, respectively. A derivative of the sum of pulling and squeezing is also mapped to other timbre factors such as envelope parameters, amount of frequency modulation, and noise frequency.

The Voice ball manipulates filter parameters of a sound with singing voice qualities. Pulling the ball changes the filter frequency so that the more it is pulled, the higher the frequency becomes; squeezing it increases the filter's resonance amount. Because these two parameters are interconnected, they create a wide spectrum of timbres.

In addition to controlling timbre qualities such as filter and noise parameters, the Theremin ball includes the added functionality of direct pitch and amplitude-level manipulation, similar to the functionality in Leon Theremin's legendary instru-

Figure 6. The composition notation includes twelve separate level/time graphs for pulling and squeezing for each ball.



ment (see, for example, Darreg 1985). The higher the ball is pulled, the higher the gliding pitch becomes; the harder it is squeezed, the louder the sound gets.

The Arpeggio ball is designed to explore notions of musical tension and stability as discussed above. The default state for this ball is an arpeggiator based on thirds that ascend and descend in a constant quarter note pulse. The higher the ball is pulled, the higher the probability that an unresolved dissonant interval may occur. When the ball is retracted, the probability for dissonant intervals is reduced and the ones that do occur are more likely to be resolved. The tonality for these manipulations is determined in real time by the current scale of the Melody ball. Squeezing the Arpeggio ball manipulates the rhythmic variation so that the harder it is squeezed, the more likely it is for faster rhythmic values to occur. The ball is also mapped to the pitch of accented notes, such that the harder the ball is squeezed, the higher the pitch of the accented notes becomes, and the higher it is pulled, the louder the accents get. A derivative of the sum of squeezing and pulling is also mapped to the frequency of directional changes in the arpeggio, so that the higher levels

Figure 7. The performance. Interdependent collaboration is essential for the creation of a coherent musical output.

of activity with this ball result in more frequent changes in directionality.

The Rhythm ball centers on the manipulation of high-level rhythmic variations. The higher the ball is pulled, the more irregular the rhythmic values of a pre-recorded sequence become. This action controls the probability for half, quarter, sixteenth, and thirty-second note values. The harder the ball is squeezed, the higher the probability is for tuplet rhythmic values (triplets, quintuplets, and septuplets). Furthermore, the sum of pulling and squeezing the ball controls timbre variations via filters, modulators, and envelope parameters, as well as subtle manipulations of tempo.

As described above, pulling the Melody ball controls the pitch contour of a scale selected interdependently so that the higher it is pulled, the higher the melody becomes. Squeezing the ball cycles through a list of sampled timbres so that the harder it is squeezed, the more percussive the sound becomes. The ball is mapped to instrumental sounds such as piano, xylophone, marimba, glockenspiel, and woodblocks, among others.

The Composition and Performance

As a case study for the instrument's sensing and mapping design, a musical piece was composed for the Squeezables by co-author Gil Weinberg. The 6′25″ composition is based on the functional and timbral tension between the accompaniment balls and the melody ball that is being shaped by them.

Special notation was created for the piece, as shown in Figure 6. Two continuous graphs are assigned for each one of the six balls. One graph indicates the level of squeezing over time, and the other indicates the level of pulling. After memorizing the score, three players performed the piece and played two balls each (see Figure 7). In certain parts of the score, the players were encouraged to improvise and to give their own interpretation to the written music. While paying close attention to their personal contribution as well as to interdependent influence, the players modified the written piece and created several other versions.

Discussion

The process of writing and performing the composition served as a useful tool for the evaluation and criticism of our design decisions. In addition, we had several discussions with novices and professionals who experimented with the instrument that led to some interesting findings. Children and novices were more inclined to prefer playing the balls that provided high-level control such as contour and stability manipulation. They often stated that these balls allowed them to be more expressive and less analytical. Professional musicians, on the other hand, often found the high-level control somewhat frustrating because it did not provide them with direct and precise access to specific desired parameters. Some professionals complained that their personal understanding of high-level controllers such as stability and tension is different than the ones that were implemented in the instrument, raising a question about the subjectivity and idiosyncratic nature of our approach.

Both novices and professional players found the multiple-channel synchronous control expressive and challenging and the pulling and squeezing gestures comfortable and intuitive. These gestures allowed delicate and easily learned control of many simultaneous parameters, which was especially compelling for children and novices. The organic and responsive nature of the balls was one of the features that was mentioned as contributing to this expressive experience.

Several interesting findings came from evaluating the effort to implement well-balanced interdependent connections in group-play scenarios. In general, players enjoyed controlling other players' music as well as being controlled by their peers, stating that this provided a new layer of creativity to their experience. However, some comments were made in regard to the heterogeneous nature of the interdependent connections. As was mentioned above, the Melody ball received the highest level of external input and was capable of controlling only some interdependent aspects in the other balls. The accompaniment balls, on the other hand, received little external input, but their output substantially influenced the melody. In providing different players with such varied sorts of interdependent control, we attempted to prevent confusion and enhance the coherency of the experience. This division, however, led to significant variations in players' responses to and enjoyment of the various balls they played. Some Melody ball players described their experience as "a constant state of trying to expect the unexpected," which required high-level of concentration in an effort to create meaningful musical phrases. One player's impression was that she was not playing the instrument, but rather the instrument was "playing her." When the accompaniment players were particularly experienced and skillful, playing the Melody ball felt to another player almost like "controlling an entity that has a life of its own." This unique experience was intriguing and challenging for some but difficult and frustrating for others.

Playing the accompaniment balls led to a completely different experience. Here, players could control and manipulate the melody without being significantly influenced themselves. However, full collaboration with the other accompaniment players was essential to create a substantial effect on the melody, because the melody's algorithm used the sum of the signals from the other five balls. In a manner similar to chamber music group interactions, body and facial gestures had to serve an important role in coordinating the accompaniment players' gestures and establishing an effective outcome. Such collaborations turned out to be especially compelling for children, who found the accompaniment balls social, intuitive, and easy to play with. Some complaints were made, however, regarding the difficulty for a specific player to significantly influence the melody without trying to coordinate such an action with the other accompaniment ball players. Some players felt that this interaction prevented them from expressing their individual voices.

Future Work

Both hardware and software improvements will be addressed in future work. The main hardware-oriented improvement would involve better implementation and installation of pressure sensors inside the balls. Although the gel balls turned out to be more robust than the foam ones (they kept their original shape and did not flake), they did tend to leak when sensors were inserted into them. New versions of the instrument would include better materials and sealing techniques in order to prevent leakage.

We also acknowledge the drawbacks and weakness in our idiosyncratic mapping scheme, as they are described in the discussion. We consider our attempt to provide high-level control for concepts such as stability, tension, and contour as a preliminary groundwork for more extensive investigations. We also see the melody/accompaniment model as only one possible approach supported by the instrument for interdependency. Future work will involve improving the software interface so that it would provide a friendly environment for interested researchers and composers to experiment with their own mapping schemes.

Acknowledgments

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References

Bischoff, J., R. Gold, and J. Horton. 1978. "Microcomputer Network Music." *Computer Music Journal* 2(3):24–29. (Reprinted in C. Roads and J. Strawn, eds. 1985. *Foundations of Computer Music.* Cambridge, Massachusetts: MIT Press.)

Blaine, T. 2000. "Jamodrum Interactive Music System." Presented at the SIGGRAPH 2000 Emerging Technologies Exhibition, 23–28 July, New Orleans, Louisiana.

Burk, P. L. 2000. "Jammin' on the Web—A New Client/Server Architecture for Multi-User Performance." *Proceedings of the 2000 International Computer Music Conference.* San Francisco: International Computer Music Association, pp. 117–120.

Chadabe, J. 1997. *Electric Sound: The Past and Promise of Electronic Music*. Upper Saddle River, New Jersey: Prentice Hall, pp. 213–240.

Darreg, I. 1985. "Theremin—The First Analog Synthesizer." *Journal of Music Research* (4):25–30.

Dibben, N. 1999. "The Perception of Structural Stability in Atonal Music: The Influence of Salience, Stability, Horizonatal Motion, Pitch Commonality, and Dissonance." *Music Perception* 16(3):265–294.

Duckworth, W. 1999. "Making Music on the Web." *Leonardo Music Journal* 9:13–18.

Gresham-Lancaster, S. 1998. "The Aesthetics and History of the Hub: The Effects of Changing Technology on Network Computer Music." *Leonardo Music Journal* 8:39–44.

Goto, M., et al. 1996. "A Jazz Session System for Interplay Among All Players." *Proceedings of the1996 International Computer Music Conference.* San Francisco: International Computer Music Association, pp. 346–349.

Jorda, S. 1999. "Faust Music On Line: An Approach to Real-Time Collective Composition on the Internet." *Leonardo Music Journal* 9:5–12.

Langer, S. 1942. *Philosophy in a New Key*. Cambridge, Massachusetts: Harvard University Press, pp. 85–94.

Lerdahl, F. 1996. "Calculating Tonal Tension." *Music Perception* 13(3):319–363.

Paradiso, J., and N. Gershenfeld. 1997. "Musical Applications of Electric Field Sensing." *Computer Music Journal* 21(3):69–89.

Pazel, D., et al. 2000. "A Distributed Interactive Music Application Using Harmonic Constraint." *Proceedings of the 2000 International Computer Music Conference.* San Francisco: International Computer Music Association, pp. 113–116.

Schmuckler, M. A. 1999. "Testing Models of Melodic Contour Similarity." *Music Perception* 16(3):295–326.

Sloboda, J. 1985. *The Musical Mind.* Oxford: Clarendon Press.

Weinberg, G. 1999. "The Musical Playpen: An Immersive Digital Musical Instrument." *Personal Technologies* 3:132–136.

Weinberg, G., T. Lackner, and J. Jay. 2000. "The Musical Fireflies—Learning About Mathematical Patterns in Music Through Expression and Play." *Proceedings of the 2000 Colloquium on Musical Informatics.* L'Aquila, Italy: Instituto GRAMMA, pp. 146–149.