The andantephone: Teaching music by walking on patio stones with sensors activated by sequential foot steps

Steve Mann
http://wearcam.org/andantephone
http://www.youtube.com/watch?v=Xd_1dpnKRFg
mann@eecg.toronto.edu

ABSTRACT

I installed patio stones, leading to a musical garden, and outfitted each stone with a pressure sensor. I connected the pressure sensors to a central computer, which I programmed to step through a song, as people walk to the garden. Each footstep activates the next note in the song, so that there is perfect synchronization between the music and the speed of your walking (i.e. if you walk faster the song plays faster, if you stop walking the song stops, etc.). In one embodiment the computer controls an outdoor pipe-organ sculpture that I made from PVC pipes. Another provides a MIDI output to control a piano or other sound-producing device. Some versions of the sculpture are human-powered, either electrically, or wholly acoustically without the use of a computer.

I also arranged various musical compositions suitable to this new form of art.

The sculptures were found to break down social barriers and create cross-cultural and cross-generational ties. For example, children and their grand parents enjoyed walking through the gardens at Pine Hill Estates where a version of my sculpture is permanently installed.

Other variations of the sculpture include arrays of hydraulophonic fountain jets that play a song in a water park when a person walks on the water. Each note or beat is triggered by a water pressure increase when one of the water jets is blocked by the foot of a user stepping on it. The instrument requires little or no skill to play, yet provides the user with the sense of empowerment that they are directly generating the music.

Categories and Subject Descriptors

H.5.2 [**User Interfaces**]; H.5.5 [**Sound and Music Computing**]; J.5 [**Computer Applications**]: ARTS AND HUMANITIES—*Fine arts*

General Terms

Design, Experimentation, Performance, Theory, Verification, Immersive

Keywords

Tangible user interface, direct user interface, computer mediated reality, musical sculptures, interactive sculptures

Figure 1: **Power-generating shoe prototype made by author in collaboration with Nike:** Piezoelectric pads running embedded in the shoe generate electricity from footsteps.

1. RELATED WORK

Tangible media [1][2] have been demonstrated in various forms. The proposed “andantephone” consists of pressure sensors arranged along a garden path, as a multimedia interactive sculptural element. This could be considered an example of tangible media. Other researchers in the area of Affective Computing have developed simple systems for teaching music, or understanding how people perceive music [3][4].

2. INTRODUCTION: STEPPING THROUGH MUSIC

For the last 30 years or so, I've been playing musical instruments while walking, so that I get a sense of tempo in the music. Most of these musical instruments are interfaces to my wearable computer which I also use to compose or arrange music while I'm walking.

I also have piezo electric pads built into my shoes to generate electricity for the wearable computer, as well as give it an awareness of tempo in my footsteps 1. The author worked in collaboration with Nike to build energy-producing shoes for a wearable computer music system [Reference to own research papers omitted to maintain double-blind reviewing]. Others have also done extensive research on human-powered computing, including electricity-generating shoes [5].

When I am listening to the music of others, rather than composing or playing my instrument, I have the music running at the tempo of my own footsteps. I have my wearable computer configured so that each step advances to the next beat of music.

I programmed the computer to step through MIDI music files, so that when I walked faster the music played faster, and when I stopped walking the music would stop.

Other people found this to be very interesting and lots of fun, and would often want to "play" my wearable computer. Even if they did not know how to play a musical instrument, they said that what they liked about my system was that it made them feel like they were generating the music. Not only were they generating the electricity to run the music, but they were, in a sense, "conducting" the music with their feet.

3. THE ANDANTEPHONE: MUSIC THAT PLAYS AT YOUR WALKING PACE

Andante is the Italian musical term for tempo that is "at a walking pace". Of course people walk at a variety of different paces, and there is some variation, from perhaps 78 to 108 on the Wittner scale, in tempo that is still considered "andante". Combining the Italian "andante" with the Greek word "phone" (meaning "sound", a commonly used suffix for musical instruments), results in "andantaphone" to describe musical instruments (such as my wearable computer and special shoes) that play or adapt themselves to a walking pace.

I decided that it would be nice to make some interactive sculptures that did not require a participant to wear any special hardware. Therefore, based on this principle of musical sequencing, I arranged a version of Gershwin's 1935 lullaby "Summertime" to play on the stairs going up to my studio, where each step was either a note or a rest.

I also used public spaces, like Toronto's Dundas Square, and similar spaces, where there are large granite slabs. I associated each slab with one beat in the song, as shown in Fig 2. I used cameras and computer vision to sense footsteps, and step through various songs, such as my arrangement of the Gershwin lullaby.

I experimented with different public spaces that had geometric patterns of patio stones, slabs, or other similar periodic design elements. See for example Fig 3. Depending on the songs, I made a variety of sculptures having different song-specific patterns. Additionally, I made some sculptures that could be programmed for a variety of different songs.

4. PRESSURE SENSING PATIO STONES

Rather than rely on computer vision, I wanted to make a more expressive garden for a permanent installation at Pine Hill Estates in Toronto, where I used pressure transducers that I attached to each patio stone.

First I prototyped the sculpture indoors, using sixteen individual pressure sensors connected to digital signal processing system I made, having sixteen analog inputs. See Fig. 4.

Then I drilled a hole in each patio stone, slightly off-center,

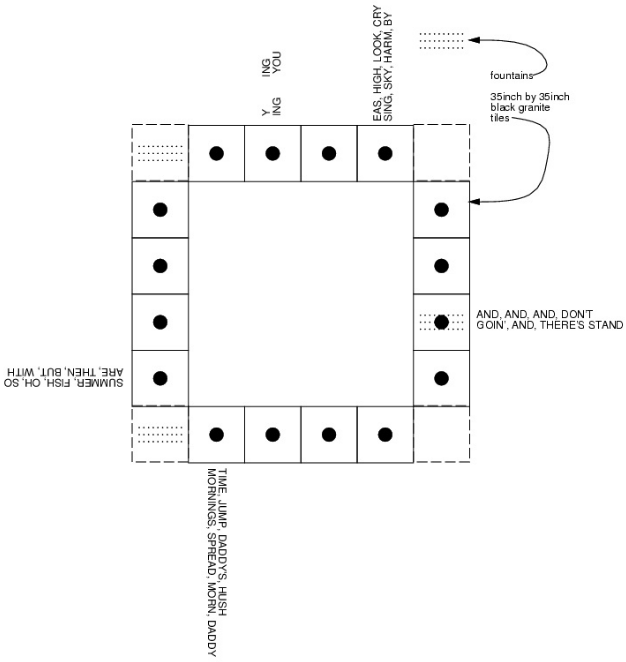

Figure 2: **Granite slabs each define one beat in the song:** Lyrics of "Summertime" are written, with chalk, on the slabs. Arrows and numbers guide users along. As people walk on the slabs they "step out" the song.

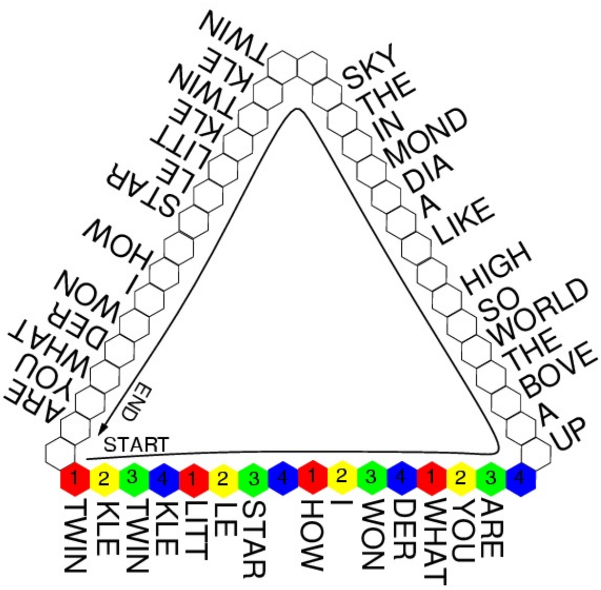

Figure 3: **Hexagonal slabs each define one beat in the song:** Lyrics of "Twinkle Twinkle Little Star" are painted, on color coded slabs. As people walk on the slabs they "step out" the song based on tracking by way of an overhead camera with a computer vision system. The unique color of each slab helps to make the background subtraction tasks very easy.

Figure 4: **Experimental prototype:** I first tried various arrangements of sixteen pressure sensors, taped to the floor, indoors. I designed, built, and programmed a system to sequence through one beat note of a song for each foot step.

to attach the pressure sensors. See Fig. 5.

On the path to the gardens there is a curved path of patio stones in the grass. Because the grass is damp, owing to the in-grass automated irrigation system, people usually step on the stones to walk to the gardens, so that they don't get their feet wet in the damp grass. Since people generally walk on the patio stones, one stone at a time, this is an ideal setting for a musical sculpture in which notes are triggered in a predetermined sequence, by footsteps.

Rather than the geometric patterns of my past installations, which I had chosen to facilitate reprogrammability of the songs, for this installation I instead chose to use a more organic song-specific path, as shown in Fig. 6.

Now, when people walk along the path defined by the stones, their footsteps step them through a song. If more than one person is on the path, a nice musical "round" results. See for example Fig 7. Sounds are produced by a computer controlled pipe organ sculpture I made from grey PVC electrical conduit pipes hanging from a tree adjacent to the garden. See Fig. 8.

5. ARRANGING OR COMPOSING MUSIC SPECIFICALLY FOR STEPPING-STONE SCULPTURES

One of the interesting observations made on the sculptures, is that when two successive notes of the song are the same, there needs to be some way to define a break in the notes. In particular, the problem arises when a person steps on one stone, and then the next, without stepping off the first stone before stepping on the next one.

This problem can be solved by putting the stones further apart, or by computer with beat-tracking. However, a more creative yet natural way of attaining a break in one long note, is to insert what I call "grace harmony". Grace harmony works like the grace notes in bagpipe music, and serves to break up a long note into smaller pieces. My arrangement of the simple children's song, Twinkle Twinkle Little Star, for the garden sculpture, is shown in Fig. 9

Figure 5: **Preparing patio stones for being equipped with the sensors of Fig. 4:** I drilled an off-center hole, and then bonded a pressure sensor in the center of the stone, with a wire passing down through the hole, to connect the sensor underground to the central processor that I mounted in a weatherproof electrical box. Using technology similar to a wearable computer (low-power battery operation) the entire sculpture can run off a small solar panel or small battery.

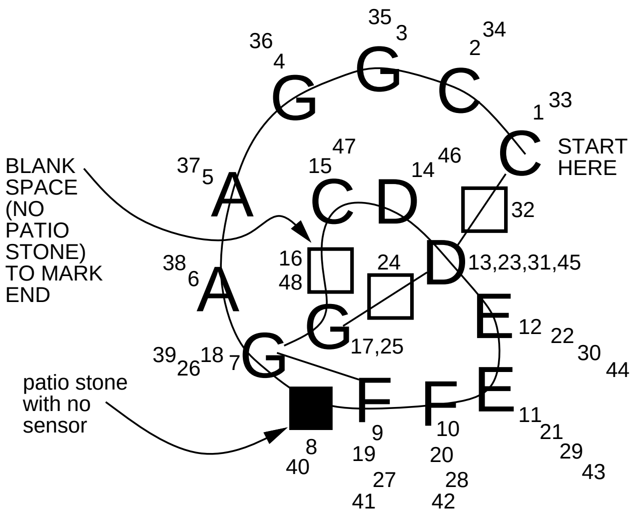

Figure 6: A less geometric (more organic) variation of my stepping-stone musical sculpture

Figure 7: **Garden stone slabs each define one beat in the song:** As people walk on the slabs they “step out” the song by way of a computer-controlled pipe organ sculpture made from grey PVC electrical conduit pipes hanging from a tree adjacent to the garden.

Figure 8: Example of sculptural organ pipe hanging from a tree branch near the garden. PVC was chosen as a material for the construction of organ pipes, because it resists the harsh weather conditions of the Canadian climate where the sculpture is located. The sound comes out the bottom of the pipe, whereas the top is sealed against rain and snow.

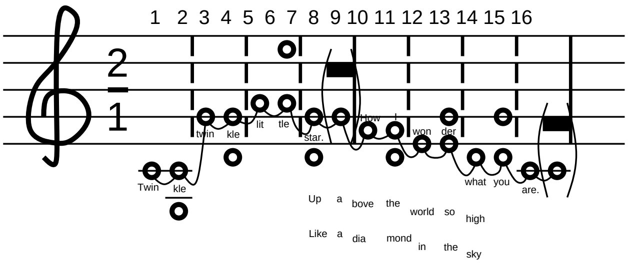

Figure 9: **Grace harmony used to break-up sequential occurrences of the same note:** Here an unusual harmony provides a whimsical reverse-emphasis, by coming in during the second beat of each bar, i.e. “twinKLE twinKLE litTLE star...”. Since the harmony comes in late (i.e. in a repeated melody note), additional creative opportunity exists to have it ride above the melody at times, without the risk of having it start the bar off on the wrong note. In this simple song, each foot step corresponds to one whole note, hence the time signature of 2/1, in which each bar of music contains both a left footstep and a right footstep. Note that I've used non-standard harmony at time-index 4, 6, and 7, rather than making the grace harmony from C, F (or C), and C, that would more expectedly form part of the chords for C-major, F-major, and C-major. The unusual harmony is in keeping with the spirit of a garden sculpture, suggestive of the playful harmony one hears from wind chimes.

6. MULTI-SONG ANDANTEPHONE SCULPTURE

The andantephones described so far, are sculptures designed to play only one specific song.

I now describe a more general form of andantephone that can be programmed for a wide variety of songs.

When my wife and I renovated our house, we included a permanently installed andantephone to teach our children music. We did not want this sculpture to be limited to only one song, so we constructed it in a way that it could be programmed with a variety of songs. I designed for 64 textured non-slip but durable tiles, running down the center of corridors that ran around the house in a square shape. We designed around the stairwell and bathroom that already formed a central “island” in the dwelling, making use of the island to define an endless path that one could walk around and around.

We designed the instrument to play, starting from the kitchen, because we would typically play just before or after dinner. We designed for 16 tiles running down the center of the corridor that runs from the kitchen to the bedroom, then another sixteen tiles running through the corridor into the living room, sixteen more tiles that run through the living room to the entrance hall, and finally another sixteen tiles that run from the entrance hall back to the kitchen. This arrangement results in a perfect square with sixteen tiles on each side of the square, as shown in Fig. 10.

Many children's songs have four beats to every measure (four beats to every bar of music), so each side of the square represents four measures, which is typically one phrase, i.e. there are:

- four beats (four tiles) per bar;
- four bars per side of the square;
- four sides of the square per revolution (once around the house).

Thus, for many songs, each verse of the song represents a

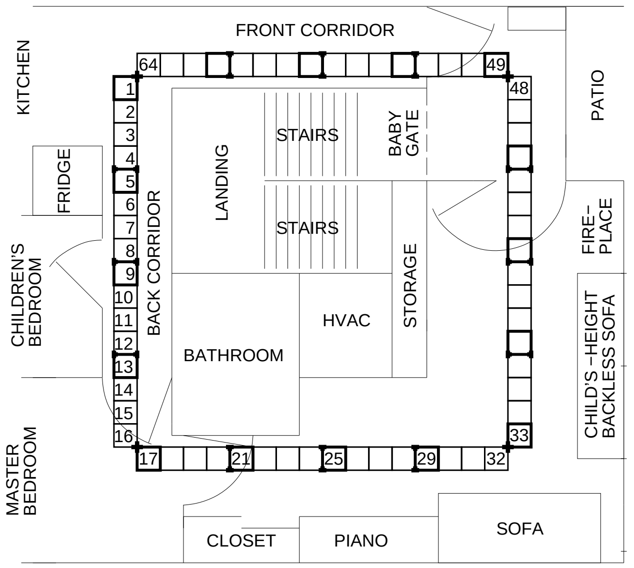

Figure 10: **General-purpose 64-tile andantephone designed as part of a home renovation project:** There are 64 tiles arranged in a square pattern in which every fourth tile is emphasized to construct one bar (measure) of music. Four bars The tiles are made of solid porcelain, with a non-slip textured surface. Each tile is a chalk board so that a word from the song's lyrics can be written on a tile, to begin the day's music lesson once the song is programmed. When it is time for a new music lesson, a new song is programmed, the "chalkboards" are erased with a standard floor mop, and new text is drawn in fresh chalk.

distance once around the square, so that each time we reach the kitchen we move to the next verse of the song.

The tiles are made of solid porcelain, set in concrete. The surface of each tile is textured to create a nonslip surface, as well as to allow it to function like the slate on a chalk board. When the andantephone is programmed with a particular song, the lyrics may either be projected onto the tiles, using data projectors, or, alternatively sidewalk chalk is used to write lyrics of the song, spread out along the tiles. The cement floor makes it easy to erase these 64 miniature chalkboards with a standard mop.

Other re-configurable andantephones use translucent tiles with rear-projection.

7. OTHER TIME SIGNATURES

The layout, depicted in Fig. 10 for the indoor sculpture is suitable for most simple songs, that have two or four beats per measure, i.e. songs in "2/4" or "4/4" time. Usually people think of a quarter note as the basic unit of time for one beat. In this paper, however, for simplicity, time signatures are normalized to one whole note. This also makes it easy for children to draw "circles" on the musical staff to represent notes, since many children's songs contain notes that are mostly of the same duration. The resulting time signatures than become "2/1", "4/1", etc.. It is certainly easier to explain to a two-year-old that a whole square tile or whole round patio stone is a whole note, than it is to explain that a whole tile or stone is actually a quarter of a note.

Unfortunately certain other songs, such as "The Ants Go Marching", "House of the Rising Sun", and "Amazing Grace" do not fit onto our present powers-of-two tiling scheme, because these songs have three or six beats per measure (not

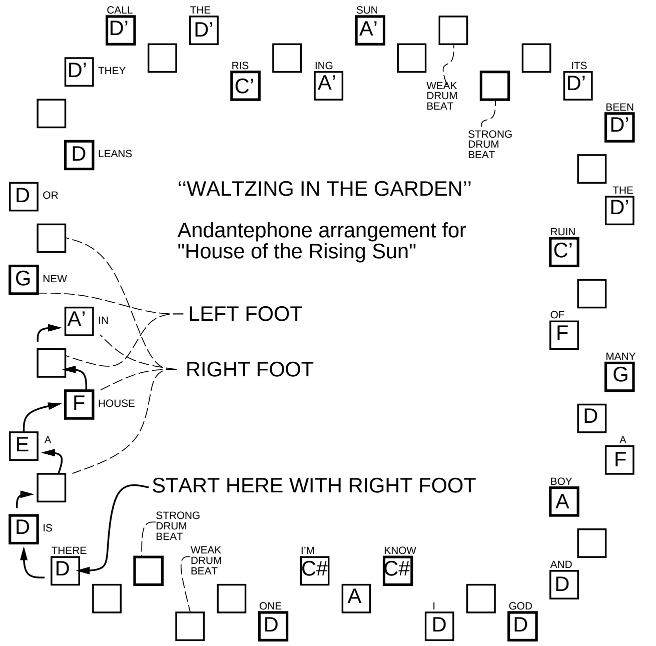

Figure 11: **48-tile andantephone designed as an outdoor sculpture suitable for most songs that have three beats per measure:** In this illustration, the song "House of the Rising Sun" is illustrated. The letters inside each tile indicate the note that plays when the tile is stepped on (chords are not shown for this arrangement). The processor is programmed to play the notes louder for the tiles that are indicated in bold lines. Alternatively, chords can be assigned to these tiles, to define an emphasis as compared with the other tiles. In this particular arrangement, there is no percussion except for four of the tiles, two of which activate a weak drum beat, and the other of which activates a strong drum beat, as indicated. These drum beats serve to maintain the footstep tempo during rests. The layout of tiles encourages a swaying back in forth of the body while walking, in order to be suggestive of a waltz.

a power of two). These songs are said to be in "3/4" or "6/8" time, which we normalize to "3/1" and "6/1" when we draw circles on the musical staff for the children.

To program songs with 3 or 6 beats per measure, I made a second sculpture in a different part of the house (outdoors, actually). The tiles in this sculpture are arranged in a square that has 12 tiles on each side, for a total of 48 tiles, as shown in Fig. 11.

8. A SINGLE SCULPTURE FOR 4-BEAT AND 3-BEAT SONGS

It would be nice to have one sculpture that can be programmed for a variety of different songs, where some of the songs are in 4/4 (or 4/1) time, whereas others are in 3/4 (3/1) or 6/8 (6/1) time. Obviously one could simply just use the first 12, 24, or 48 of the 64 tiles, but then the start of the second verse of the song would no longer line up with the beginning (tile number 1 in the figure).

To solve this problem, I made some modifications to our indoor sculpture, so that it could be programmed to play 3-beat or 6-beat songs as well as the 4-beat songs it did before. The required change involves only using six of the tiles on each side of the square, and taking larger steps, as illustrated in Fig. 12. The children enjoyed the larger steps required of this re-programming of the sculpture, especially with fast songs in 6/8 time such as Tarantella Dance, which resulted in very fast running around the house.

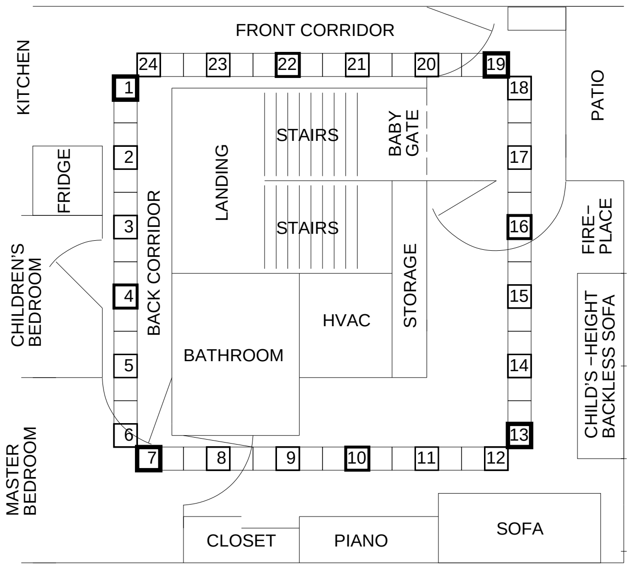

Figure 12: **Using the 64-tile andantephone sculpture for songs in 3/4 (3/1) or 6/8 (6/1) time:** Six tiles on each edge of the square are used, for a total of 24 tiles.

9. THE NOTES GO MARCH—-ING ONE BY ONE, HURRAH!

I now illustrate an example of programming for six of the sixteen tiles on each edge of the square, with a simple song that I adapted from the popular nursery rhyme "The Ants go Marching" (based on "Johnny Comes Marching Home", which is itself based on the Irish folk song entitled "Johnny I Hardly Knew Ye").

I slightly changed the lyrics to suit the andantephone's "marching notes" theme, and came up with the following:

> The notes go marching one by one, hurrah! hurrah!
>
> The notes go marching one by one, hurrah! hurrah!
>
> The men will cheer, the boys will shout, the ladies, they will dance about, and
>
> We'll all be there, when notes come marching home.

To program this song, I decided to use a chord at the beginning of every non-rest barline, in order to exaggerate the sense of rhythm. I also programmed it so that the chords at the corners of the square are louder, and those at the edges, less so. The resulting emphasis is shown in Fig 13.

The programming of the tiles is as follows: The song starts on tile 24, which sounds a lead-in note, just before the first bar of music that starts on tile 1. Each bar of music is formed by six tiles on a side of the square. In 6/8 time, each of these six tiles represents an eighth note. Lyrics of the song are written in chalk, on the tiles, at the beginning of a music lesson.

Tiles are programmed as follows:

- Tiles 1, 7, 13, and 19 (the ones drawn in bold lines) play a loud chord, together with a note of the melody. These tiles correspond to the first note in each bar. Words of the song that are written on these tiles are written in all capital letters, so that the children know that these words are to be strongly emphasized when they sing along with the computer-generated music. For example, the first tile has the words "NOTES", "NOTES", "MEN", and "ALL" written on it. Note that these words are written so that they will appear right-side-up when walking from the kitchen to the master bedroom. However, for simplicity, all of the words are shown in the same orientation in this illustration, contrary to how they appear in reality.
- Tiles 4, 10, 16, and 22 (the ones drawn in medium-thickness lines) correspond to exactly half way through the bar of music. These tiles play either a medium strength chord with a note of the melody or a medium strength drum during a rest in the melody. The drum sounds only when there is no note or chord playing, and this serves to give the children a sense of the passage of time, as well as a sense of consistency (i.e. these tiles always produce sound when they are stepped on, even if no notes are happening then). These percussive rests occur on tiles 16 and 22 during the first two lines of the song, and on tile 22 during the last line of the song. Words of the song that are written on these tiles are written in mixed case (i.e. with the first letter of the word capitalized), so that the children know that these words are to be slightly emphasized when they sing along with the computer-generated music.
- Tiles 24, 3, 6, 9, 12, 15, 18, and 21 play either an individual note of the melody, or a weak drum sound, except that tile 18 plays a chord in only the last line of the song (only once near the end of each verse). The weak drum sounds only when there is no note being sounded. This serves to give the children a sense of the passage of time, as well as a sense of consistency (i.e. these tiles always produce sound when they are stepped on). Words of the song that are written on these tiles are written in lower case, so that the children know that these words are to be less emphasized when they sing along with the computer-generated music.
- Tiles 2, 5, 8, 11, 14, 17, 20, and 23 make no sound when they are stepped on, except at the end of the third line of the song, where tile 23 just makes one note when it is stepped on, but only once in each verse of the song. On average tile 23 only makes sound a 25% of the time that it is stepped on.

10. TECHNICAL DETAILS AND IMPLEMENTATION

I've made many different kinds of andantephones that work by way of a wide variety of different technical design principles. They are broadly categorized as:

- **Distributed:** each stone or slab has its own sensing and sound-producing mechanism. There need be no connection between stones. This allows the stones to be moved around in the garden. Examples of distributed andantephones include:
  - a small Atmel AVR microcontroller potted in epoxy to make it waterproof. The microcontroller drives

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      Am          Am             Am          Am           C        drums         C       drums
 The NOTES     go March-------ing ONE      by One,     hur-RAH,     o-0       hur-RAH     o-0.

      Am          Am             Am          Am           C        drums         C       drums
 The NOTES     go March-------ing ONE      by One,     hur-RAH,     o-0       hur-RAH     o-0,

      Am          Am             Dm          Dm           Am          Am         E          E
 The MEN      will Cheer,     the BOYS    will Shout,   the LAD     ies They   will DANCE  a-Bout, and

      Am       no chord          Am       no chord        Am          Am     E   Am
we'll ALL         Be            THERE        When         NOTES    come March-----ing HOME    o-0
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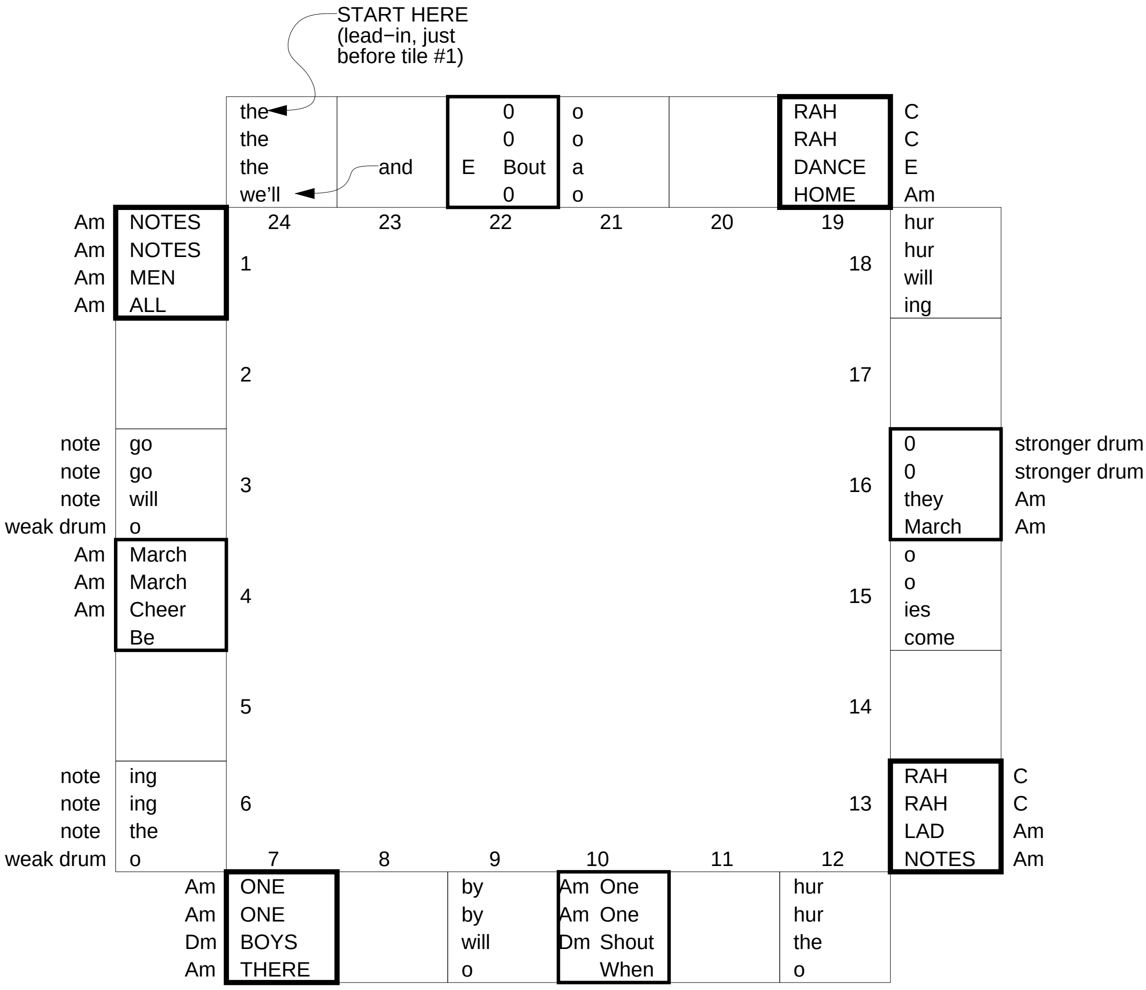

Figure 13: Arrangement of "The notes go marching" using six tiles on each edge of a square path, for a total of 24 tiles. Since each verse of the song contains 96 beats, playing the first verse of the song requires walking around the island four times. Thus there are four words written on each tile. For example, the first tile has the words "NOTES", "NOTES", "MEN", and "ALL" written on it. Note that these words are written so that they will appear right-side-up when walking from the kitchen to the master bedroom. However, for simplicity, all of the words are shown in the same orientation in this illustration, contrary to how they appear in reality. In the text, I have capitalized the words I wanted to fully emphasize, and capitalized only the first letter of the words I wanted to somewhat emphasize. These lyrics are written in chalk, on the tiles, at the beginning of a music lesson. The music programming plays alternating strong and weak chords to define a rhythmic beat. Drums are sounded only when rests occur within the beat pattern, as indicated, where a weak drum is sounded in place of a note, and a stronger drum is sounded in place of a chord. The symbol "o" is used to denote a weak drum-rest, and the symbol "0" is used to denote a strong drum-rest.

  - a waterproof speaker under each stone. A simple sound synthesis algorithm generates a musical tone when a person steps on the stone;
  - a bell or gong that is activated by stepping on it;
  - a wind-blown or water-blown organ pipe in a hollow cavity under each stone. The organ pipe is activated pneumatically, hydraulically, mechanically, or electrically, sometimes with a small microcontroller in each slab to activate the organ pipe.

- **Centralized:** a sensor in each stone is connected to a central processor that generates the sound. Examples include:
  - a pneumatic bellows for each stone, supplying wind to a central pipe organ sculpture. One-way valves are used for each supply of wind going to one or more organ pipes. This arrangement allows a small number of organ pipes, for example, eight organ pipes, to be used by a large number (e.g. 64) of tiles;
  - a water jet associated with a water jet on each slab, hydraulically connected to a central bank of acoustic hydraulophones;
  - a pressure sensor for each slab that connects to a central computer that synthesizes the sounds;
  - a pressure sensor for each slab that connects to a central processor controlling an acoustic instrument. The pressure sensor typically sends a mechanical, pneumatic, hydraulic, or electrical signal to the central processor, which then process this signal into sound. For example, an electrical sensor on each slab is often used to control an acoustic wind-blown sculpture.

Distributed andantephones generally consist of slabs where each slab always produces the same note and/or chord each time it is stepped on. This means that the granularity of the music cannot be finer than one beat per slab. So if a song is in “4/4” time, and we define each slab as a quarter note, there can be no eighth notes in the song.

Centralized andantephones allow notes that have shorter duration than the footstep note duration. So if a song is in “4/4” time, and we define each slab as a quarter note, we can also include some eighth notes, sixteenth notes, etc.. This is done by a tempo-tracking algorithm. However I prefer to avoid using too much sub-footstep timing, because it takes away from the illusion of simplicity that otherwise occurs when each note corresponds to one footstep. Sub-footstep timing also takes away fine control over the amplitude expression, because each note can no longer be stomped out with a unique amount of force, velocity, and pressure.

In most of the sculptures I’ve made, I use electrical actuation by way of an analog pressure signal with 10-bit, 12-bit, or 16-bit precision. This allows, for example, 65535 different pressure levels to be conveyed to the processor. The differences in pressure affect the amount of chiff, the overblow of the organ pipes, and other aspects of the sound, so that the instrument can be very expressive.

These degrees of fine control over the musical expression allows the user to stomp harder on some pads than others, in order to impart a unique expression to a particular performance of a song. The use of pressure sensors allows the instrument to be velocity-sensing (by way of taking the derivative of the signal) as well as displacement-sensing, acceleration-sensing, and so on.

This degree of musical expression goes beyond the standard musical keyboards that often respond primarily to velocity.

For example, sometimes the andantephone is set up to control both an organ and a piano at the same time. The piano responds to the dynamics of velocity (how fast one stomps on the sensors) whereas the organ responds to how hard one presses down on the sensors. Whether controlling acoustic instruments, or synthesizing sounds, maintaining velocity, force, and displacement sensing allows a nearly infinite degree of musical expression to take place.

Thus although the song is usually pre-scripted, in terms of which notes will be played, the way it is played can vary widely in terms of tempo, dynamics, and various forms of footstep-induced expression.

10.1 Programming an andantephone

First consider songs that have entirely (or at least mostly) one note per beat. These are the easiest to program, and serve as good teaching examples. Programming begins with an arrangement of the song. Consider, for example, a simple nursery rhyme like “Mary had a little lamb”. I first lay this out in a table, as shown below, where note-rests are denoted “o” and chord rests as “0”.

Tile #	lyric	chord	note	foot	2/ time	4/ time	8/ time
1	**MAR**	**loud C**	e	L	**1**	**1**	**1**
2	y		d	R	2	2	2
3	HAD	quiet C	c	L	**1**	3	3
4	a		d	R	2	4	4
5	LIT	medium C	e	L	**1**	**1**	5
6	tle		e	R	2	2	6
7	LAMB	quiet C	e	L	**1**	3	7
8	o		o	R	2	4	8
9	**LIT**	**loud G**	d	L	**1**	**1**	**1**
10	tle		d	R	2	2	2
11	LAMB	quiet G	d	L	**1**	3	3
12	o		o	R	2	4	4
13	LIT	medium C	e	L	**1**	**1**	5
14	tle		g	R	2	2	6
15	LAMB	quiet C	g	L	**1**	3	7
16	o		o	R	2	4	8
17	**MAR**	**loud C**	e	L	**1**	**1**	**1**
18	y		d	R	2	2	2
19	HAD	quiet C	c	L	**1**	3	3
20	a		d	R	2	4	4
21	LIT	medium C	e	L	**1**	**1**	5
22	tle		e	R	2	2	6
23	LAMB	quiet C	e	L	**1**	3	7
24	its		e	R	2	4	8
25	**FLEECE**	**loud G**	d	L	**1**	**1**	**1**
26	was		d	R	2	2	2
27	WHITE	quiet C*	e	L	**1**	3	3
28	as		d	R	2	4	4
29	SNOW	medium C	c	L	**1**	**1**	5
30	o		o	R	2	2	6
31	0	drum 0	0	L	**1**	3	7
32	o		o	R	2	4	8

*This chord may seem “wrong” to persons more familiar with the usual chord progression of the “1234” tempo, but serves to create the “12” tempo, in which the finer granularity of the chord progression more closely follows the melody (i.e. the note “e” is a member of the chord “C” but not “G”). Removing all of the quiet chords would make the melody match what most people are familiar with, i.e. to emphasize only every 4th beat, so the volume of the quiet chords is set low enough that the “1-2-1-2-...” effect is as subtle as desired.

This song uses 32 tiles, so if it is being programmed on a 64-tile andantephone, simply repeat the song twice (i.e. do two verses for each revolution around the andantephone). In the case of a large outdoor linear andantephone, perhaps the number of tiles used (i.e. whether or not you can keep going around for each verse) is less important.

Let us suppose that, for this arrangement, we wish to have a strong walking beat. We an achieve this by alternating chord, note, chord, note, and so on. Thus if you begin with your left foot, then, for this particular arrangement, each time your left foot hits a tile, a chord (or rest) will play. Each time your right foot hits a tile, only an individual note (or rest) will play. This creates a sense of 1-2-1-2-1-2... timing.

Moreover, each four steps has medium accentuation, so the sculpture also expresses an element of 1-2-3-4-1-2-3-4-... timing.

Additionally, each eight steps has a strong accentuation, so the sculpture also expresses some degree of 1-2-3-4-5-6-7-8-1-2-3-4-5-6-7-8-... timing.

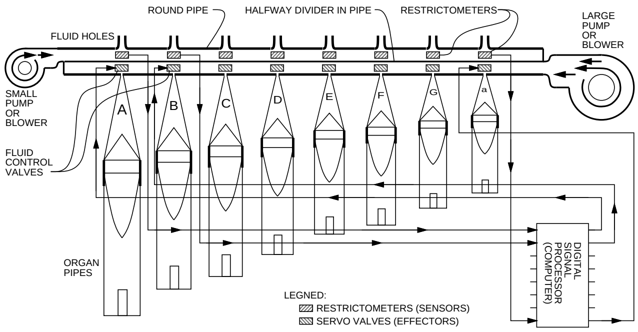

Figure 14: **Example of one of my hydraulopone-based acoustic andantephonic sculptures:** This sculpture has eight hydraulically modulated organ pipes that provide the notes of a natural minor scale. Songs in a major key often start on the third pipe (“C”). A digital signal processing system is used merely for process control, to achieve system stability, and to provide some fluid amplification. In all regards this is a truly acoustic musical instrument with the full expressive capability to capture the nuances in the different ways that people step on each of the hydraulic actuator pads.

The next step in programming is to encode this table into the sculpture. Let us first consider the case of a centralized acoustic sculpture, using pneumatic or hydraulic action, as shown in Fig. 14.

In this case, each tile has a small hose emerging from it, and the song is programmed by way of a small patch bay using “one touch” pneumatic (or hydraulic) fittings.

Chords are implemented by having a three or four port fluid manifold for each chord, as shown in Fig. 15.

Some of the sculptures use electric actuation of acoustic organ pipes in a similar way, to maintain the same full range of expression. In this case an analog electric current takes the place of the fluid. In some versions of the sculpture, the entire process is modeled in a computer program, and sensor pads in the tiles are each connected to an individual analog input on the computer. A typical computer with a sixteen channel analog to digital converter allows for 16 tiles. Larger numbers of channels are facilitated by stringing together multiple low cost analog to digital converters, or by using one that has a larger number of inputs.

In this case, the table is simply loaded into the computer. Songs can be downloaded over the Internet and changed easily. Additionally, the sculptures can be used over the Internet, so that walking on one garden plays an andantephone elsewhere in the world. This form of interaction is particularly fun in waterparks in which hydraulophonically-based andantephones are linked to each other through the World Wide Web, so that children in one park can stomp on the water jets to turn on jets in another waterpark. This creates the illusion that they are pushing water across cyberspace.

By adding a video conferencing link, people can play a round or harmony together in different gardens around the world. Certain songs go well together in this way. For example, a sculpture in one city playing “Land of the Silver Birch” will play well together with a sculpture in another city playing “My Paddle”, as long as participants in the two cities walk at the same pace. The challenge of walking at the same pace creates a new form of interaction over the Internet.

11. CONCLUSIONS AND FUTURE WORK

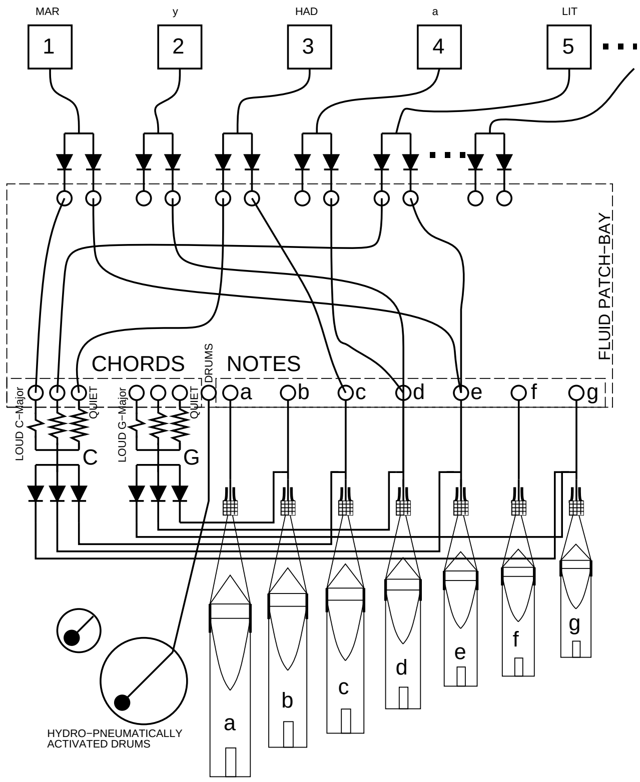

Figure 15: **Hydraulic patch bay:** A song is programmed into the sculpture by connecting hoses in the patch bay as illustrated. The one-way valves (fluidic diodes) keep fluid flowing in the proper direction. Flow control valves (denoted as resistors) reduce the volume levels so that the chords do not overpower the melody, and so that loud or quiet chords can be separately programmed, as desired. Rather than patch the chords as individual notes, for simplicity, they are grouped as separate sub-patch panels, made from one-touch tee fittings. For simplicity, only the first five slabs are shown patched in.

Walkable user-interfaces were explored. In particular, an arrangement of patio stones or tiles along a walkable path, together with appropriate sensing technology, formed a new and fun input device that taught children musical timing concepts like rhythm and tempo. It was also fun to use, and helped to break down cultural and generational barriers.

Presently we are building other multimedia parks in public spaces, including waterparks, that use rows of water jets in place of the patio stones and sensors. Songs are played by walking on water, sequentially blocking water from coming out of the water jets. A long winding path through the waterpark allows participants to walk from one water jet to the next. Each jet produces a different part of a musical composition when it is blocked. The full range of expressive capability is increased, because of the infinitely many different ways in which the water jet is blocked. The sculpture, for example, responds to differences in the pressure, displacement, velocity, and acceleration with which the foot comes down on the water stream. Additionally, the sound depends on whether the jet is blocked straight across or obliquely. Finally, there are differences in whether the user's foot goes down on the jet from above or "slices" into the side of the jet. As a result, people with no musical training can play music in a very soulful and expressive way that captures their emotional engagement their specific performance of the song that is programmed into the andantephone.

12. REFERENCES

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