

Squeezables: Tactile and Expressive Interfaces for Children of All Ages

by

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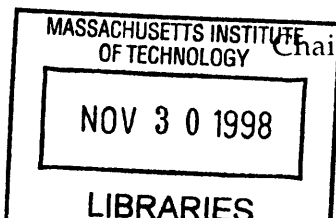
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Abstract

Electronic musical instruments are used in a wide variety of roles in the professional production and performance of all kinds of music. Moreover, they have great potential for use by non-professionals in the applications of interactive entertainment and music education. Despite the wide range of current and potential roles for these instruments, the range of interfaces commonly used to control them is quite narrow. Musical interfaces are usually limited to organ-style keyboards, buttons, knobs, and sliders. Since these interfaces can be intimidating and/or hard to learn, the investigation of alternate interfaces is particularly relevant for use by non-professionals. Even professionals who have taken the time to master traditional interfaces could benefit from the different modes of physical expression made possible by alternate interfaces.

Rather than confining ourselves to one of these traditional kinds of input interfaces for sounds and music, we are pursuing an ambitious dream from a radically new perspective. The ultimate goal of this thesis is to demonstrate that the everyday actions we do with our hands, such as squeezing and pulling, can be tapped and used for creating sounds and music. The control of this instrument is universal and perceptually meaningful for children of all ages in their quest for creativity.

This thesis describes a new class of interfaces, *Squeezables*, which can be used as an expressive input interface for controlling musical outputs in place of traditional interfaces usually found on electronic musical instruments. This thesis presents three major forms of the *Squeezables* developed. They are the cluster, the pole and the table. It also presents two related works, *Musical Play Pen*. and *Digital Maracas*. Issues addressed include selection of materials, selection of sensors, sensor placement, and mapping of sensor values for various musical applications. This thesis will also describe the evolution of the *Squeezables*, from the first version to the latest table version. Furthermore, this thesis will discuss the pros and cons of each version of *Squeezables* and how *Squeezables* may evolve in the future.

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Chapter 1

Introduction

Composer Morton Subotnick said in 1989 in an interview with Tod Machover "It is important to have new instrumentation which can be more expressive" and "We need to address electronic media and understand that we must create art using all media, especially new interactive media." [SM96]

The Story

The thought of creating new musical instruments is not new: it has been around since the beginning of the century. In 1916, composer Edgard Varese said "Our musical alphabet must be enriched... We also need new instruments very badly... In my own works I have always felt the need for new medium of expression." [Cha97:p59] Then again, in 1939, he said "I need an entirely new medium of expression: a sound producing machine." [Cha97:p258]

Many others have tried to develop solutions for the needs mentioned. One of the first was Leon Theremin, who, in 1920, invented the *theremin* [Cha97:p9][Wax95], an instrument that gave the performer, for the first time, a "free-air" playing environment. It is also not based on any previous instrument. The Russian leader Lenin was introduced to the *theremin* and started playing it a few hours later. One hand controls the volume and the other hand controls the pitch. One can play a whole range of notes either by sliding or jumping from one to the other using well coordinated movements of both hands. The world's best *theremin* soloist, Clara Rockmore, who died recently in May 1998 at the age of 87, was able to subtly control the sound by using finger movements. This kind of playing accuracy requires

an intimate understanding of the behavior of the instrument and years of playing experience. Everyone can play the *theremin* but not to an extent comparable to Clara's intricacy. Part of the instrument's difficulty comes from the lack of physical or tactile feedback. Sound is the only feedback. The player must listen very carefully and respond very quickly to what he/she hears.

Since the *theremin*, there have been many other new instruments. Researchers at STEIM (Stichting Elektro-Instrumentale Muzeik) [Kre90][Rya91][WRC93], an arts research institution in Amsterdam, have made many interfaces for music. These include the *Sweatstick* [WRC93], *the Hands* [Bon98][Kre90][Rya91][WRC93], and the *Web* [Bon98][Rya91][WRC93], which are geared towards bringing out expression and controlling timbre in performances.

In electronic music, this practice of having a live performance is rare even though it is a very traditional way of using musical instruments. The STEIM researchers have put emphasis on creating electronic musical instruments that can be used in live performance. This not only gives the audience the opportunity to see the instruments, it also allows the audience to understand and enjoy the music through the movements and gestures of the performers on stage.

Developed by Ray Edgar, the *Sweatstick* is an alternative MIDI controller. It is a one-meter aluminum rod, articulated in the middle, with a sliding keypad for each hand. The performance of the instrument resembles that of a Chinese martial art performance with fighting sticks. Like the *theremin*, the *Sweatstick* is a "free-air" controller except that there is a physical object to maneuver which gives the player more tactile feedback. I would imagine that Chinese martial art masters could actually transform their acts into musical outputs using the *Sweatstick*. Since there is tactile feedback, it might be interesting to do a duo for *Sweatsticks* where additional sensors were added so that "stick contacts" could create another musical or sound output.

The *Hands*, created by Michel Waisvisz in 1984, is essentially a pair of miniature 16-key keyboards worn on the performer's hands. Together with many different combinations of sensors, the *Hands* can capture movements of the hands, the fingers and the arm. In 1989, Bert Bongers worked together with Waisvisz and made many improvements to the first version and called it *Hands II* [Bon98]. Later, it evolved into another controller called the *MIDI-Conductor* [Bon98]. It is an ultrasound-based, spatial hand-held instrument created in active collaborations among STEIM, the Royal Conservatory of Music in Den Haag, Netherlands and the Institute of Sonology. The ultrasound is used to measure the distance between both hands. There is also a pressure sensor, two tilt sensors, a movement sensor, and a number of switches. The *Hands* and its successors are all very "free-air" instruments but are very much less tactile than the *Sweatstick*. This is mainly because the *Hands* is in a handle-like configuration. It also has a lot more sensors and controls, making it a more difficult instrument to play than the *theremin*. The greatest drawback of the *Hands* are the wires that connect them to the digitizer. Very often, handheld or portable interfaces with wires obstruct the performer's mobility. A wireless version of the *Hands* would definitely provide much better mobility for the performer. A problem with the *MIDI-Conductor* is that, although ultrasound can be used to measure distance effectively, it is highly directional. With the hands of the performers holding the interface, unless the movement and orientation of the *MIDI-Conductor* is restricted, the ultrasound measurement will very often be cut off and become useless. If there were two *MIDI-Conductors* being used at the same time, the deflection of the ultrasound might trigger a false measurement of distance between the two hands of one performer. On the other hand, one may be able to make use of this "crosstalk" to create more interactive *MIDI-Conductors* for multiple performers.

The *Web* is a musical instrument designed to control the timbre in multi-instrumental set ups on stage with single finger movements of a solo performer. Also created by Michel Waisvisz, it has been extended to a very large scale installation called *Soundnet* [Bon98] where one or more performers climb up and move about the various cables or "threads" like "spiders." The idea behind *Soundnet* was to scale the *Web* to a size proportional to a

human “spider.” The weights, tensions and even pulls on the cables are all captured and used for the performance. The instrument can be set up with the web plane either in the vertical or horizontal position. The *Web* is a highly tactile instrument that requires a lot of energy and concentration as one needs to sustain his own body weight and balance. Like rock climbing, one has to be cautious while playing. The spacing of the cables also makes it suitable for taller players. It would be an interesting experiment to actually push a huge ball on the *Web* when it is in a horizontal position, with all the cable obstacles. One effect that the ball will have is to create oscillations as it attempts to find an equilibrium. Another interesting and more challenging experiment would be to put the *Web*, either in its original layout, a modified tree-like layout or other layout, in a zoo with monkeys and other tree-climbing creatures. These creatures have far better climbing and swinging skills than human performers and they might produce very interesting results even with the original mapping of the *Web*. This could truly become a “Nature Symphony” for the zoo. Not only would this make music, it would certainly make going to the zoo more fun and educational.

In 1991, Neil Gershenfeld, Joe Chung and Tod Machover designed the *Hypercello* [Mac92][Par97] where, in addition to the audio signals from each string and the finger positions on the fingerboard, the bow position and placement were measured using capacitive sensing methods which are much less sensitive to background noise than most optical or other techniques. Tod Machover’s *Hyperinstrument* [Mac92][Par97] composition *Begin Again Again...* premiered at Tanglewood, where cellist Yo-Yo Ma played the *Hypercello*. Since then, there have been more than a dozen performances worldwide. The *Hypercello* is a very good model for controlling other instruments. Unlike many new musical instruments, it is actually a controller built into a traditional acoustic musical instrument, which makes it more familiar to the cellist. The downsides of the *Hypercello* are probably the amount of equipment involved, the time it takes to be set up and the need to strap up one of the hands of the cellist for other measurements.

Recently, Tod Machover *et al.* created the *Sensor Chair* [BOChair94] [Par97] in October 1994 for Penn & Teller, who are professional magicians. The *Sensor Chair* allows performers to

select different sounds to be played by just pointing their fingers or waving their hands in front of an “invisible map.” The player sits on a conductive mesh on the chair and is thereby coupled to an electric field transmitter. Four electric field sensors in a square formation in front of the player sense the strength of the field emitted from the player’s hand, allowing software to track the exact position. The only drawback of this instrument is that it can only sense one point in the “invisible map.” If the player puts both his hands in, it will average the two to form just one position. Through clever software tracking, the strengths of the four sensor outputs are mapped to electronic instrumentation. There are also two pairs of foot switches used for mode changing and triggering. Like the *theremin*, the *Sensor Chair* needs calibration for each and every performer. It is also a “free-air” instrument where there is no physical object to hold on to when playing. Unlike the *theremin*, the *Sensor Chair* has a very high-level mapping with pre-composed pieces being triggered at different places and times, so it can be easily played by non-musicians, which was clearly demonstrated by Penn & Teller.

After the *Sensor Chair*, Tod Machover *et al.* created the *Brain Opera* [Par94][Orth97][Wax95][Par97]. The *Brain Opera* is a set of interactive musical activities designed to allow people, both young and old, to experience electronic music. There are the *Rhythm Tree*, *Melody Easel*, *Harmonic Driving*, *Gesture Wall* and *Singing Tree*. With the *Rhythm Tree*, users can hit many pads to trigger different sounds. These pads, made of hard urethane, are sensitive to impacts from different directions and several dozens of them are mounted on the surface of a huge bag. There are a few of these “trees” around in the activity area where many people can play them together like bands. The *Melody Easel* essentially lets users draw music on a touchscreen. Different parts of the screen have different musical pieces and voices. There are a few different easels in the area and each one can create different graphics and music. Very much like an arcade racing game, *Harmonic Driving* gives users control over the flow of a piece using a steering wheel. The wheel can be turned and bent in all directions, making it very flexible. The goal of the player is to steer a graphic representation of a note through a series of tunnels where the choice of tunnels determines

what is played. The *Gesture Wall* is a combination of the *Sensor Chair* and *Melody Easel* but it is not tactile. It lets users select sounds and draw on an image projected on a screen. The *Singing Tree* encourages the user to sing and hold a note as purely as possible. When a perfect note is detected, the screen will slowly unfold beautiful graphics of a rose or a dancer.

The whole *Brain Opera* is designed for people from all walks of life to play and enjoy. Many of the concepts are good but some are not implemented as well as they were supposed to be. For example, the *Melody Easel* has a touchscreen that becomes very tiresome to play after just a while because the drawing surface is too hard and both the audio and visual responses are too slow; the pads of the *Rhythm Trees* are also too hard for prolonged playing and because of the different shapes and surface design, many actually hurt the hands of players; the steering response of the *Harmonic Driving* is not always as quick as what you would expect; the *Gesture Wall* animation is slow. There are certain areas where the job is very well done, like the *Singing Tree* and the *Sensor Chair*, which is used in a different portion of the *Brain Opera* that does not involve audience interaction.

The mixed sound generated from the various experiences of the *Brain Opera* is rather noisy. A challenging idea would be to make all the experiences work with one another in real-time to turn this mixture of sound into harmonized and orderly sound.

The *Digital Baton* [Par94][MP97][Mar96][Par97], another instrument that came out of the *Brain Opera*, made use of both infra-red tracking and a 3-axis accelerometer. An infra-red transmitter at the tip of the baton is picked up by a special camera in front of the conductor, allowing the baton tip's position to be tracked. An accelerometer allows directional beats and large gestures to be detected. There are also force sensing resistors in the over-sized handle of the baton for limited finger squeezing control. The *Digital Baton* is used on stage during the performance of the *Brain Opera* and is a remarkable instrument that combines both "free-air" movement and a "tactile interface". Aside from the over-sized and hard handle, which would make it difficult for children to play, it can be played by non-musicians too. Like many interfaces, the *Digital Baton* has a wire and a stationary infra-red tracking device. With

these gone, with just the baton, the conductor would be able to move freely in space while conducting and creating an entirely new form of control.

Don Buchla, a famous builder of new instruments, has made an instrument called *Lightning* [Par97]. It is a pair of wands, transmitting infra-red and tracked by optical triangulation. It gives instantaneous position, velocity and acceleration of the wands in space. Unlike the *Hands*, the wands are wireless and have no contact sensors. This makes them less complicated and can be played by almost anyone. On the other hand, they are like a pair of batons, where a player expresses his intentions purely through intricate gestures by swinging and moving them in the air.

Buchla also made another instrument called *Thunder* [Par97]. It is a specialized MIDI controller that senses various aspects of the touch of hands, through the multi-faceted playing surface, organized to complement the shape and reach of the human hand. It transmits the resultant gestural information via MIDI to responsive electronic instruments. It introduces new concepts for defining musically interesting relationships between performance gestures and modern electronic vocabularies. With this, it has a steep learning curve since it takes the user time to understand it and to learn to use it to its fullest potential.

Any new instrument that comes out will always provoke strong reactions, from future predictions of what the next generation of instruments will be to just an announcement of its imminent demise. Even a very powerful controller can fail to catch on due to the lack of knowledge and experience of it by the general public. One such example is the *Airdrums* [LT93][Par97]. Invented by Pat Downs, they are also nicknamed the "MIDI maracas," and were made by Palmtree Instruments in 1987. This was a pair of sticks, about the size of claves, that send MIDI messages when moved on their axes in various directions with the use of acceleration, tilt, and rotation sensors.

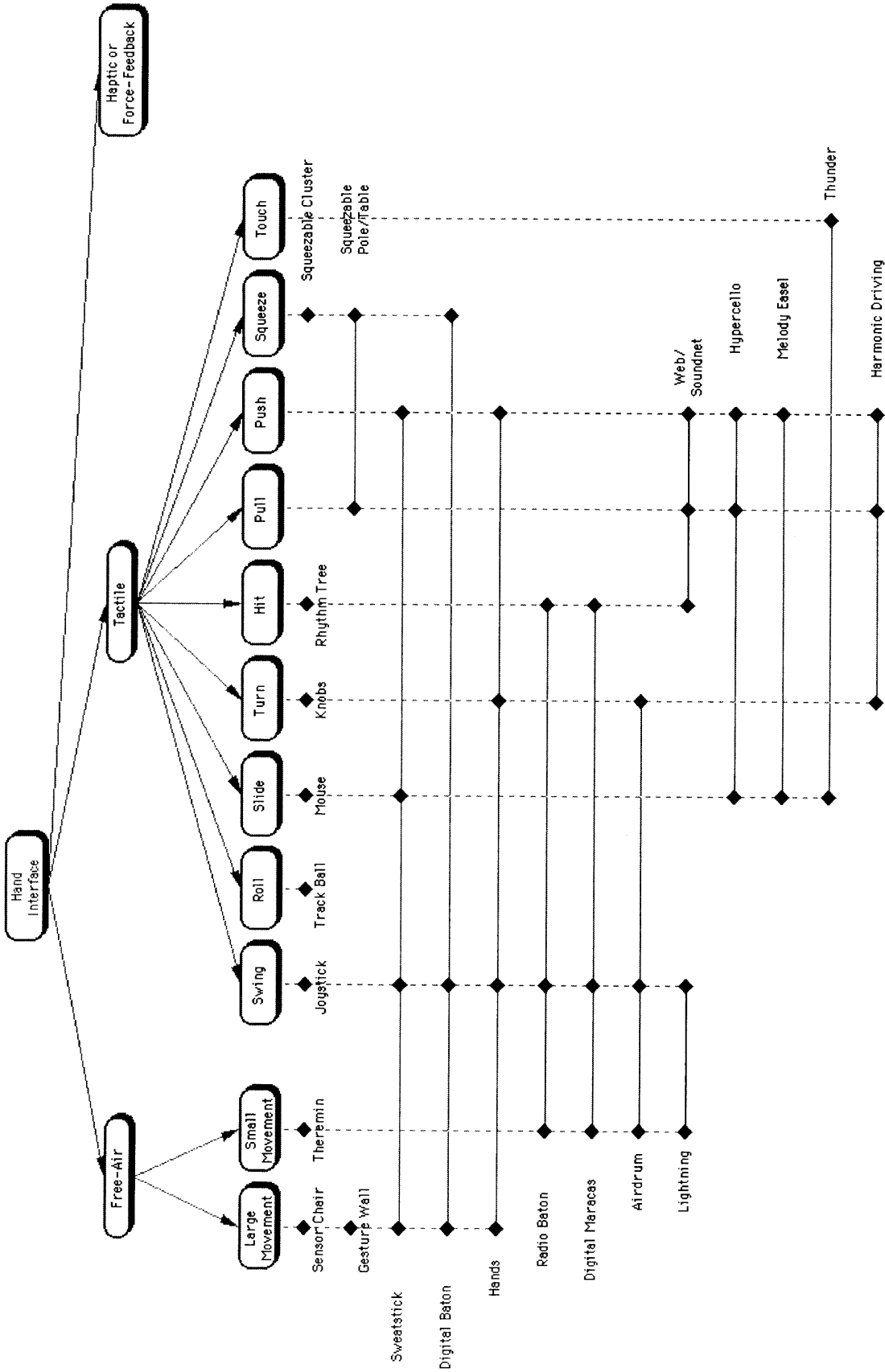


Fig. 1.1 : The Classes of Hand Interface

Fig. 1.1 is an attempt to categorize all these instruments into the various classes. It turns out that some of them have the combined “free-air” and tactile features, while others are entirely “free-air” or tactile. None of them, however, is considered haptic, i.e. using force-feedback.

The Inspiration

People love music! It gives them sheer pleasure. Playing on the keyboard or pressing buttons to create music is fun but many people cannot play well because they are untrained. In fact, a lot of people do not compose, play an instrument, or even dance to music. For such persons, there is nothing easier than to simply squeeze out the music.

While all of these new musical instruments described explore new possibilities of a single expression or multiple expressions, only the *Digital Baton* has included “squeeze” as one of its inputs. Even then, the squeezing of the *Digital Baton* is very limited and proved to be tiresome. There is a need to create an interface that falls into this class to exploit its potential in music or sound manipulation. There is also a need to create more instruments that are not just intended for stage performance or for professional musicians and technologists.

This thesis will focus on the area of squeezing and explore the possibilities of multiple-player musical instruments for non-professionals or amateurs. It will attempt to fill in the gap for “squeeze” interface and also expand to both “squeeze and pull” combination of hand interface in Fig. 1.1.

An advantage of squeezing is that it is intuitively connected to emotions like happiness, fear and anger. For example, when a person is angry or tense, he tends to hold on to things very tightly; if a person is fearful, he tends not to hold things properly because he shivers. Also, many things that we do everyday require some amount of squeezing like washing and picking up a pillow. Squeezing is also a very intimate and delicate action, something that is very close and private like hugging loved ones or the way children treat their favorite teddy

bears and dolls. In order to squeeze, there has to be an object that is tactile and physical. This makes squeezing a familiar way for people to explore the context of music and sound.

For the purpose of this thesis, the *Squeezable* is a category of interface that users squeeze to control the major behavior of a musical system. A *Squeezable* with a large range of continuous control is an obvious next step as an interface to complement the world of buttons, knobs and sliders in computer music. These conventional interfaces can have hard surfaces and can be uncomfortable to use. Also, they may not be the best way to capture the true feelings of the performer. With the *Squeezables*, sound designers and computer musicians will be able to enhance their expressions. Instead of conventional inputs like piano keys or cello strings, *Squeezables* have an interface that requires less practice to master, but which is still capable of careful manipulation, so amateurs will be encouraged to explore sound and music. Children will be able to play with this toy-like object and control the outcome of a piece of music. The *Squeezables* is an instrument meant for children and amateurs as well as professionals, both young and old. All these experiences can be accomplished by having the *Squeezable* exert high-level control over the music being created. For example, a *Squeezable* could control the parameters of rhythm and melody generation algorithms.

The group play feature of the *Squeezables* also gives players the shared controls of a piece of music. This not only promotes interaction among the players, it also frees the single player of the ever increasing number of control parameters he has to take care of. This seems to contradict the goal of creating more controls for one person, but it does introduce an element of fun when more people are playing in front of one another, especially to the young.

In the chapters that follow, I will describe the evolution of the *Squeezables* from its inception up to the latest version that senses more than just squeezing. All the important design steps of its development will be described, including experiments with materials, sensors, and packaging.

Chapter 2

Squeezable Cluster

This chapter will describe the evolution of the first successful Squeezable from the earlier water tube to the foam ball cluster configuration, details of the making of the cluster including its shape, materials, sensors, sensing techniques involved and also the experience gained and lessons learned from using foams.

Shapes and materials

Before arriving at the final shape of the *Squeezable*, I considered many irregularly shaped objects. One of the important things I kept in mind was that the shape should be comfortable to hold and should also fit well into the contour of the palms. If this rule is not followed, users will find the object tiring to squeeze after a while. Objects with sharp edges, for example, a square block, are not suitable as the edges may become a strong barrier to squeezing. The flat surfaces of the square block do not fit well into the natural curling shape of our hands, making the block difficult to squeeze.

The Squeezable Liquid

The solution to this problem is to use an object that has a curved surface. For example, a cylinder-shaped object will fit very well into the grip of the palm.

A cylinder-shaped tube of liquid was then chosen for this. The liquid is held together by a piece of almost-transparent polyurethane membrane that wraps around forming an infinite loop (Fig. 2.1).

The elastic nature of the polyurethane membrane is a very good feature of the liquid *Squeezable*. It is able to transform into many other shapes when squeezed and return to its original shape and size when released. The liquid nature of the object makes it feel very “organic,” i.e. like squeezing part of your own body.

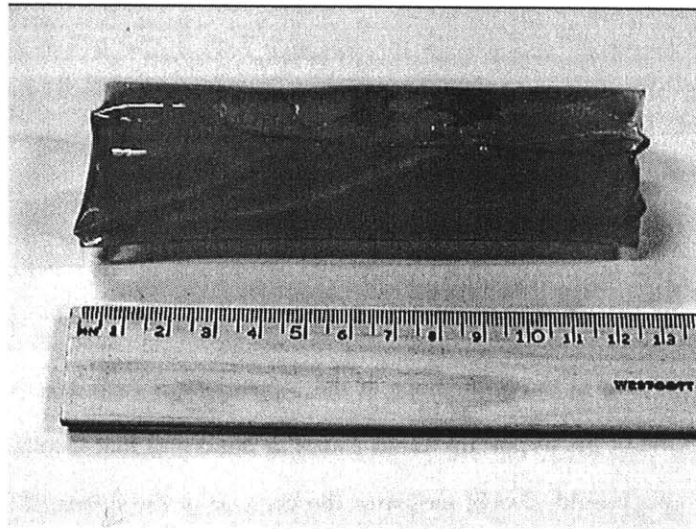


Fig. 2.1 - The polyurethane wrapped liquid as the *Squeezable*

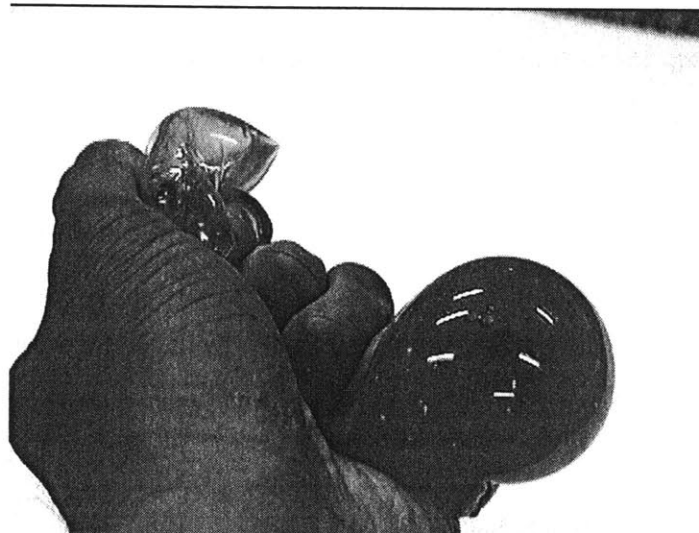


Fig 2.2 - Irregular shape of the liquid *Squeezable*

However, after several experiments with the liquid *Squeezable*, I decided that it is not a good thing to use. The reasons were :

- 1.) the polyurethane membrane ages and leaks;
- 2.) sensors cannot be put inside of the *Squeezable* as this will damage the polyurethane membrane;
- 3.) indirect squeeze sensing from the surface of the *Squeezable* is not effective, as the pressure comes from the inside of the object;
- 4.) taping sensors directly onto the polyurethane membrane will reduce the elasticity of the membrane and also damage it.

From the big squeezable foam ball to the cluster

The problems with the liquid *Squeezable* lead me to experiment with foam objects. When choosing the right type of foam, I used the type that is not too soft and not too hard so that it would not collapse under its own weight and also would not be too difficult to squeeze. The foam *Squeezable* is the shape of a ball measuring about 18 cm in diameter (Fig. 2.3). The idea is to sense the internal pressure of the ball when it is squeezed. So, I built a sensor cube measuring 4x4x4 cm with perspex (clear plastic) and mounted six Force Sensing Resistors or FSRs (Fig. 2.4) on all the faces of the cube (Fig. 2.6). After emptying out the center of the foam ball (Fig. 2.5) to roughly the size of the cube, the sensor cube was then buried and the ball sealed with spray glue.

The next question to ask is : why did I choose to put six sensors on a single cube? Why not three with each one along one axis? The reason why six is better than just three is : I can divide the surface of the ball into six regions. Each region can be pressed independently of the others. If there are only three sensors, though I can tell there is a force acting on one axis,

I will not know which direction it comes from. This will mean that squeezing the ball on these opposite regions will not do anything different. Furthermore, the characteristics of foam actually allows me to do just that. Unlike liquid, when the foam ball is compressed on one side, except for the surrounding region of the pressure point, the whole ball is virtually in the same state. This is because this foam is elastic and is not totally solid. There is room for compression and elasticity for expansion without displacing and taking up material around the pressure point.

The foam ball used was of a comfortable size for both hands but the foam was not soft enough for prolonged squeezing and therefore, users found it tiresome to squeeze. Also, because the ball was too thick, the sensors were not sufficiently sensitive to the squeezing.

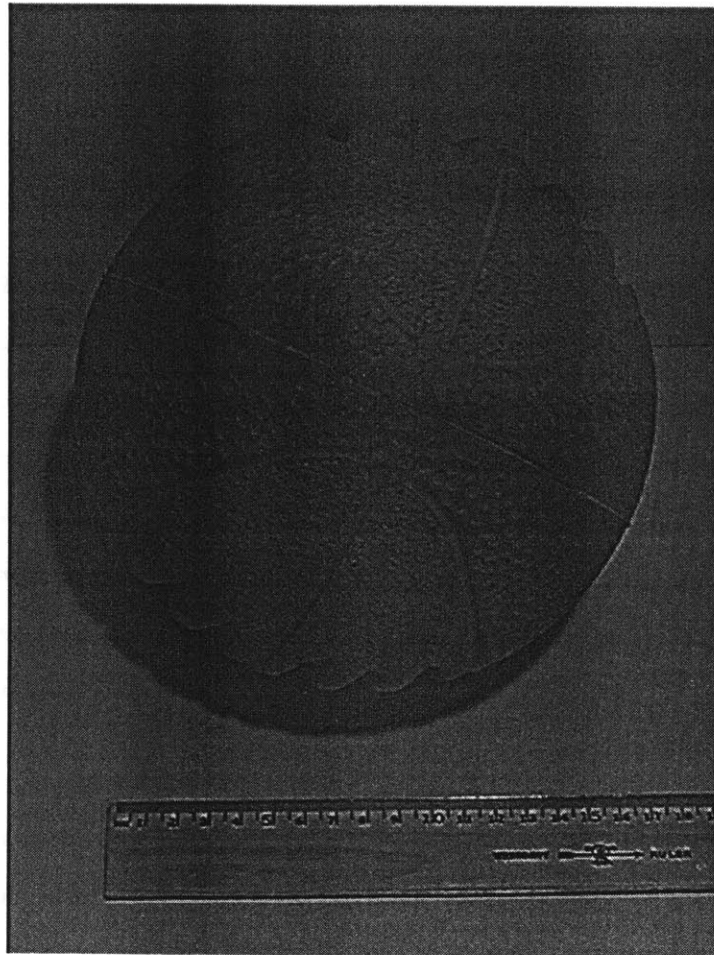


Fig. 2.3 : The big foam ball

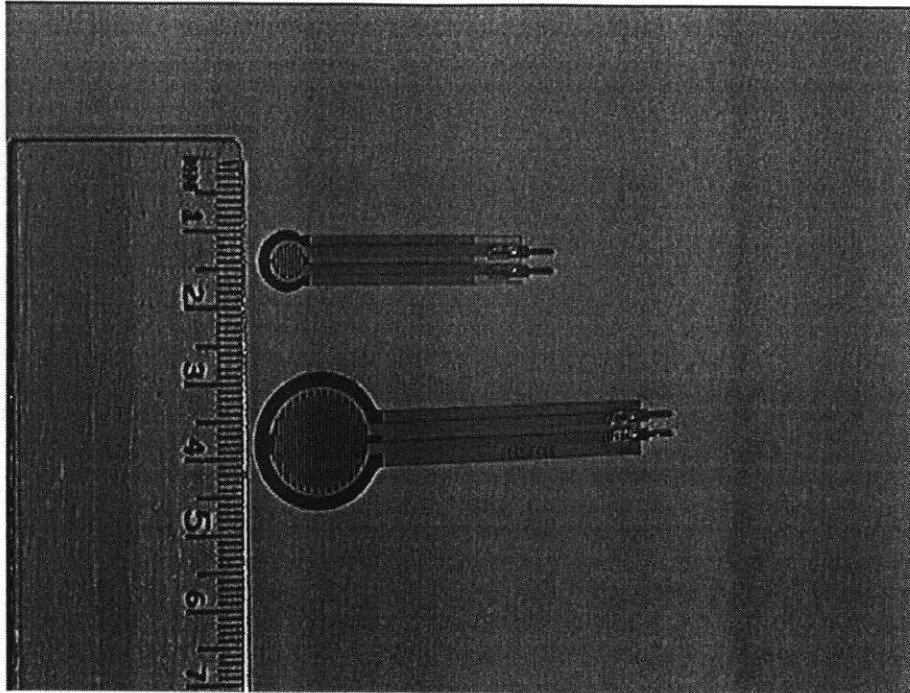


Fig 2.4 : The 8mm and 18mm force sensing resistors

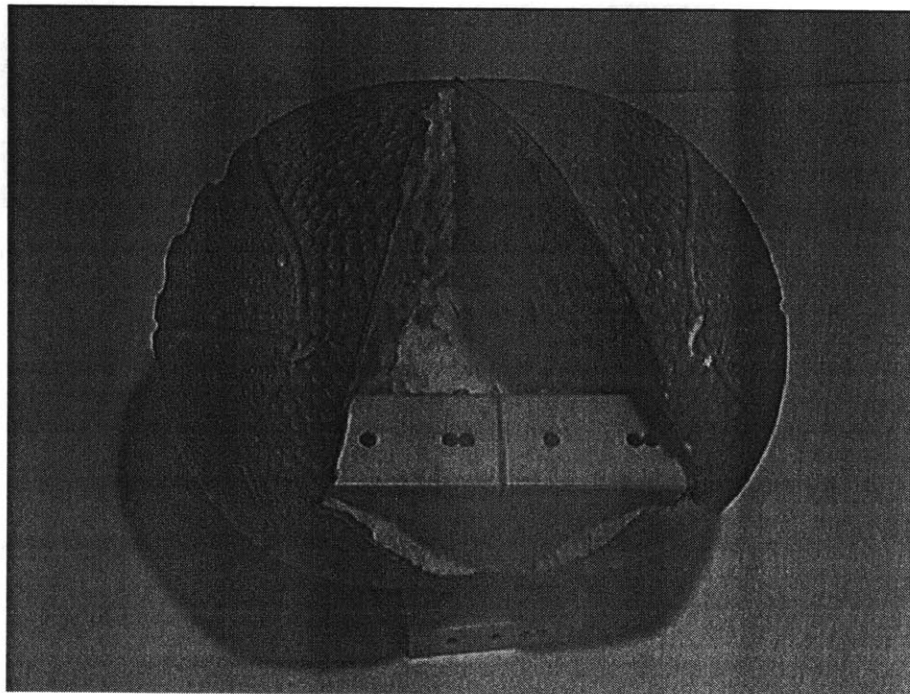


Fig. 2.5 : The hollow center of the big foam ball

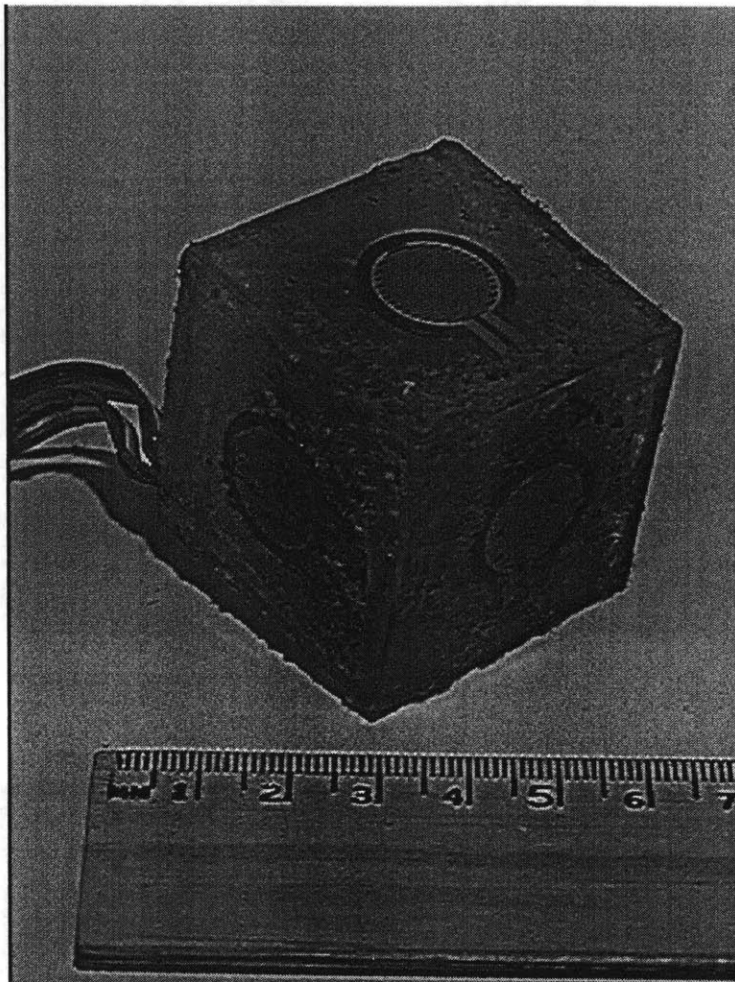


Fig. 2.6 : The Sensor Cube with the 18mm Force Sensing Resistors

The next version of the *Squeezable* was a cluster (about 12 cm in diameter) of equally sized soft foam balls (about 6 cm in diameter) with the same sensor cube (Fig. 2.6) within the cluster. Since the sensor cube has one Force Sensing Resistor (FSR) on each of its faces, one foam ball sits on each FSR (Fig. 2.7) forming an uncompleted cluster with “holes” or “openings” between balls. These “holes” are then covered by additional foam balls. This makes a 14-ball cluster which is symmetrical and is shown in Figs. 2.8, 2.9 and 2.10.

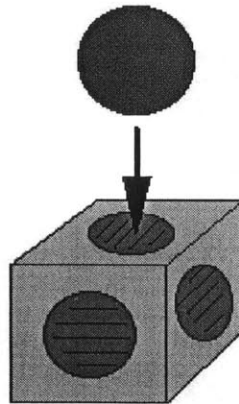


Fig. 2.7 A foam ball sits directly on the Force Sensing Resistor on one face of the sensor cube

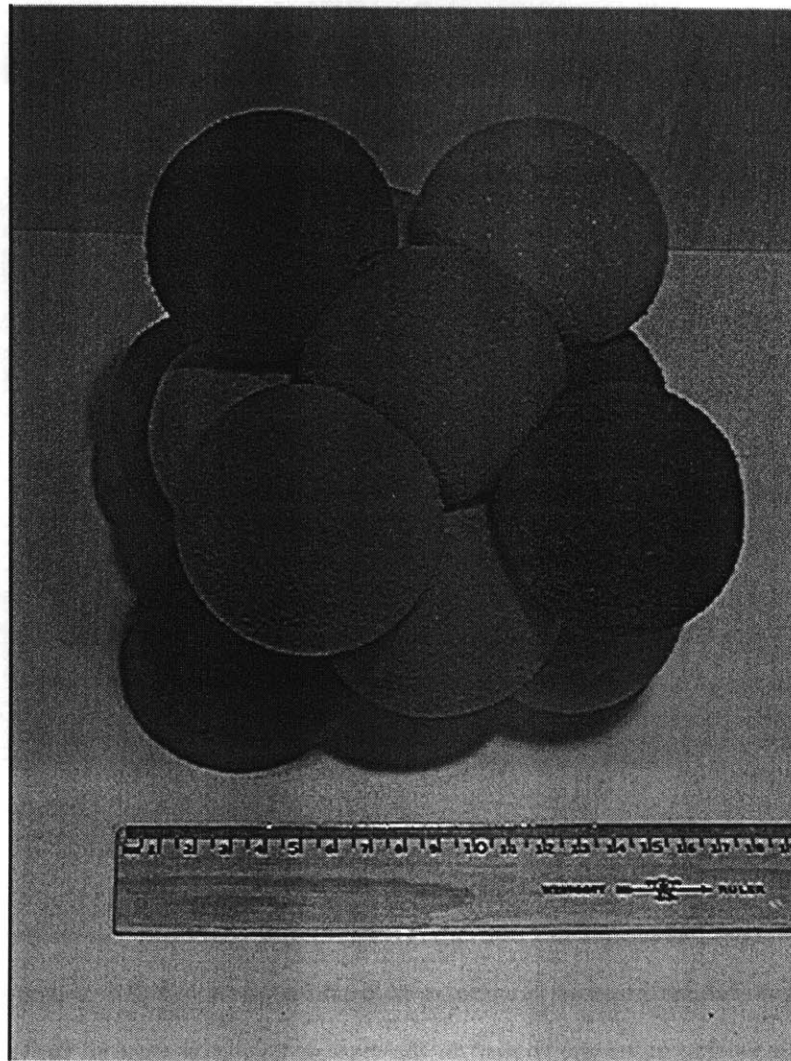


Fig. 2.8 : The squeezable foam ball cluster

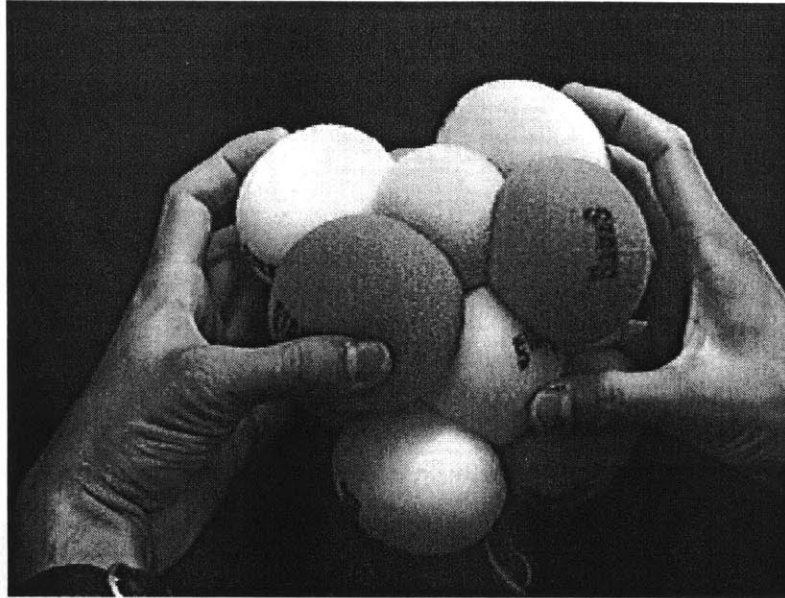


Fig. 2.9 : Holding the squeezable foam ball cluster



Fig. 2.10 : Squeezing the squeezable foam ball cluster

The foam ball cluster has been a very successful *Squeezable*. The sensor cube is able to detect not just direct pressure from foam balls sitting on it, but also pressure caused by the foam balls used to fill up the “holes” in the cluster. This is because all the foam balls are glued to

their nearest neighbors, creating an interdependency among the balls, i.e. pushing a ball will affect the sensors of neighboring balls. This version is also soft, comfortable and lightweight.

The next step was to test the *Squeezable* during the MIT Media Laboratory's bi-annual sponsor meeting and open house. Many people came by and did many different things to the *Squeezable*. They did more than just squeezing the cluster, e.g. hugging, rolling, throwing, shaking and stretching.



Fig 2.11 : A girl squeezing the cluster

After the open house and user testing, I have collected some observations and feedback from users. The summary of these observations :

1. the foam tears and progressively flakes off when squeezed
2. the sensors are not responsive when only one ball is squeezed
3. the sensors used are flat and only sensitive in one axis
4. only one person can play with it at one time

These observations and feedback led to the development of the next version of the *Squeezable* called the *Pole of Squeezables* which will be discussed in the next chapter.

The Analog-to-Digital Converter and electronic circuit for the sensor cube

The I-Cube Digitizer

The I-Cube (Figs. 2.12, 2.13) is a MIDI based 32-channel analog-to-digital converter from Infusion Systems, Inc.. It came with a library of tools for Opcode's Max graphical programming environment. These tools give full control of the digitizer's sampling rates, resolutions and channels.

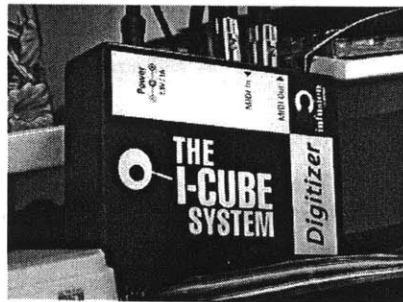


Fig 2.12 : The I-Cube digitizer

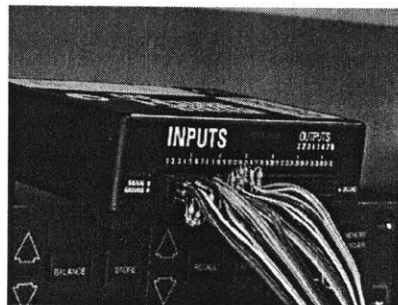


Fig 2.13 : Input sockets of the I-Cube

The electrical circuits

Since the value of one FSR can vary from open circuit to as low as about 2 kilo-ohms, I have put it in series with another resistor R_2 (47 kilo-ohms) to form a potential divider below :

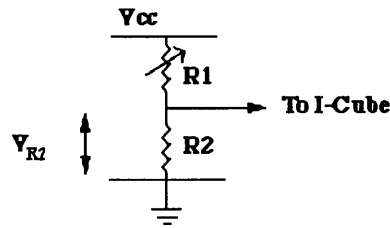


Fig. 2.14

The I-Cube has a supply voltage of 5 Volts for each channel of input and this is used to supply the potential divider with power. The voltage measured by the digitizer is governed by the following equation (Eq. 2.1) :

$$V_{R2} = \frac{V_{\alpha}}{\left(1 + \frac{R_1}{R_2}\right)} \quad \text{Eq. 2.1}$$

where V_{R2} is the voltage measured, V_{α} is the supply voltage of 5 Volts, R_1 is the resistance of the FSR and R_2 is the resistance of the fixed resistor (47 kilo-ohms) in series. When the FSR value is infinite, i.e. open circuit, the digitizer will not sense any voltage, giving a zero value. When squeezing is at maximum, the FSR will have about 2 kilo-ohms of resistance and the voltage measured will be about 4.8 Volts, giving a MIDI value of about 122. The range of MIDI values obtained will be used in Max for mapping musical notes and control values to synthesizers.

Chapter 3

Pole of Squeezables

After the testing of the squeezable foam ball cluster, several observations led to the development of the pole of squeezables. Here, the design and construction of the pole station is described.

Lessons from the cluster

The most important lesson learned from the squeezable foam ball cluster is the desirability of “group play.” The cluster cannot be played by more than one person at a time, causing people to queue up to wait for their turn to play with the *Squeezable*.

The next version of the *Squeezable*, called the *Pole of Squeezables*, has all the little squeezable balls on top of a pole as a group but they can be separated. Each and every ball can be squeezed independently. This way, the cluster configuration is still preserved and at the same time, it is possible to reshape the cluster into many different shapes. With the cluster that can be separated, a group of people can play the *Squeezable* together and not have to wait in line.

Since the cluster is now on top of the pole and the balls separable, it makes sense to let people pull the individual balls from the pole or station. The elastic bands that hold the balls together pull them back when they are released from pulling.

To prevent the foam balls from tearing and flaking off, they were wrapped in cloth. This layer of colorful and decorative cloth not only protects the foam, it also gives the balls a much nicer feel when touched.

The height of the pole was made to be about 117 cm or 3 feet 10 inches from the floor so that users could just walk up to the pole and place their hands on the *Squeezables*. The outer diameter of the pole was 8 cm and it was made of thick (about 3 mm) cardboard material.

The sensors/sensing techniques and construction

In order to detect the pressures applied on each and every ball, all of them needed to have pressure sensors embedded. The first idea that came along was to use a little balloon filled with air (a bulb) that attached to an air pressure sensor and was buried in the ball.

However, the bulb will always have some amount of pressure when it is inside of the foam ball because it needs to be positioned at the center. Furthermore, air pressure sensors are precision sensors that are very sensitive to the slightest change in pressure and will always need to be recalibrated for “no squeezing.” This is a disadvantage because I wanted the sensors to have a zero value or some constant value when the balls are not squeezed.

This led me to make a “sensor block” which consists of five 8mm FSRs (Fig. 2.4) at one end of the block (Fig. 3.1).

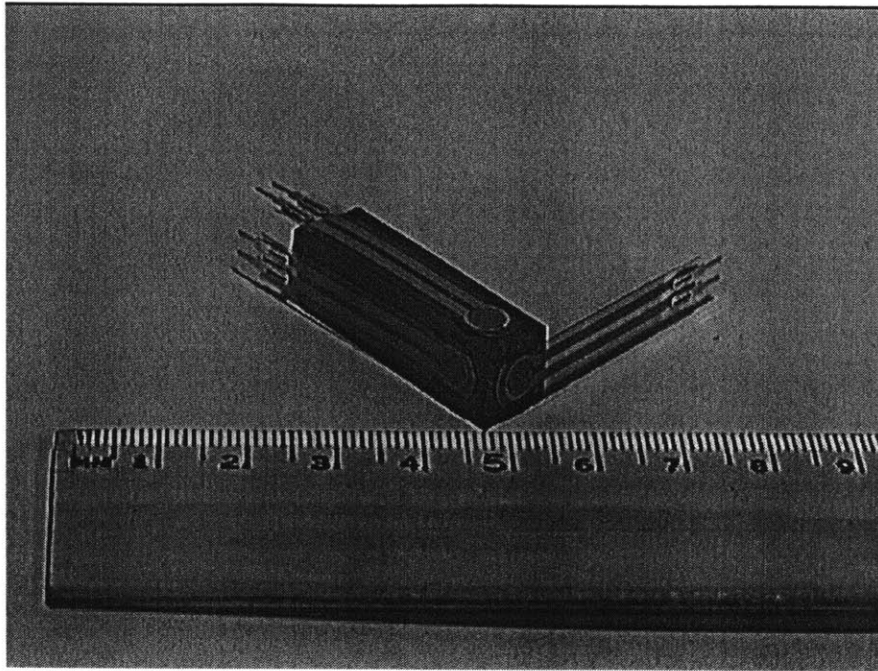


Fig. 3.1 : The sensor block with five 8mm Force Sensing Resistors

The five FSRs at the tip simulate the shape of the air bulb and the length of the block serves as protection for the sensor's body and connection. This sensor block is then embedded into the cloth-protected foam ball with the top of the block in the center of the ball. The FSRs are connected in parallel to one another electrically so that they all act like one pressure sensor.

Since the FSRs are less sensitive when compared with the air pressure sensors, they will not require calibration and will give zero values when there is no squeezing. Another advantage is that since it does not use air, there is no air leakage problem to take care of, making it virtually maintenance-free.

To sense the pulling of the balls from the top of the pole, the original idea was to use a strain gauge. This was too expensive so I came up with the idea of using the 18mm FSRs in a reverse direction. By placing an FSR on a flat surface with some holes around the FSR and a short wire loop, the pulling can be sensed by attaching the elastic band from the ball to the back of the loop (Fig. 3.2). The pull on the loop from the back will push the FSR in front.

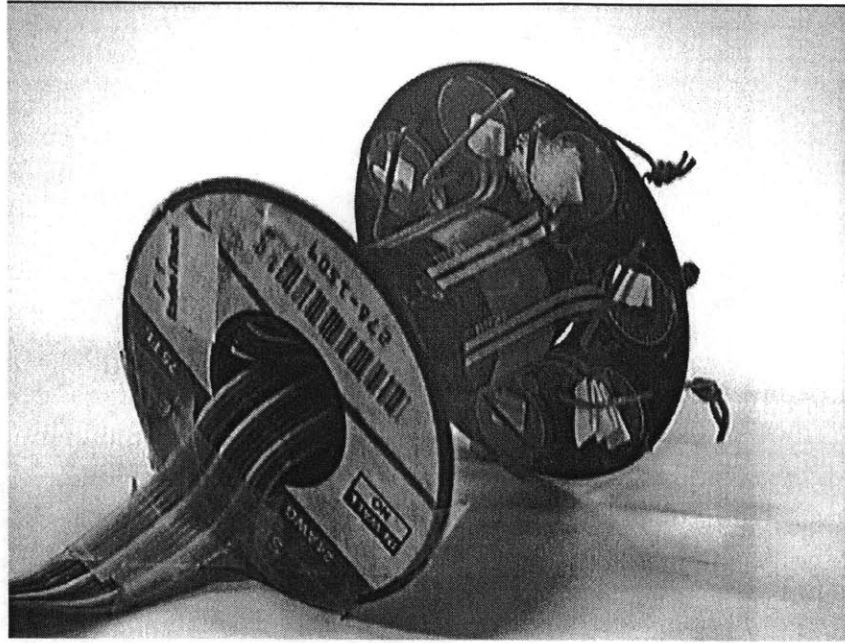


Fig 3.2 : The converted FSR pull sensor assembly

This pull sensor assembly is installed at the base of the tube in a frame. The top of the frame holds the tube steadily through a PVC closet flange (Fig. 3.3) which is screwed down tight onto the frame.

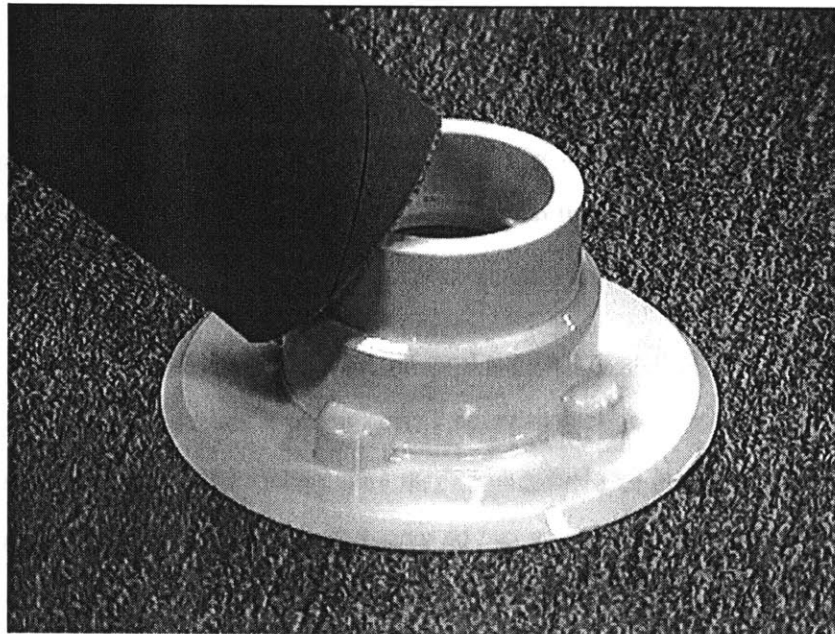


Fig 3.3 : Coupling the tube onto the closet flange

The wires of the balls are then tied at mid-way down the tube with elastic bands to the pull sensors below. When the balls are not pulled from the top of the pole, the elastic bands are not stretched. When they get stretched from pulling, this will pull the wire loop, applying pressure to the FSRs.

To prevent the wires and elastic bands from tangling up inside the pole, the inside of the pole is partitioned using 7 smaller plastic tubes bundled together forming a “machine gun” (Fig. 3.4). The size of these smaller tubes is about 2 cm in diameter.

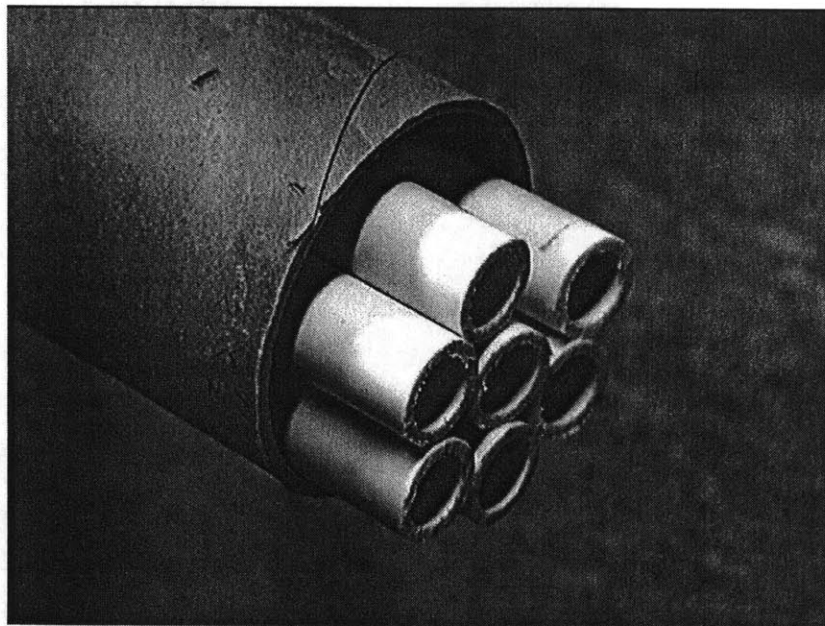


Fig 3.4 : The partitioning tubes in the main tube

When the whole tube assembly is put together with the base frame, it will stand by itself on the floor (Fig. 3.5). The pull sensor is installed at the base of the frame (Fig. 3.6) by two pieces of nylon blocks with the wire loops facing up. With the squeezable balls on top of the pole, the elastics from the wires are then tied to the wire loops of the pull sensor in a way that they are just released. The *Pole of Squeezables* is then decorated by a piece of cloth wrapped

around its body and the players will stand around the pole to squeeze and pull (Figs. 3.7 and 3.8).

The FSRs in the balls and those in the pull sensor assembly are connected to potential bridges (Fig. 2.14) with a 5-Volt power supply and are governed by Eq. 2.1. The output from the bridges are connected the different channels of the I-Cube digitizer (Figs. 2.12 and 2.13) as in the squeezable cluster in Chapter 2. There are fourteen channels of analog signal all together, seven from the squeezing and another seven from the pulling.

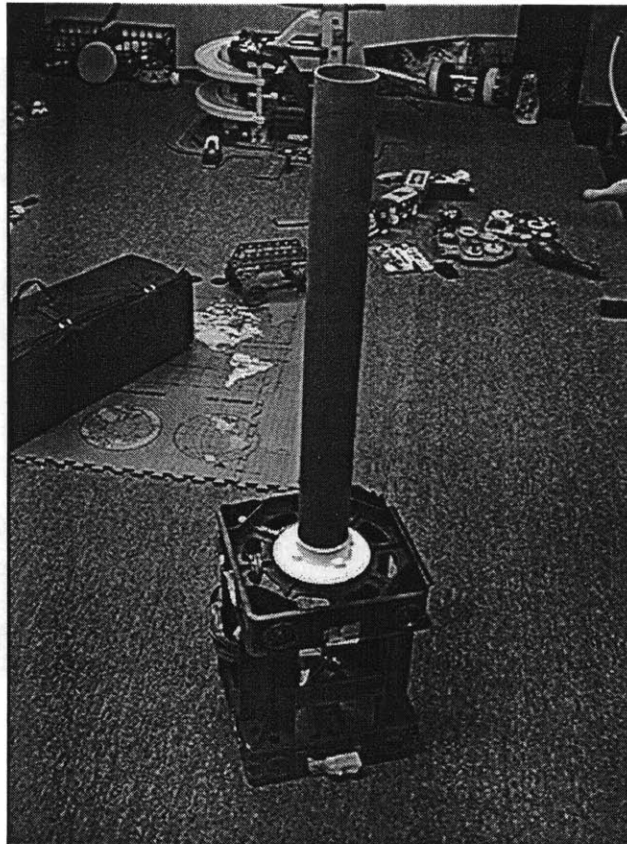


Fig. 3.5 : Pole coupled to frame

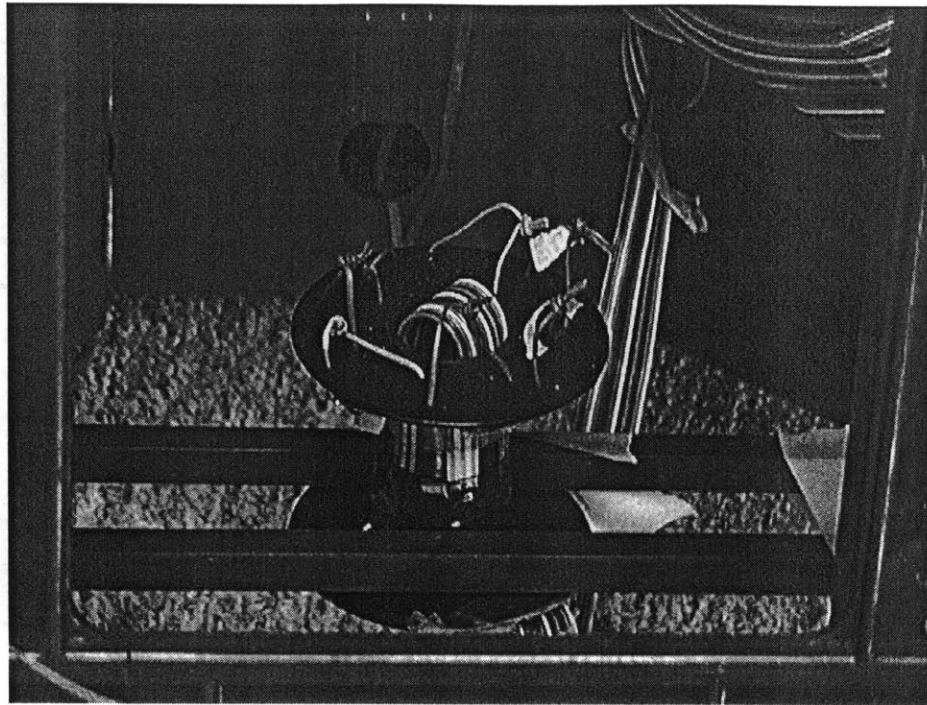


Fig 3.6 : Pull sensor at the base of the pole frame

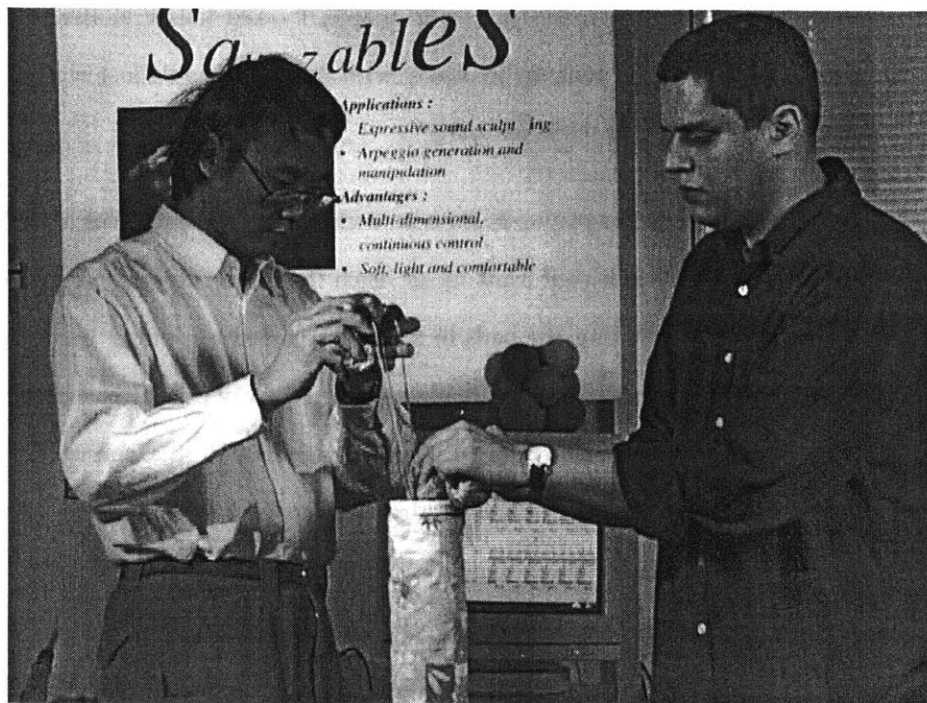


Fig 3.7 : Pole of Squeezables

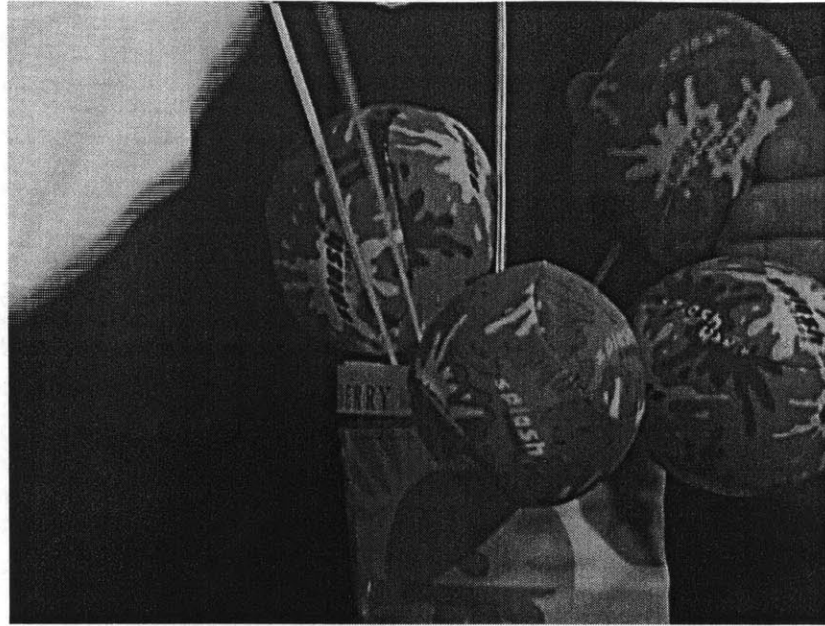


Fig 3.8 : Close up of the Pole of Squeezables

User testing and lessons learned

To test the *Pole of Squeezables* out with people, I asked fellow students, faculty and staff members from the lab to come by and play with it. Many people just walked up and started squeezing and pulling the balls naturally.

However, when children played it, it became clear that the pole was actually too high for them. They had to stretch their arms up to reach the *Squeezables* and could only pull them to the sides, not up. Pulling the balls to the sides instead of pulling them up damaged the wires after a while. Another observation about the sideways pulling is that the pole started to become unstable because the base was not heavy enough to counteract the horizontal pulling force. To prevent this, I had children or shorter people stand on a raised platform next to the pole and I also added some weight to the base to stabilize the pole. Even with this inconvenience, the children liked the *Pole of Squeezables* and said it was a different kind of music playing experience than they had ever had. They could stand around, watch one another and also dance with the music/sound generated.

Another issue that came up from user testing is the softness of the foam balls. Many people find that the foam balls are too soft when compared to a cluster of foam balls. This softness of the balls also meant that the users have to squeeze a long distance, almost like collapsing the ball, before their squeezing can be measured by the sensor block.

There were some comments saying that the pole looked strange and “phallic” from a distance because of its shape, color and height.

For the elastics that pull the balls back to the top of the pole, since I used rubber bands, they deteriorate after a while and have to be changed regularly.

Here is a summary of the lessons learned :

1. pole is too high for short people
2. pole is not stable
3. wires get damaged from side pulling
4. rubber bands break easily
5. foam balls too soft for individual squeezing

These lessons led to the development of the next version of the *Squeezable* called the *Table of Squeezables* which will be discussed in the next chapter.

Chapter 4

Table of Squeezables

Both the lessons of the squeezable cluster and pole of squeezables have led to the making of this very unique table of squeezables. It is not only made for adults, but also made in such a way that both children and adults can enjoy squeezing and pulling in the same place and at the same time. What is more, it looks like a magician's table.

Putting it all together

With the experience from building the squeezable cluster and *Pole of Squeezables*, the *Table of Squeezables* was built to assume the various characters of the previous versions and also to answer some of the problems raised.

The very first issue raised in the *Pole of Squeezables* is the height. Here, the height is reduced to about 40 cm and the diameter of the table is about 70cm. This height accommodates both adults sitting on chairs or the floor and also children standing by the side of the table. Since the center of gravity of the structure is drastically reduced and also the weight of the wooden barrel is great, it is very stable as compared to the *Pole of Squeezables*.

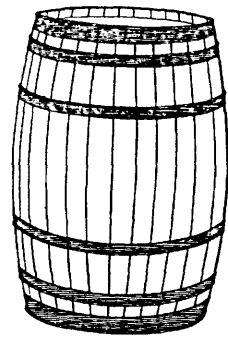


Fig. 4.1 : A wooden barrel

The table is made from a wooden barrel (Fig.4.1) that has been cut into two halves. It was bought from a nursery where it was sold to be used as an over-sized planting pot. The table top is sunken in by about 4cm with a combination of wooden and iron rim. To raise the table top above the level of the side rim, a cut-to-shape round foam pad was used. This made a soft table top which was more comfortable for hands to rest on than a hard table top.

I decided to use six squeezable balls laid at the center of the table top. Six is a good number because that way, there are not too many balls crowding the table top and also not so few that the table top would look empty. The six balls were arranged in a triangular formation but they can also be rearranged into other formations since only one point of each ball is tied down by the cable/wire.

There are six holes in the triangular formation (Fig. 4.2), one underneath each ball, that let the cable through into the table for sensors and mechanical construction.

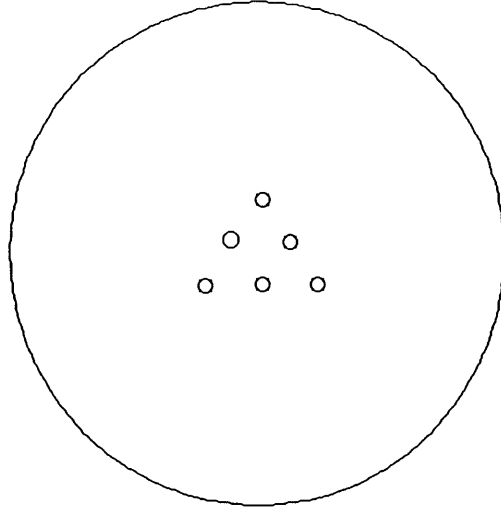



Fig. 4.2 The six holes in triangular formation

Why did I place the balls at the center of the table ? Why not next to or along the rim/side of the barrel ? The main reason for this decision is that with the balls in the center, they can still be a cluster. This is good because, instead of just squeezing two balls with two hands, a person can still squeeze all the balls collectively as a cluster. The fact that these balls can be lifted from the table and pulled a short distance from one another, the shape of the cluster can be changed, from anything symmetrical to very irregular shapes. Another advantage of this is that when more than one person plays, the balls can be separated easily for two pairs of hands. With the balls at the side/rim, all this would not be possible.

Materials for the balls

The squeezable balls here use jelly or gel-like material. It is in a crystallize state and not in a liquid state so that it will not flow like liquid. However, the gel material becomes wet and sticky eventually when its crystalline structure is destroyed by excessive squashing or smashing.



The change in material makes the balls feel more “organic” :

1. it has weight
2. when squeezed on one side, the balls will bulge out from another side, i.e. will not collapse like foam
3. when squeezed on the whole, there will be more resistance from the gel. This is because when the gel cannot be displaced, it has to be compressed.

These gels are wrapped in latex membrane to prevent leaking and the latex layer is in turn wrapped by a decorative and colorful cloth.

Cables/wires

The wires on the *Pole of Squeezables* were too weak to take the constant pulling and scraping from the sides. Here I used coaxial cables. Coaxial cables are thin and also reinforced by a woven copper sheath underneath the insulation which makes them more durable and resistant to stretching.

Squeeze sensors and sealing of balls

The squeeze sensor here is also the sensor block (Fig. 3.1) used in the *Pole of Squeezables*. Since the sensor block has to go into the ball, the gel material is cut away by inserting a hollow block that is of the same dimension as the sensor block. This will create a block-like opening in the gel without destroying it. The sensor block is then inserted all the way into this opening. At the bottom of the sensor block where the cable will come out, a little length of the cable is left between the block and the cable knot. This knot is done by tying the cable

onto itself. The knot is necessary so that it will act as a frontier to the pulling of the ball without transmitting any movement to the sensor block which may cause it to damage the gel. This way, the sensor block is completely stationary relative to the gel around it. Previous experiments when the sensor block was left moving within the ball showed that in this mode, the gel gets destroyed and severe leaking problem develop.

After the insertion of the sensor block, the knot is left in between the latex layer and the cloth layer. Both layers are sealed by sewing (Fig. 4.3).

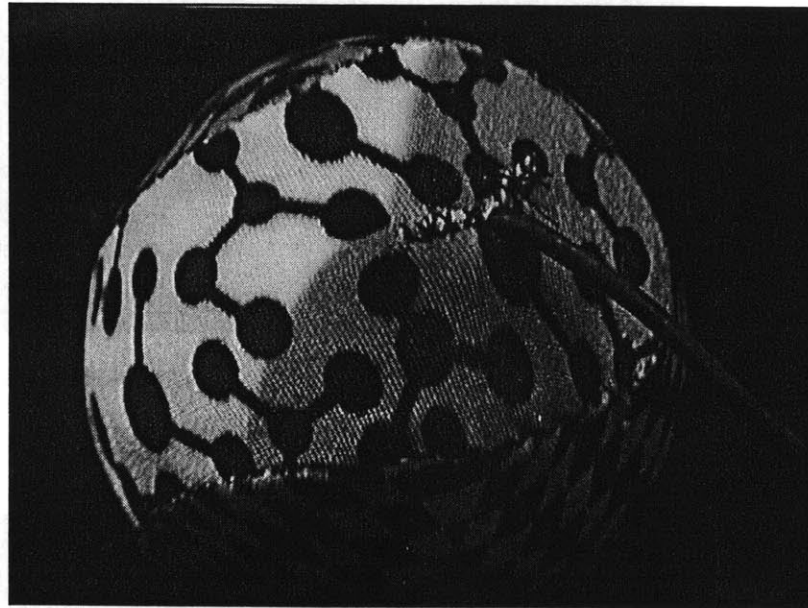


Fig. 4.3 : Ball sealed by sewing

Sensing the pull

To sense the pulling of the balls from the top of the table, the coaxial cable that holds the ball is tied to a 10 K ohm variable resistor slider (Fig. 4.4). The travel length of the slider is 10 cm. To get the ball to return to the table top automatically, the slider is tied to a piece of elastic (Fig. 4.5). This elastic is the type used for making the stretchy parts of wearable items like underwear and beach wears. One end of the elastic is tied to the base of the T-shaped holder (Fig. 4.6) underneath the table which holds all the sliders. The T-shaped holder is held under the barrel by six screws from the top.

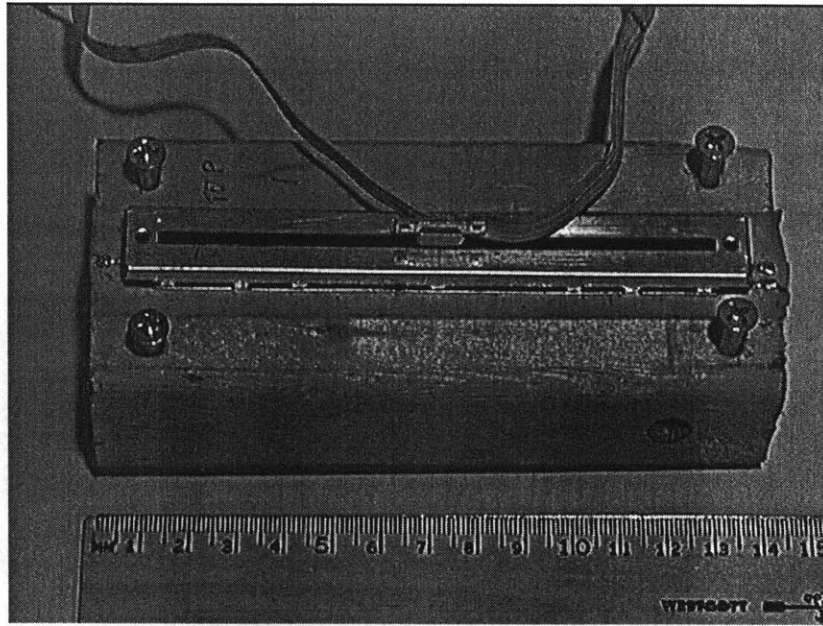


Fig. 4.4 : The variable resistor slider and with elastic band



Fig. 4.5 : Slider head tied to the elastic

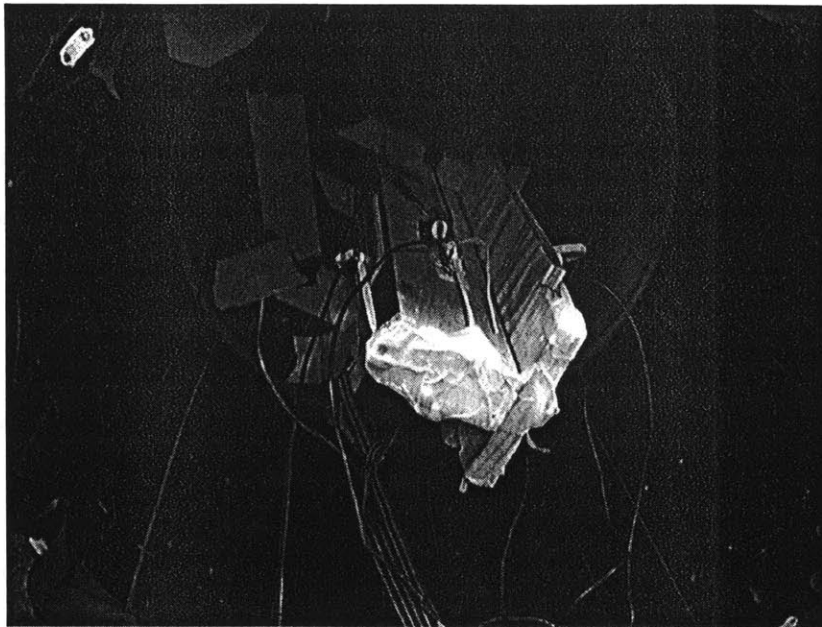


Fig 4.6 : End of elastic tied/taped to the base of T-shaped holder

The “magician’s” table

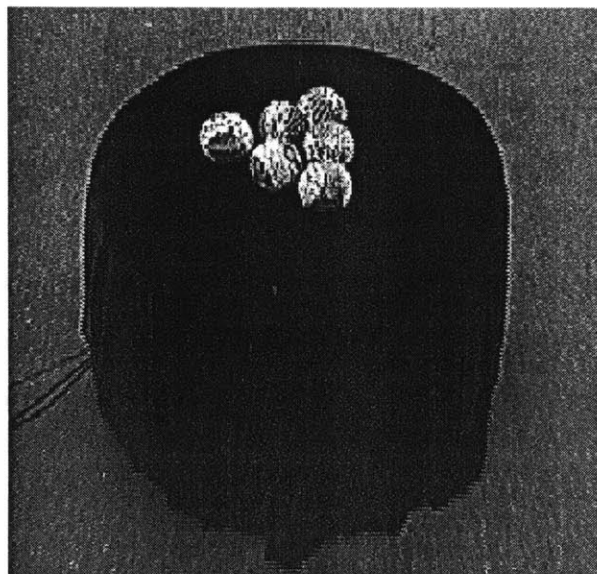



Fig. 4.7 : The *Table of Squeezables*/magician’s table



Together with the foam pad on the table top, the whole wooden barrel was covered with a black-colored velvet cloth that was smooth across table surface and wrinkled on the sides.

Initial feedback from people suggested the *Table of Squeezables* looks like a magician's table [WebVideo1]. After construction, the table underwent testing during the bi-annual sponsor visit open house of the lab. Many people, senior and very young, including my 2-year old son (Figs. 4.7 and 4.8), came and played with the *Table of Squeezables*.

Gil Weinberg, who is a fellow graduate student and also a musician, composed a piece called "*Squeezadelic*" [Wei98] utilizing an extensive mapping he did in Max for the *Table of Squeezables* for three performers.

"*Squeezadelic*" allowed each of the three performers to squeeze and pull two *Squeezables*. Each *Squeezable* has its own character. For example, sine-wave sounds like the *theremin*, voice-like sound like "wohh-wohh", rhythm generation with percussion instruments and random melodies with piano sound. All the *Squeezables* are interdependent among one another. For example, each *Squeezable* will change the mapping parameters of the others. The change in parameter mapping is done to a limited degree so that no one *Squeezable* can entirely control the others.

One unique feature of this musical instrument is that it can be played by more than one person at the same time. Myself, Gil Weinberg, and another fellow graduate student, Teresa Marrin, became the pioneer performers of this score and had a 6-minute performance on video tape for the prestigious Ars Electronica competition for 1998. This performance demonstrated that the *Table of Squeezables* can be used as a serious musical instrument. In this case, three performers played on the same musical instrument (Figs. 4.9, 4.10 and 4.11).



Fig : 4.7 : My son, Cheng Hann, pulling and squeezing the *Squeezables*

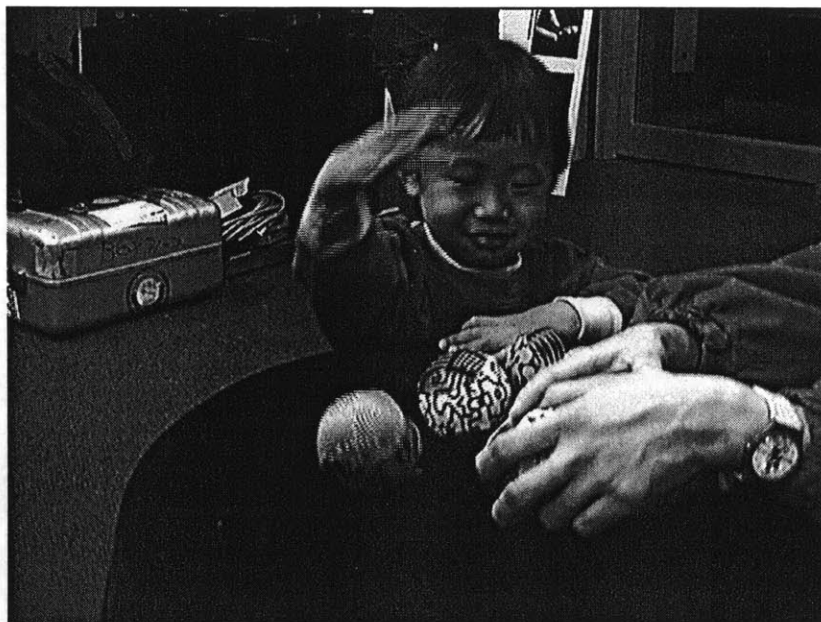


Fig. 4.8 : My son, Cheng Hann, pounding one of the *Squeezables*

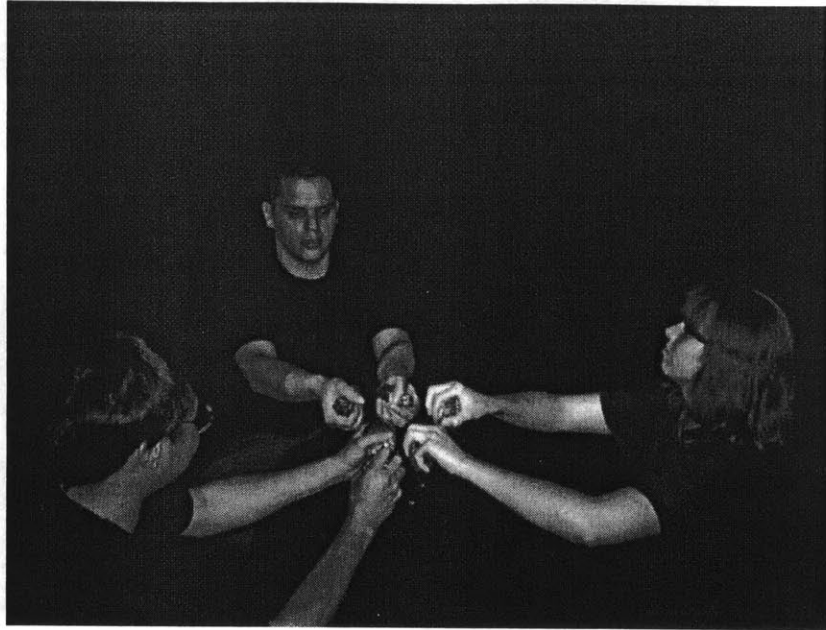


Fig. 4.9 : Three performers on the *Table of Squeezables* in "Squeezadelic"



Fig. 4.10 : Close up of the hands on the *Squeezables* in "Squeezadelic"



Fig. 4.11 : Top view of the *Table of Squeezables* with the hands in “*Squeezadelic*”

Chapter 5

The Digital Maracas and Musical Play Pen

Two alternative controllers were developed along with the Squeezables. One uses shaking while the other senses the overall human body movement, to complete the little "trio-able" of "squeezable", "shakable" and "swimmable" !

The Digital Maracas

The *Digital Maracas* [WebVideo2] is an alternative controller that utilizes the shaking movement of the hands. Anyone will be able to guess that it uses an accelerometer to measure the acceleration of the maracas. Typical one-axis accelerometers cost at least five US dollars each. They are housed in little metal casings with leads like integrated circuit (IC) chips. Two major drawbacks of these conventional accelerometers are that they all require a power supply and their output voltages are very small. Besides these disadvantages, one needs to build a circuit around the accelerometer in order to get useful signals.

A Very Cheap Way to Sense Acceleration

A typical piezo transducer (Fig. 5.1) is used as an output device in pocket pagers, cellular phones and the beepers in toys. It is essentially a very compact speaker made by sandwiching piezo crystals between two different metal plates (Fig. 5.2). Since the two metal plates are coupled together only by the piezo crystals, the outcome of this packaging made it possible for the Piezo transducer to sense mechanical acceleration. These crystals can be compressed and expanded when one of the plates is secured at the end of a moving stick. When one

swings the stick, the other metal plate that is not on the stick, due to momentum, compresses and expands the piezo crystals (Fig. 5.2), creating a voltage like a little generator. This is known as the piezoelectric effect. Unlike a conventional accelerometer, it does not need any power.

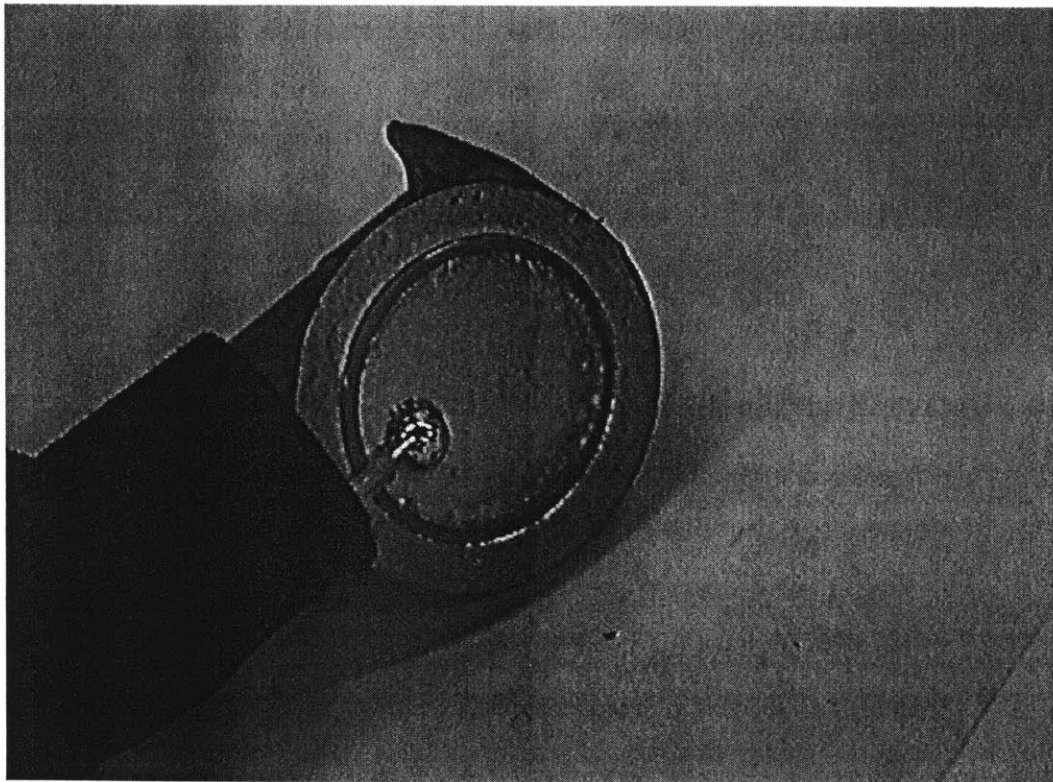


Fig. 5.1 A piece of piezo transducer

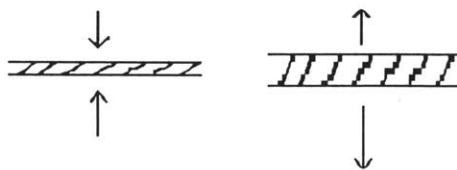


Fig. 5.2 Compressing and expanding the piezo crystals

The output voltage of a piezo transducer that is 2.5 cm in diameter can be as high as 200 mV. This means that, compared to conventional accelerometers, less amplification is required to achieve a usable signal and hence, less surrounding electronics are required.

Packaging the *Digital Maracas*

Using a nylon rod, the piezo transducer is secured on one end by means of tape and glue. Two wires run along the rod from the transducer to the other end (Fig. 5.3). The piezo transducer can then be covered by a decorated foam ball to look like the shell of a maraca (Fig. 5.4).

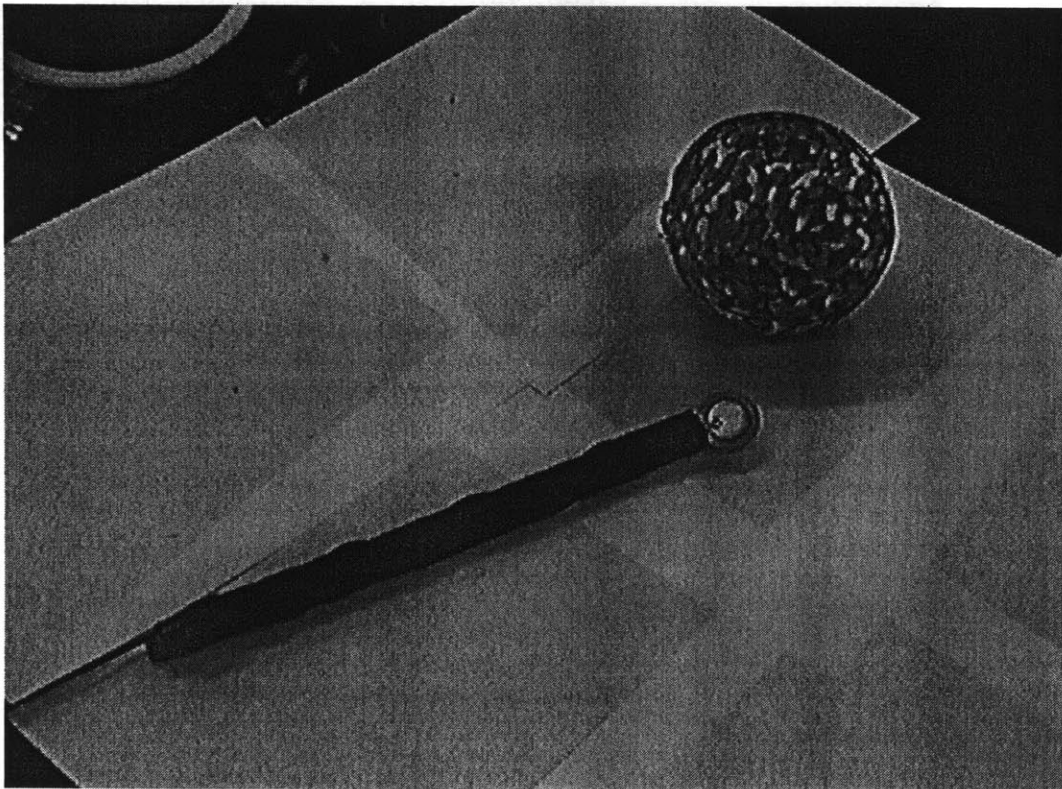


Fig. 5.3 Piezo transducer on the rod with wire

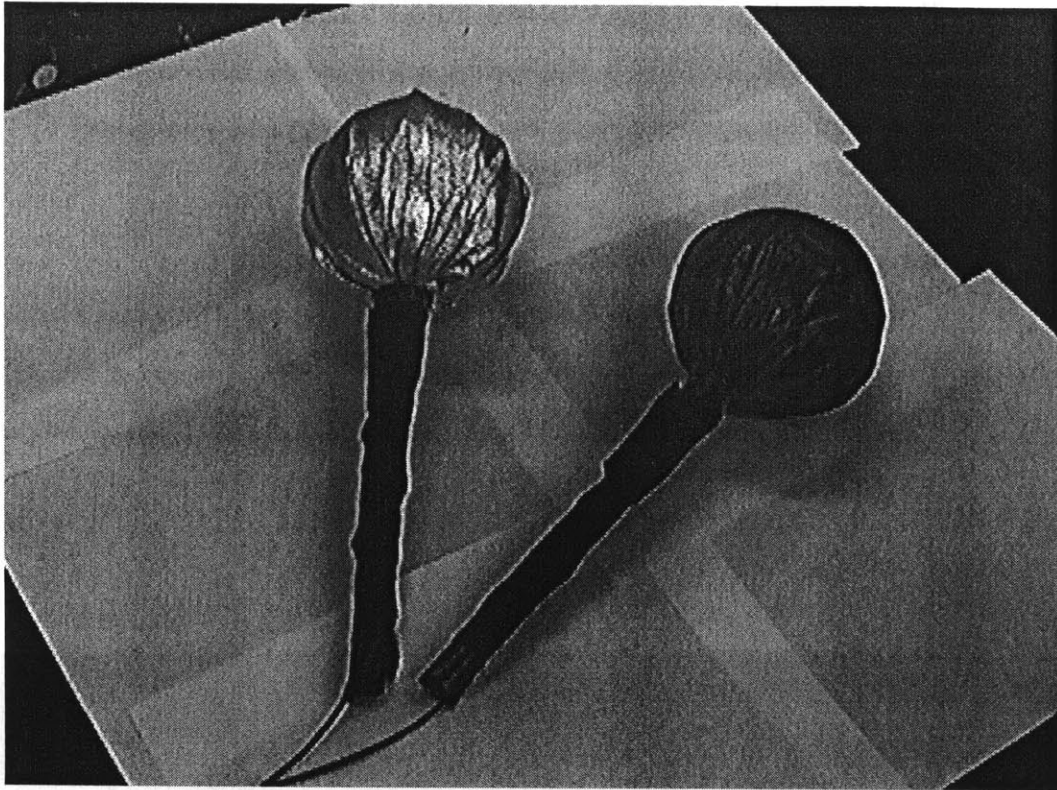


Fig. 5.4 Decorated *Digital Maracas*

The signal of the piezo transducer is then connected to the circuit in Fig. 5.5 for amplification and averaging to produce a bigger and smoother signal for the digitizer (Fig. 5.6).

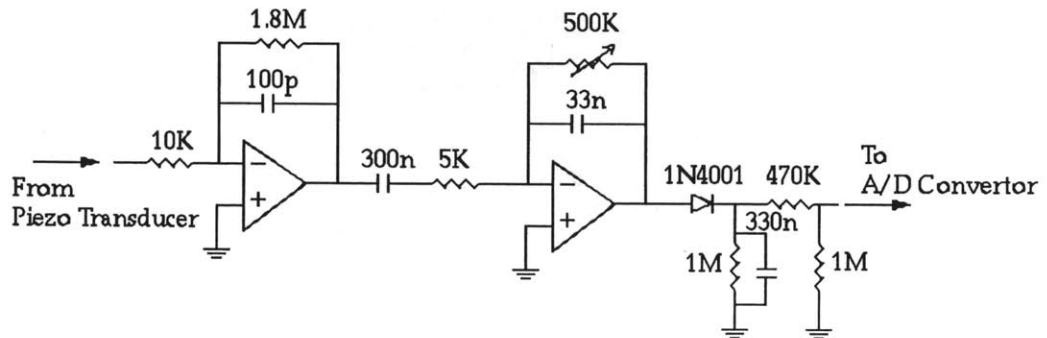


Fig. 5.5 *Digital Maracas* circuit for amplification and averaging

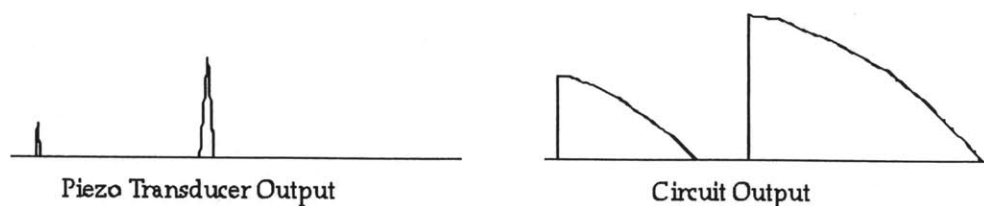


Fig. 5.6 Processing the raw signal to a useful signal

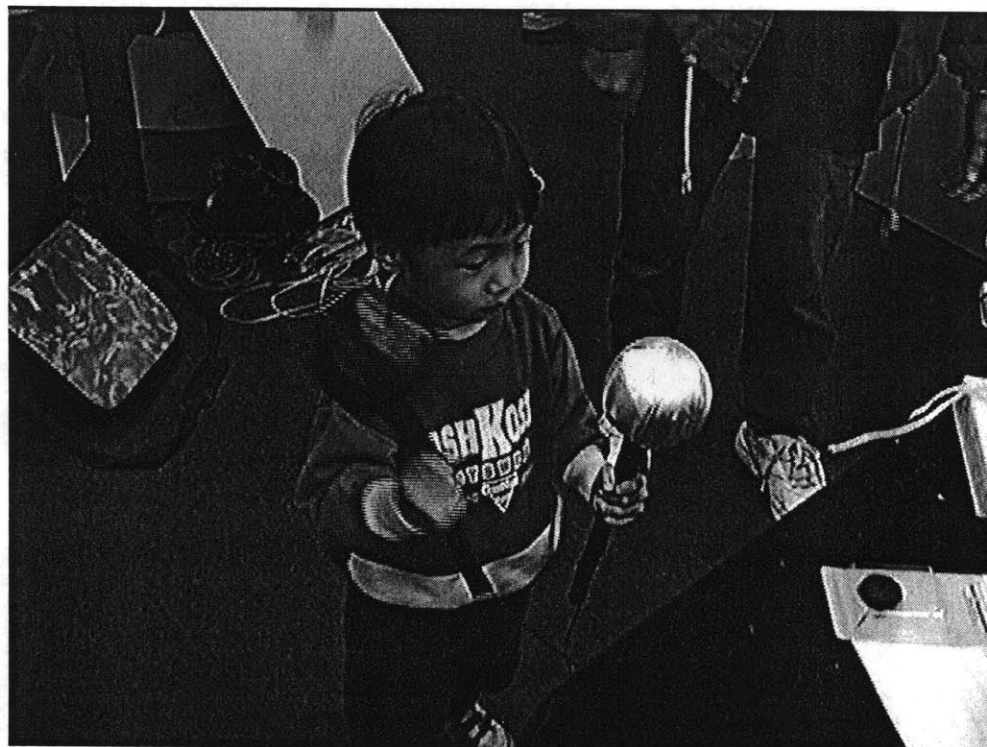


Fig. 5.7 My son, Cheng Hann, playing with the *Digital Maracas*

The Combo Maracas

The output from the *Digital Maracas* can be used to trigger a table of sounds or used as a control parameter to make an effects processor apply different amounts of effects to another sound. In Fig. 5.7, a PVC tube is used to house a microphone and a piezo transducer. Using different resonators (Fig. 5.8) like a coconut shell or a plastic light bulb housing, and also different types of beans, various kinds of sound textures can be produced. The microphone will pick up the inner acoustics of the resonator and the piezo transducer controls the amount of effects to add into the original sound, producing a rich variety of sound from raw to full effects.

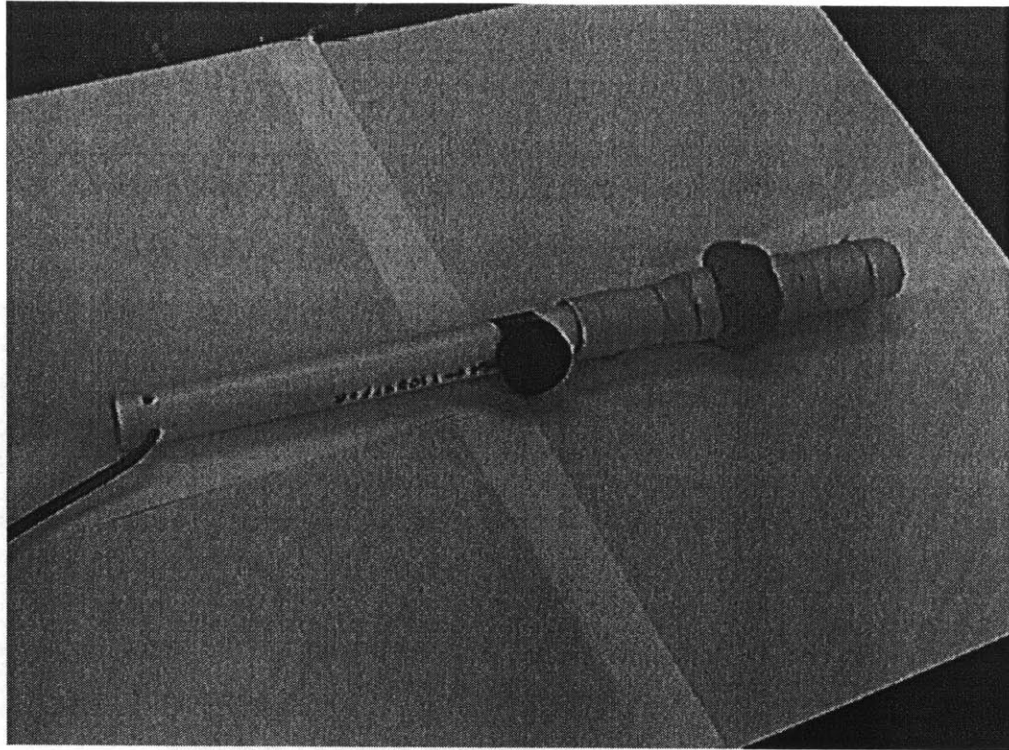


Fig. 5.7 The Handle of one of the *Combo Maracas*

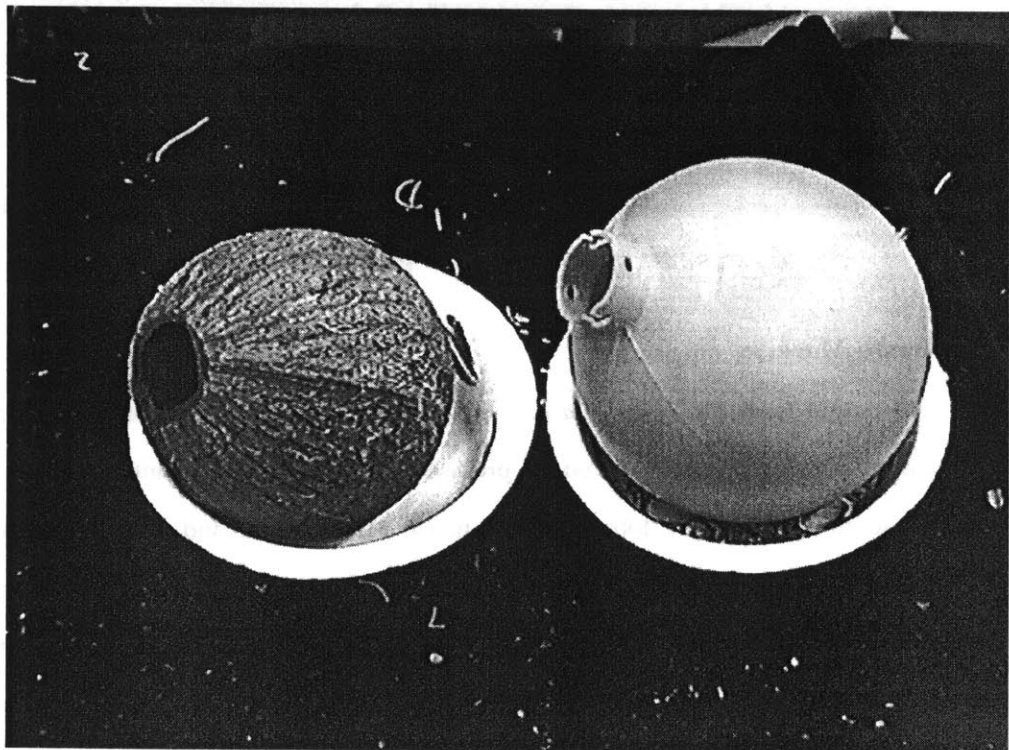


Fig. 5.8 Coconut Shell and Plastic Bulb Housing as Resonators

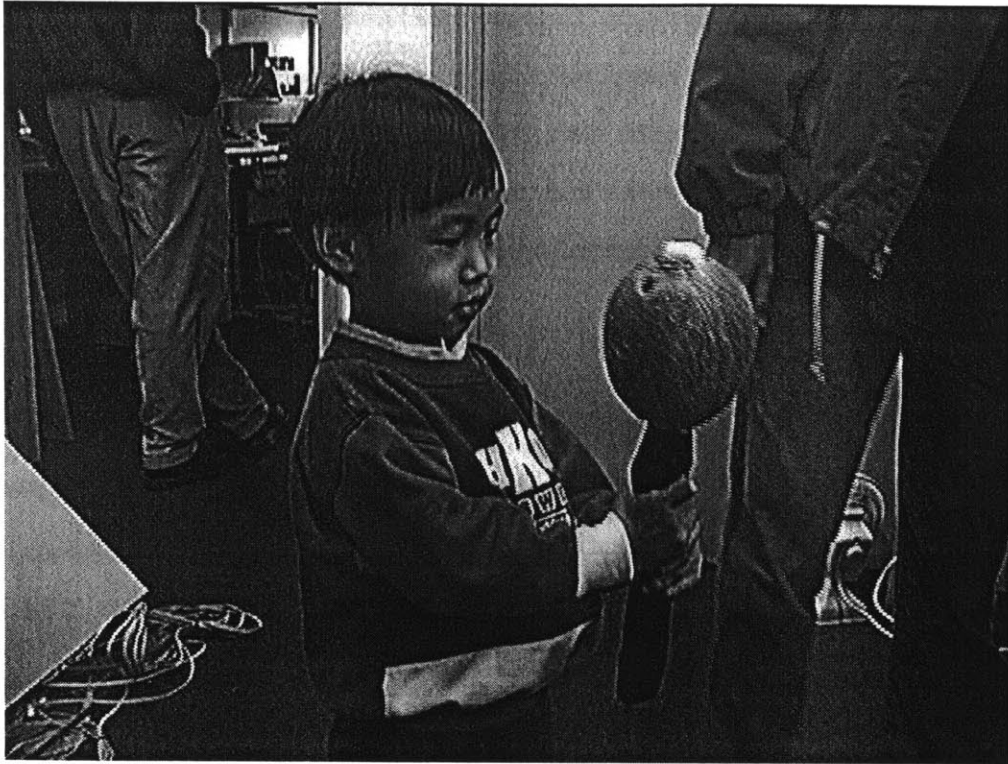


Fig. 5.9 My son, Cheng Hann, playing with one of the *Combo Maracas*

Musical Play Pen

With the collaboration of Gil Weinberg, I constructed an initial, scaled down version of the *Musical Play Pen* using a plastic ice cream tub. Gil suggested using M&M's chocolates to fill up the tub (Fig. 5.10). The tub is essentially a rough prototype to demonstrate Gil's idea of "composing through play." It has eight 18-mm Force Sensing Resistors (FSRs) (Fig. 2.4). When the hand of the player is immersed into the pool of M&M's and moved, the M&M's will strike against the wall of the tub and also the FSRs. This is mapped to a table of notes in Max and played.

After this prototype, a bigger version of this interface was built using a play pen filled with more than 400 pieces of ball-pit balls. Using the same sensor as the *Digital Maracas*, the *Musical Play Pen* has four piezo transducers, one at each corner of the play pen, forming

four quadrants of resolution. The piezo transducers are housed in the top ball of a chain of 3 balls (Fig. 5.11). The reason for chaining up a few balls is to prevent limbs from getting caught by the wires. When the balls in a particular quadrant are moved, only that region will be activated. If a child is in the middle of the play pen, he can use his limbs to trigger the different regions at different times or all the regions at once.

Fig. 5.12 shows my 2-year-old son, Cheng Hann, making music in the *Musical Play Pen*. [WebVideo3]

The circuit used for the piezo transducers is the same as that of the *Digital Maracas* (Fig. 5.5) with their outputs connected to the I-Cube digitizer controlled by a computer. The values taken are then used to play a table of notes. The music or sound comes from two speakers that are actually inside the play pen.

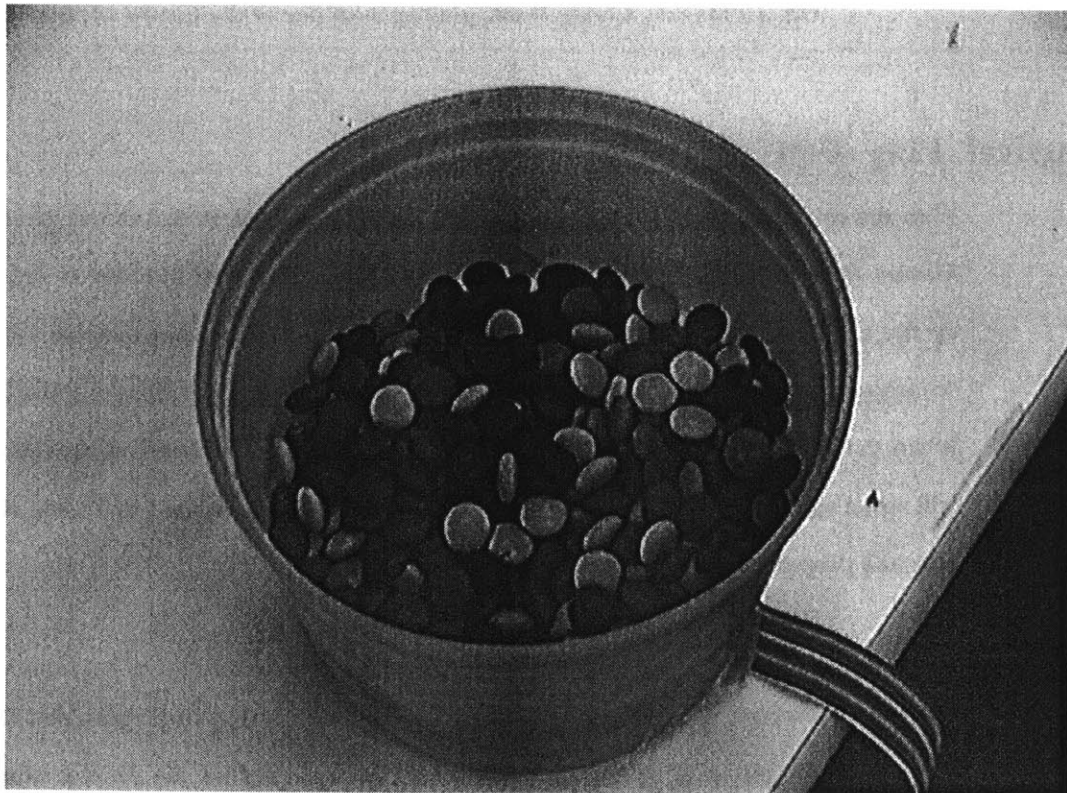


Fig. 5.10 M&M's music tub

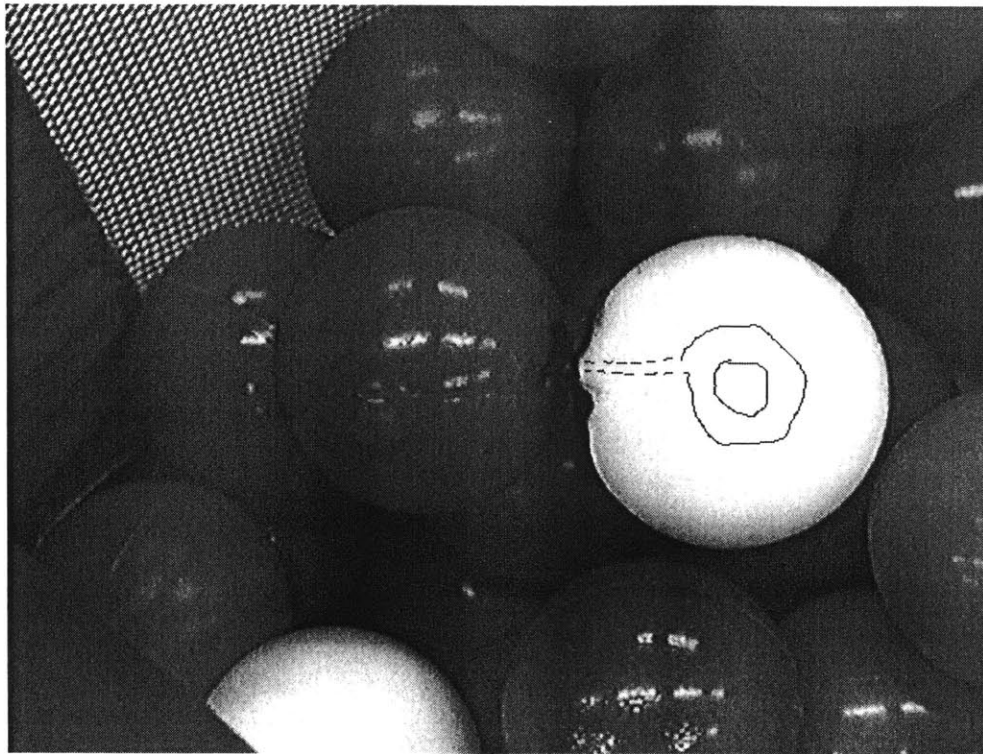


Fig. 5.11 Sensor location in the top ball



Fig. 5.12 My son, Cheng Hann, playing in the *Musical Play Pen*

Chapter 6

Applications

The applications very much depends on the choice of music synthesizers. Or, the choice of synthesizers depends on the applications. Which one is more important ? It all depends on what you want to do ! This chapter will describe two examples of applications for the Squeezables.

Sound Sculpting, sound shaping

The first application of the *Squeezables* that came to mind was to shape sound. But how do we want to shape the sound ? One idea is to change its Fourier spectrum or timbre. Since there are many ways of changing the characteristics of a sound, I had to look for a suitable sound synthesis method that allowed me to manipulate its parameters to produce noticeable changes.

With the squeezable cluster, I have six different continuous controls that give me MIDI values from 0 to 127. The Yamaha VL-1 was chosen at the beginning because it has at least eight parameters for each and every sound it models using acoustic modeling. One disadvantage of the controls of the VL-1 is that besides the usual pitch shifting and tremolo effect, the other controls are all too subtle to be perceived, rendering it not a suitable synthesizer to use for sound sculpting.

I also considered the possibility of using the Yamaha SY-77 synthesizer, which is based on Frequency Modulation (FM) [Cho73] synthesis. The controllable parameters are the carrier

and modulator frequencies and also the modulation indices. Although FM synthesis can give very noticeable timbre changes, with only FM synthesis available, the sounds generated are very “FM” and noise-like.

In collaboration with Gil Weinberg, the Nord Lead [Cla97] “Virtual Analog” synthesizer was chosen. The Nord Lead is basically a simulated analog synthesizer with MIDI controls to the parameters of its filters and oscillators [Moo65]. FM synthesis can also be done by making the right connections between oscillators. Furthermore, each and every channel of MIDI in the Nord Lead can be assigned different patches to do different sets of analog synthesis, making it possible to generate 16 different sounds with real-time changes of their timbres. All the analog synthesis in the Nord Lead is done digitally making it a very powerful MIDI controllable sound module. It is well suited to our sound sculpting or sound shaping application.

After we chose to use the Nord Lead for the sound sculpting, the next step was to do the mapping. We used a graphical programming environment for MIDI called Max [Opc95].

After experimenting with the parameters and values on the Nord Lead, Gil determined and recommended that the best controls to use are frequency, resonance, FM amount, pitch bend, semi-tone, arpeggio rate, arpeggio range and morph wheel. These parameter names are exactly as labeled on the Nord Lead. The frequency parameter controls the fundamental of the note; resonance sets the frequency of the peak in the filter spectrum; FM amount is the modulation index of the FM generator; pitch bend is the shift in the fundamental frequency; semi-tone is the tuning between the carrier frequency and modulator frequency in FM; the rate of change is the frequency of the LFO (Low Frequency Oscillator) or “the speed of the vibrator;” arpeggio rate is the speed of the built-in arpeggio generator; arpeggio range is the range of notes of the arpeggio generator; and morph wheel is the control to blend or “transfer” between two sounds generated by the Nord Lead or the continuous fade between two sounds. These parameters are interdependent among one another because of the fact that we are only changing the timbre of one note.

I wrote and designed many Max objects that control the various parameters Gil recommended. There is also a limit patch I called FSRXlateTimbre that makes sure values used are not beyond the boundaries defined earlier. This object is used many times in the main Max patch called Nord Lead Timbre Demo. They are tied in between the output values from the digitizer and the controllers for the Nord Lead.

Gil then used the main Max patch to select and tune the parameters for the Sound Sculptor, and we both became the judges for the sounds produced during the active squeeze test sessions.

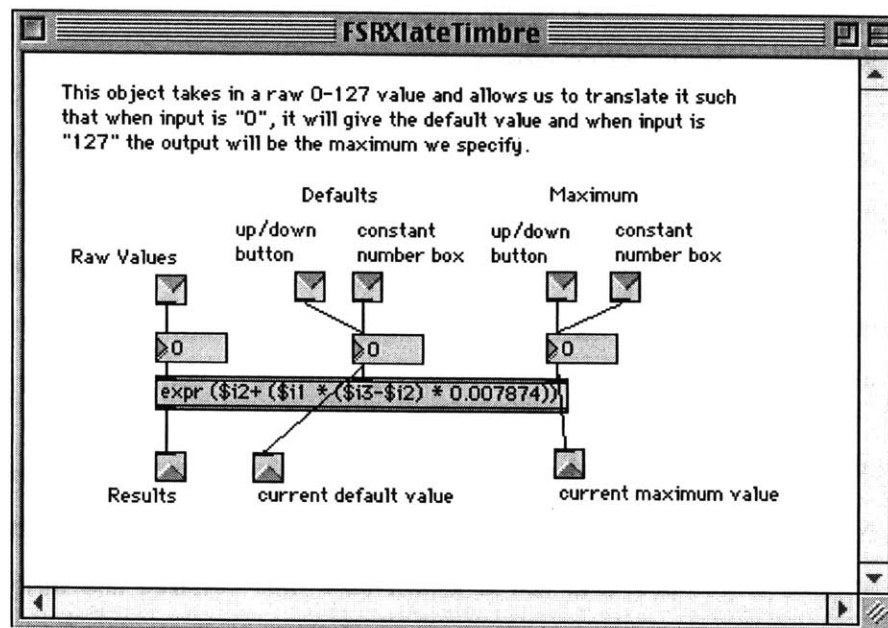


Fig. 6.1 : FSRXlate Max patch

The FSRXlateTimbre Max patch

This Max patch takes in three values. The first value it takes in, "Raw Values" or \$i1, has a range from 0 to 127. It is then scaled to be between the "Default" or \$i2 and "Maximum" or \$i3. This is done by dividing \$i1 by 127, which is the same as multiplying by 0.007874. This result is then multiplied by the difference of the "Maximum" and "Default" which is then added to the "Default". This yields the effective range of numbers with the new boundaries.

The Nord Lead Timbre Demo Max patch

This is the main Max patch which controls everything in the sound sculptor (Fig. 6.2).

In this patch, there are the START and STOP buttons which start and stop the I-Cube digitizer and also the Nord Lead synthesizer. When the START button is pressed, the I-Cube digitizer will start the A/D conversion of the specified channels and we will see the values in the various number boxes change as we squeeze the cluster. These numbers are passed through to the various FSRXlateTimbre sub patches that will scale the incoming values into a range of values between the “default” and the “maximum.” For example, for the “FSRXlateTimbre 1” sub patch for “Freq,” the minimum and maximum values the patch will produce are 40 and 127 respectively.

The controller numbers for frequency, resonance, FM amount, arpeggio rate, arpeggio range, morph wheel, semi tone and mix of oscillators 1 and 2 are 74, 42, 70, 23, 25, 1, 78 and 8 respectively. The pitch bend is done through the “bendout” object. The graphical dials and number boxes appearing after each FSRXlate sub patch are used for debugging and monitoring purposes.

When the START button is triggered, a MIDI note number 36 will be switched on at the Nord Lead synthesizer. Until the STOP button is triggered, the note will be held as long as we need it. The note held will be shown on a little keyboard and then passed into the “borax” object and into the synthesizer. The number 2 box appearing after the START button on the left gets sent to all objects that need to know the MIDI channel where everything is supposed to happen. In this case, it is MIDI channel 2. The “borax” object is used to make sure that whatever notes we switch on will be switched off completely when we trigger the “All Notes OFF” button on its right. This will ensure that there will not be any stuck MIDI notes when we stop the main patch.

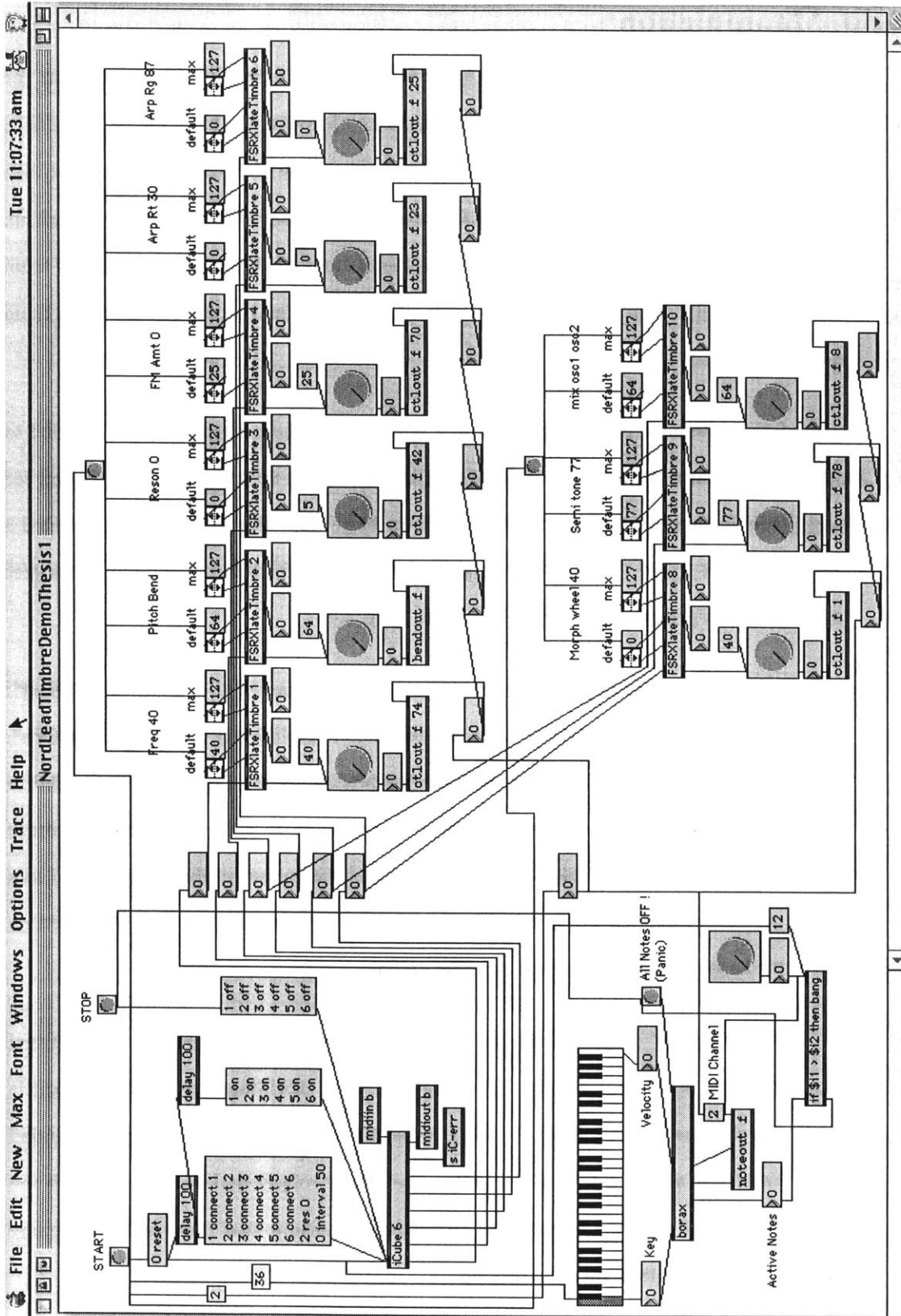


Fig 6.2 : Nord Lead Timbre main Max patch

Arpeggio Manipulation

In order to create this application, I took some basic lessons from Gil Weinberg about the various functions and components of an arpeggio. It consists of a few basic inputs : base note, register, interval, accent, note hold duration and of course the tempo. There are also different ways to play the notes generated. One example is to play from the base note and up, down, up and so on. Other ways may be to always start from the base note and up and from the base note again; from the base note and down, up, down and so on; always down from the base note etc.

I wanted to create an arpeggio generator that could do all these variations but decided to create one that starts playing from the base note and up, down, up and so on. The reason for doing this is to simplify the programming tasks in Max. With this information, I created a main Max patch called "UltraProteusArpeggio" (Fig. 6.3) that handles all the parameter changes for the arpeggio engine called "PlayNote" (Fig. 6.4).

In the "UltraProteusArpeggio" main patch, there are the "InstrumentSelect", "RegisterSelect", "IntervalSelect", "AccentSelect", "HoldSelect", "TrackNoteOns", "FSRXlateArpeggio" and "CubeBox06b0106" sub patches. All these sub patches are created to hide away the detailed functions described by their names so that the main patch is more easily understood and presentable. The long keyboard at the bottom of the patch is used as a monitor for the generated notes whereas the shorter keyboard on the right is used to monitor the base note selected for the arpeggio engine.

The "CubeBox06b0106" (Fig. 6.5) sub patch has all the controls, sampling rate, channel assignments and resolutions for the ICube digitizer. The "FSRXlateArpeggio" (Fig. 6.6) is basically the same as the "FSRXlate" (Fig. 6.1) that scales the input to a defined and bounded range. "TrackNoteOns" (Fig. 6.7), which utilizes the "flush" object that keeps track of all the note ons, is used at the output end of the "PlayNote" to ensure that there will not be any stuck MIDI notes after they are done playing.

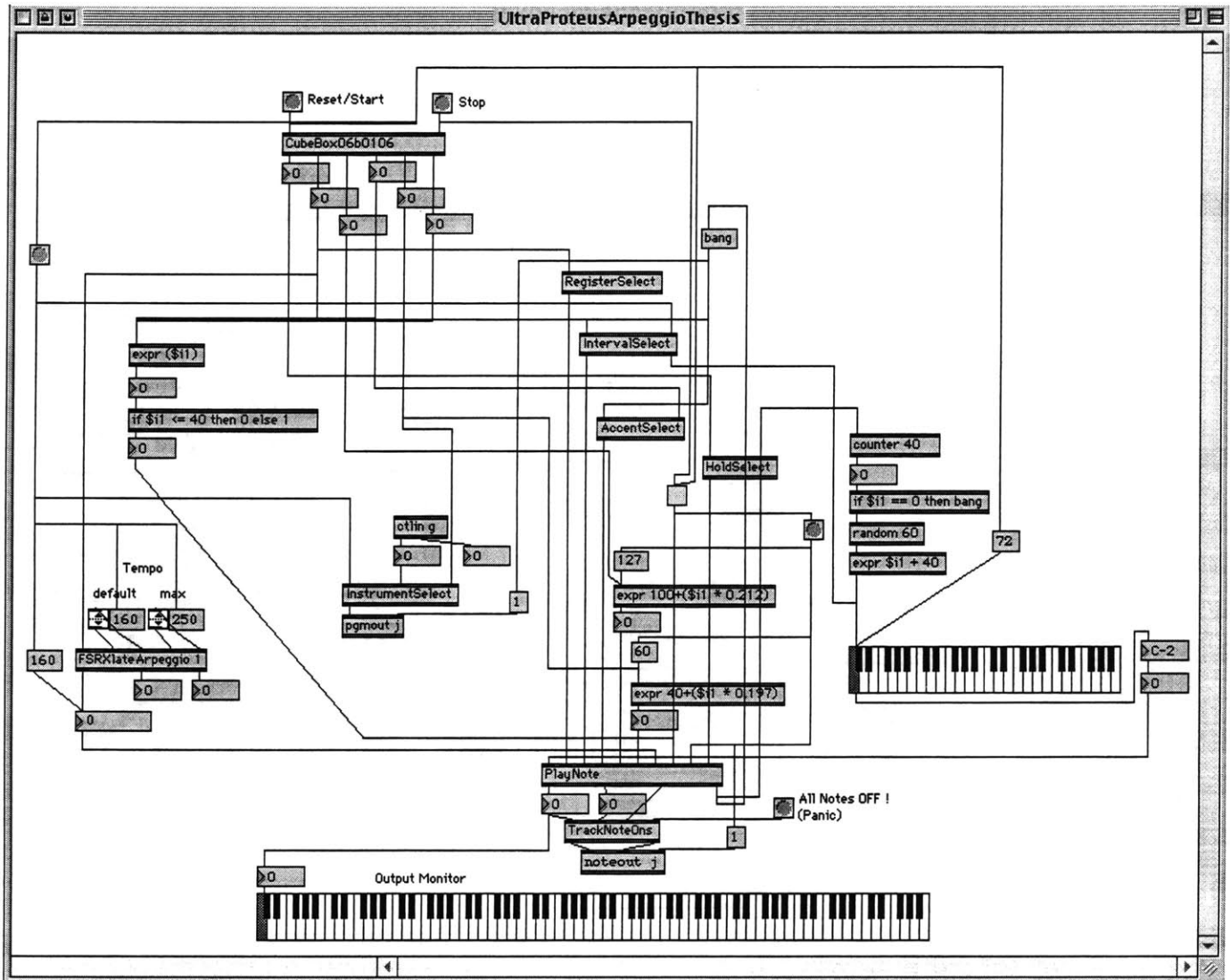


Fig. 6.3 : UltraProteusArpeggio main Max patch

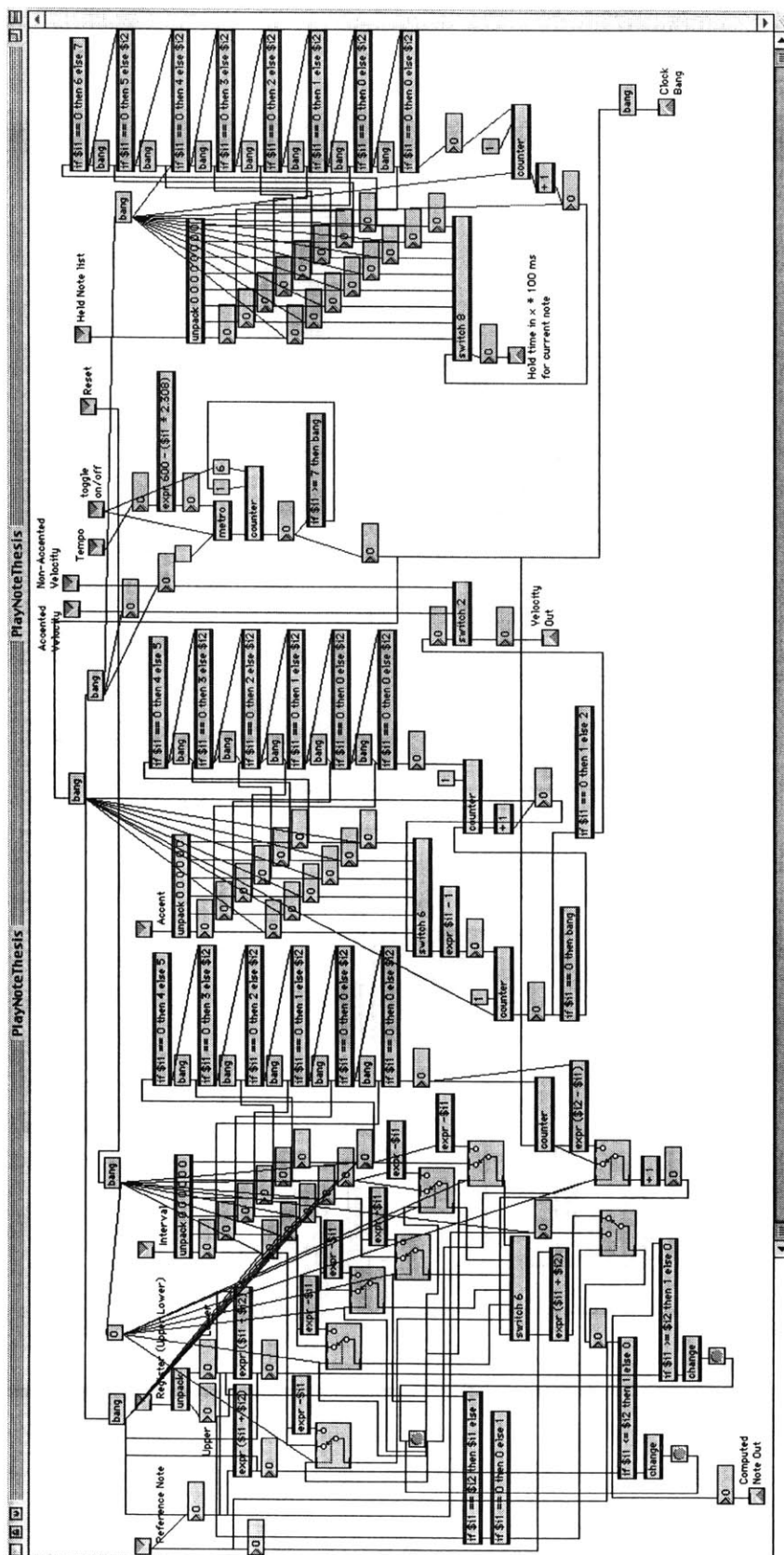


Fig. 6.4 : PlayNote sub patch, the arpeggiator engine

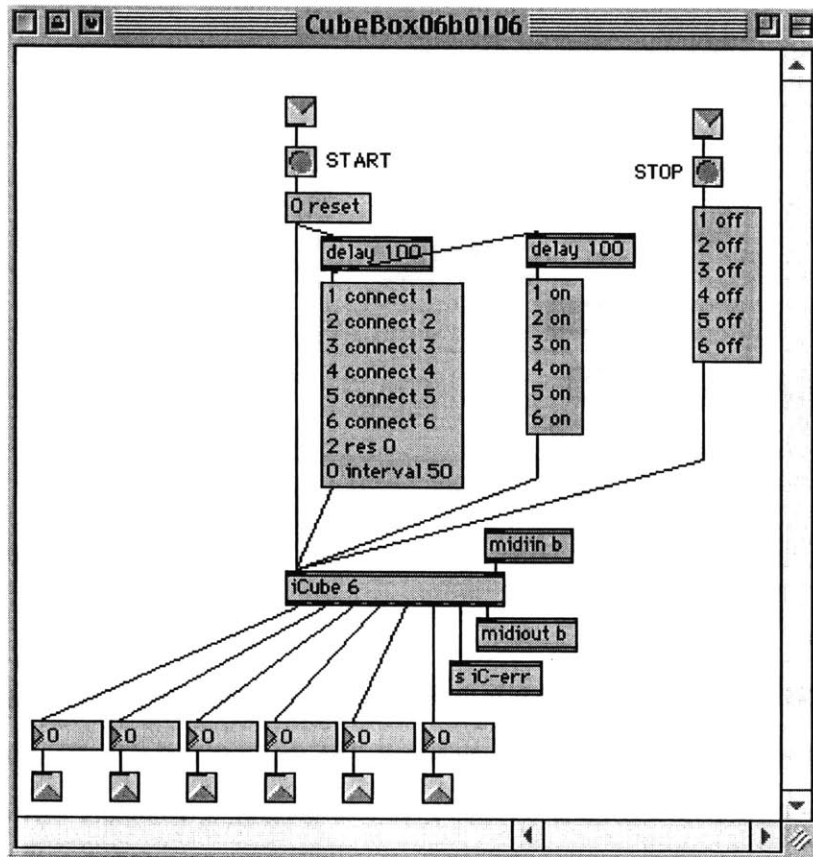


Fig 6.5 : CubeBox06b0106 sub patch for controlling the I-Cube

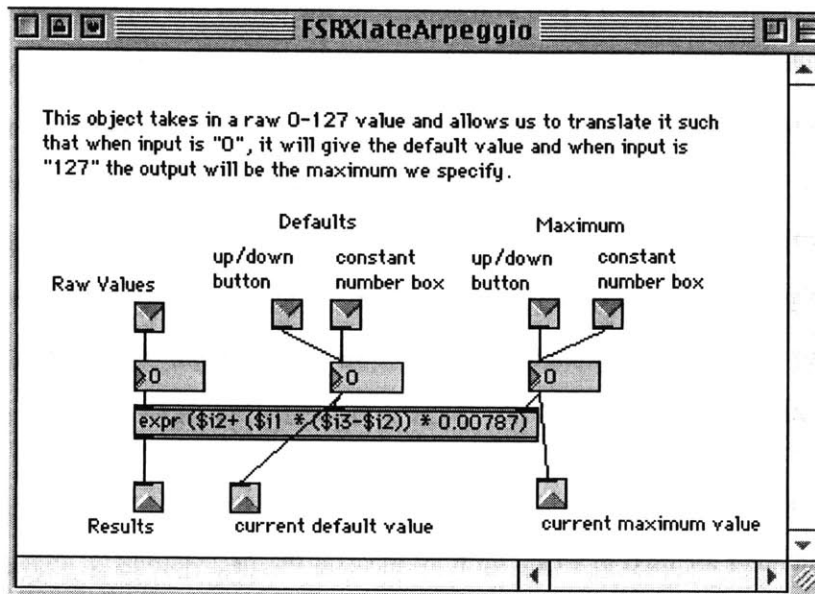


Fig 6.6 : FSRXlateArpeggio for scaling input to predefined range

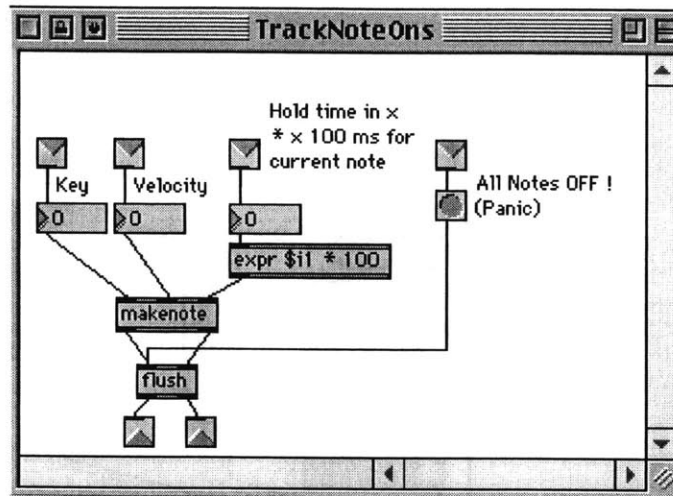


Fig 6.7 : TrackNoteOms ensures all notes is switched off after playing

The "PlayNote" sub patch, which is essentially the arpeggio engine itself, takes in a total of 10 parameters for an arpeggio to be generated. The first one is the "Reference" or base note, which is taken from a random number generator generating a number between 40 and 100. This note can also be assigned by the user at any time. A counter keeps count of the time length this note will be used before changing to a new note.

The "Register," consists of a pair of numbers, i.e. the lowest and highest MIDI note numbers relative to the base MIDI note to play and is used to make sure the notes generated for any arpeggio does not go beyond these boundaries. When the next calculated note is higher or lower than the preset boundaries, it gets wrapped around at the boundaries, changing the direction of the arpeggio from up to down or vice versa. Values for this input come from the sub patch "RegisterSelect" (Fig. 6.8) which divide up the 0-127 sensor values into 7 segments. When the sensor input falls within the first segment, "0 0" will be used. The next values will be "7 5", "12 12", "19 17", "24 24", "31 29" and "36 36."

The "Interval" is a list of numbers, up to a maximum of 5, ended by a "0" or zero value. These numbers are used in a loop form to calculate the next note to be played. For example, a list of "7 5 0" will result in note 7 semi-tones away from the base note with the next one at

5 semi-tones away from the second note. The whole process repeats itself by adding 7 and then adding 5. If it is a downward arpeggio, 5 will be used to subtract from the base note and then 7 will be used to subtract from the next note. The "Interval" input takes values from the sub patch "IntervalSelect" (Fig. 6.9). This sub patch loops the 10 predefined interval values "0", "7 5", "4 3 5", "5 5", "6 6", "4 4", "1 2 3 4 2", "2 3 1", "1 2" and "1 1".

The "Accent" is also a list of numbers, up to a maximum of 5, also ended by a "0" or zero value. These numbers are also used in a loop form to put emphasis on notes generated. Together with the next two inputs "Accented Velocity" and "Non-Accented Velocity", this part of the patch will generate a velocity for the computed note. For example, the list "3 2 2 0" will emphasize the 3rd note, the 2nd note after that and then the 2nd note after that one. This will repeat starting with 3. The inputs come from the sub patch "AccentSelect" (Fig. 5.10) which splits the 0-127 sensor input into 10 segments covering "8", "4", "5", "2", "4 3", "3 3 2", "3 2 2 1", "2 2 3", "1 1 2" and "1".

The next three inputs "Tempo", "toggle on/off" and "Reset" determine the speed of the chord progression, whether to start or stop the generation of the note and to set the arpeggio engine to the beginning (starting at the base note) respectively. Since the tempo object in Max is not able to generate very fast clock ticks for the arpeggio generator, this "Tempo" value is different from the normal beats per second. It takes values from 0 to 260 and will generate a value from 600 to 1 and is used as a timing number in milliseconds for the "metro" or metronome object in Max.

The last input of "PlayNote" is the "Held Note List". This takes an input of a list, up to a maximum of 8 numbers, that tells the engine the hold time of a generated note. For example, a list of "2 2 15 0" will hold the first and second notes for 200 milliseconds, the third note for 1.5 seconds and not hold the fourth note at all. The data comes from the sub patch "HoldSelect" (Fig. 6.11) which segments the incoming 0-127 sensor values into 10 parts. The 10 sets of values are "1 0", "1 1 1 5 1 0", "2 1 3 20 1 6 1 7", "2 2 15 0", "1 3 1 16 1 0", "1 1 10 1 1 15 0", "16 3 1 1 10", "1 1 15 1 1 1 1 20", "1 4 1 1 6" and "2 1 2 1 10 5 12 1".

The only sub patch that is not used by "PlayNote" is "InstrumentSelect" (Fig. 6.12). The patch also splits the 0-127 sensor values into 10 segments covering 10 sets of numbers "0", "16", "106", "48", "9", "96", "62", "5", "13" and "100". These are instrument numbers in the E-Mu Ultra Proteus synthesizer. One difference this sub patch has when compared with the others is the ability to switch to a fixed number, 15, when it detects a press in the foot pedal. When the foot pedal is tapped once, the arpeggio engine will play only percussive sounds from the synthesizer. When the pedal is tapped another time, one of the 10 numbers will be selected again and the arpeggio will drop out of percussion mode back into other musical instruments. The "Reset" in the "InstrumentSelect" sub patch will set the arpeggio engine to play the grand piano sound from the synthesizer.

In this application, the E-Mu Ultra Proteus synthesizer is a good choice because with this instrument, notes do not get cut off during instrument change.

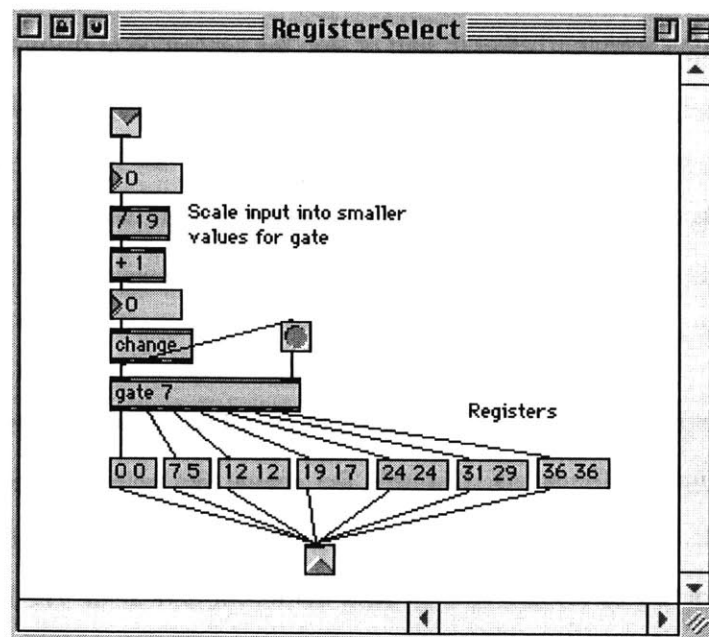


Fig. 6.8 : RegisterSelect sub patch

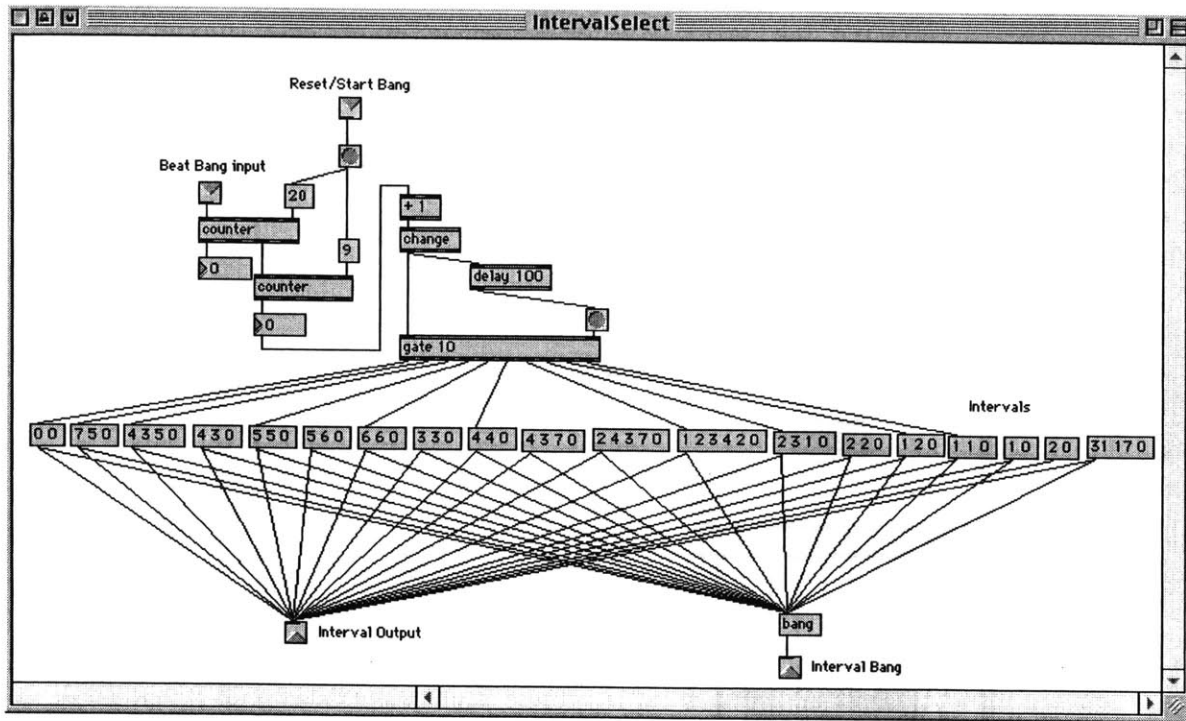


Fig. 6.9 : IntervalSelect sub patch

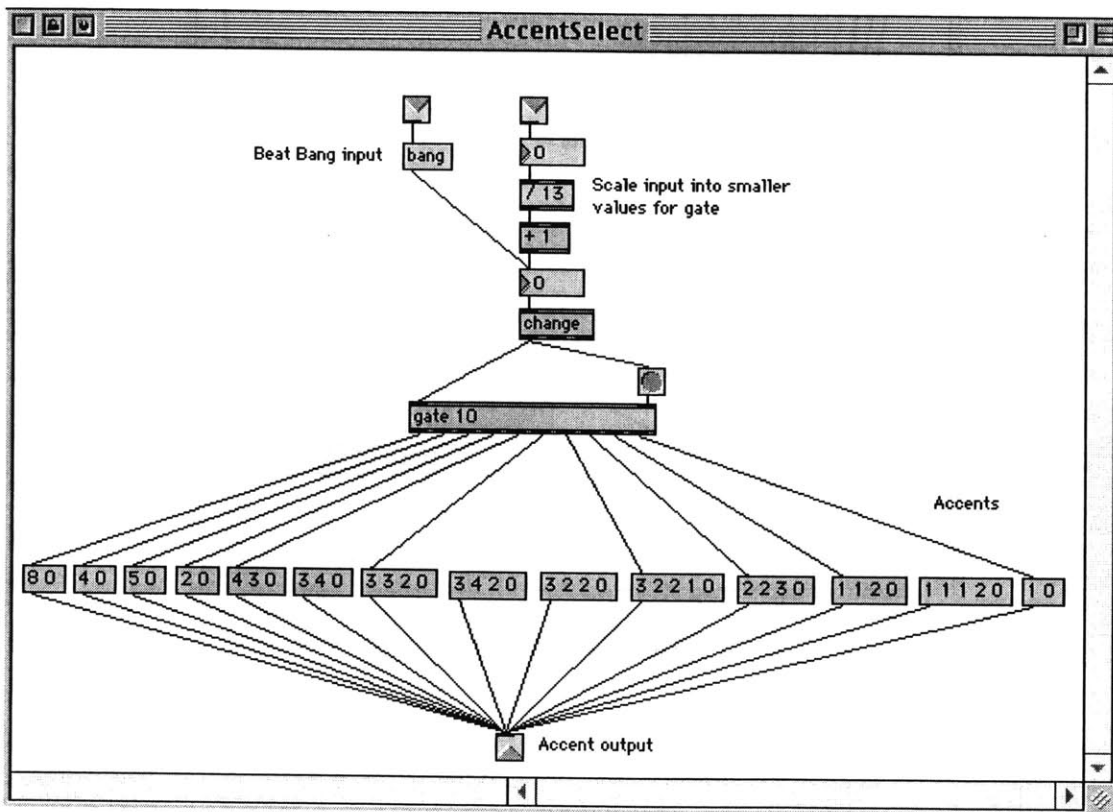


Fig. 6.10 : AccentSelect sub patch

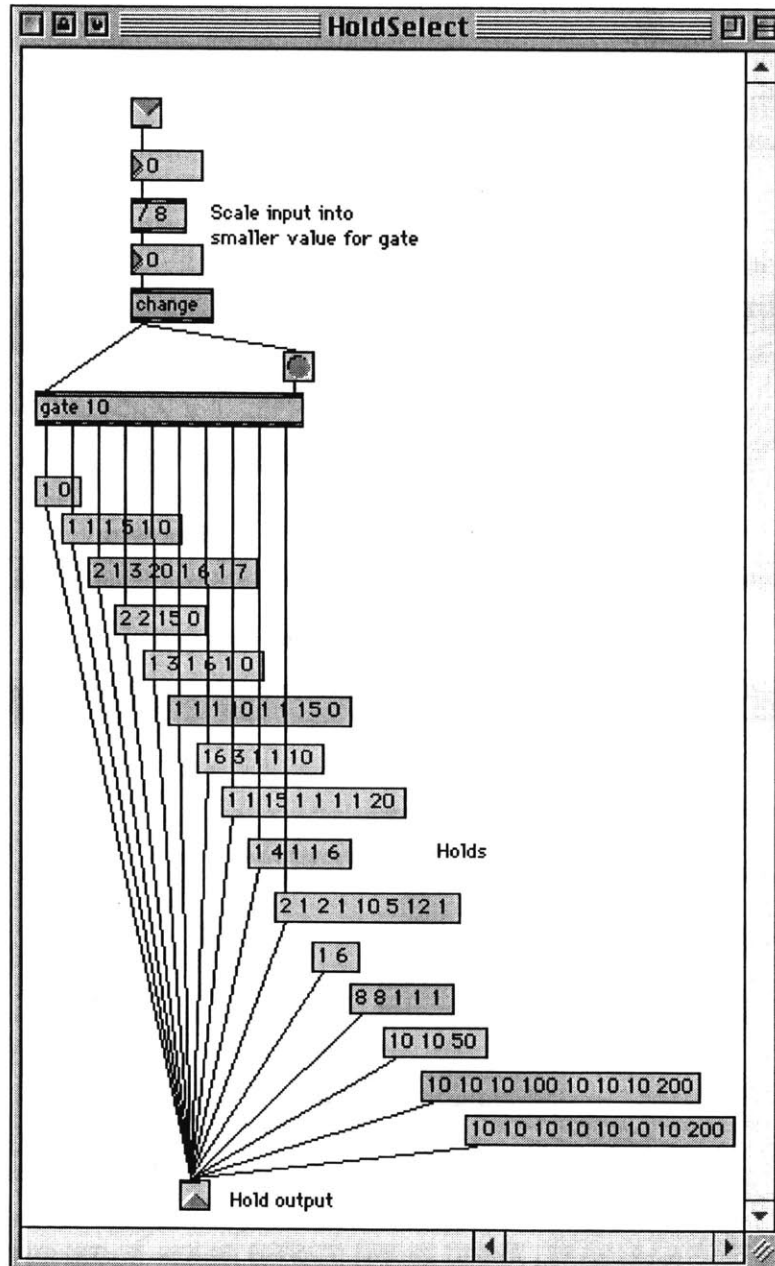


Fig. 6.11 : HoldSelect sub patch

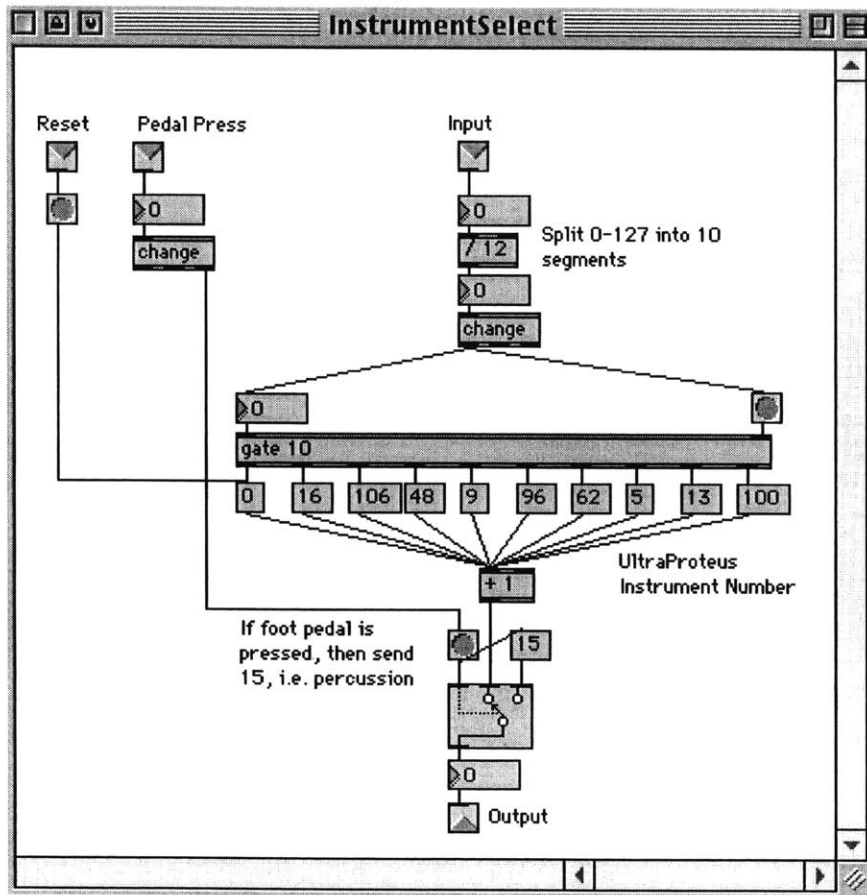


Fig. 6.12 : InstrumentSelect sub patch

Chapter 7

Conclusions

To conclude, I will first discuss the possible future directions of the *Squeezables* and then summarize the work done.

Future Directions

Many lessons can be learned from the various instruments or interfaces discussed in the introduction. The lessons could be incorporated into the future versions of the *Squeezables*. One of them is to measure the distance between every one of these *Squeezables*. Though this may fall into the “many body problem “ in physics where solving for the resultant or exact equation is virtually non-existent, the ability to even know where the neighboring *Squeezables* are could be very useful information in music. In STEIM, the *MIDI-Conductor* used ultrasound to measure distance between two hands which may result in the interruption of the ultrasonic beams from hands and blind spots. The possibility of fan-out or wide angle ultrasonic beams could be useful to achieve measurements of distance among multiple *Squeezables*. These wide ultrasonic beams could also be used to transmit the different states of the *Squeezables*, making them wireless. Infra-red beams can also be used for higher transmission bandwidth.

Another direction would be to extend the capabilities of the *Squeezables* to include other classes of tactile features and even “free-air” movements (Fig. 1.1). Incorporating haptic or force-feedback mechanisms, like vibrators and actuators into the *Squeezables* would also

give more information to the users about the systems they play, or even allow the *Squeezables* to deform into other shapes for different hands and preferences.

Imagine a classroom of the future where children would pick up the *Squeezables* and learn about the foundations of music and sound or even to use the *Squeezables* as tools for their music projects. Another example application would be a room full of *Squeezables*, where the performers can pick up one or two of his choice and start to move and squeeze them around in the air. The performers could even jump into a pool of these *Squeezables* like the *Musical Play Pen*. With built-in 3-axis accelerometers like the *Hands* from STEIM and *Digital Baton* from the *Brain Opera*, the free movement in the air or the body movement in the pool can be measured and used to control other aspects of music, like beats, rhythms and intensity.

The *Digital Maracas* have handles that are only used for holding the accelerometers. These handles could well be transformed into *Squeezables*, expanding the *Digital Maracas* into the “squeeze” category in the taxonomy of hand interface (Fig. 1.1).

With future parasitic power, i.e. electricity harnessed from wasted energy like walking, bouncing a ball or squeezing, the issue of power will no longer be important. This parasitic power can also be used to directly alter the power of a radio-frequency transmitter, allowing the *Squeezables* to have varying transmission distance, affecting surrounding *Squeezables* differently, depending on their power. Thus, this “artifact” of parasitic power would become an expressive variable in such a squeezable interface.

At this time, the sound produced by the *Squeezables* comes from external synthesizers and speakers. It is possible to house a synthesizer on a chip and embed it into each and every *Squeezable*. Miniature speaker technology that allows sounds to be amplified and reproduced at the source will enable *Squeezables* to have multiple sound colors and spatialization.

With mappings that incorporate learning algorithms, the *Squeezables* could be able to adapt to different squeezing/playing styles, i.e. they could become a musical instrument that learns the behaviors of users.

Recapitulation and Contributions

From the very first version of the *Squeezables* to the last, I have looked into many kinds of materials and sensing methods. Various kinds of materials have been used for creating and shaping the *Squeezables*. The versions that had liquid in a polyurethane tube had the best shape and flexibility but also had some disadvantages. It helped to identify problems with sensing when there is water and where leakage is a constant issue.

Foam is a light and flexible material that made it suitable to create the *Squeezables*. The best thing about foam is that it has no leakage problem. With a cube-like pressure sensor, many foam balls can be placed on the faces forming a squeezable cluster that has multiple continuous controls on one interface.

Three major issues evolved from the squeezable cluster.

First, the lack of sensitivity of the foam cluster became apparent when children with little hands started to squeeze just one ball among the cluster. Second, the flaking and tearing caused me to look into materials that will protect the foam. Lastly, it became clear that it was desirable to turn the *Squeezable* from a one person interface into a group play instrument.

With the making of the *Pole of Squeezables*, besides addressing all the issues, a new feature was added : pulling. Each foam ball is sensitive to being squeezed independently, protected by decorative cloth and can be pulled from its station at the top of the pole. There are seven of these balls on the station and they retract to the station when released. They can also be squeezed as a collective like the *Squeezable Cluster*, and they have the ability to form irregular shapes through different configurations of the balls.

Two other observations were made about the *Pole of Squeezables* : foam balls are too light and do not have enough tactile response and the pole is too high for children or shorter people to reach.

The *Table of Squeezables*, about 40 cm high, gives children much easier access to the balls. With gel material in insulating latex and decorative cloth, these *Squeezables* have much more mass and flesh-like response. It had six balls on the table top that retracted when released. Irregular shapes could also be formed with different configurations. With better pull sensors, the balls were more responsive to pulling and lifting.

The creation of the *Squeezables* gave the electronic music world a new and standalone controller with multiple continuous controls within a single interface. Hopefully, it will evolve into an auxiliary controller to enhance traditional discrete input devices like keyboards. With the *Table of Squeezables*, a new instrument that supports group play is born, suitable for both young and old. A group play instrument lets the team players respond to one another's playing habits and encourages team work while learning to anticipate what others will do. Unlike the *theremin* or "free-air" instruments, *Squeezables* are physical interfaces that give users tactile feedback when playing, while retaining the freedom of movement and gesture so attractive to all of us.

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