Rainboard and Musix: Building dynamic isomorphic interfaces

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ABSTRACT

Musix (an iOS application) and *Rainboard* (a physical device) are two new musical instruments built to overcome limitations of existing isomorphic instruments. Musix was developed to allow experimentation with a wide variety of different isomorphic layouts to assess the advantages and disadvantages of each. The Rainboard consists of a hexagonal array of arcade buttons embedded with RGB-LEDs, which are used to indicate characteristics of the isomorphism currently in use on the Rainboard. The creation of these two instruments/experimentation platforms allows for isomorphic layouts to be explored in ways that are not possible with existing isomorphic instruments.

Keywords

isomorphic, mobile application, hexagon, keyboard

1. INTRODUCTION

Since Euler's development of the Tonnetz in 1739, musicians, composers and instrument designers have been fascinated with the concept of musical isomorphism, the idea that by arranging tones by their harmonic relationships rather than by their physical properties, the common shapes of musical constructs will appear, facilitating learning and new ways of exploring harmonic spaces. The construction of isomorphic instruments, beyond limited square isomorphisms present in many stringed instruments, has been a challenge in the past for two reasons: The first problem, that of re-arranging note actuators from their sounding elements, has been solved by digital instrument design. The second, more conceptual problem, is that only a single isomorphism can be designed for any one instrument, requiring the instrument designer (as well as composer and performer) to "lock in" to a single isomorphism, or to have a different instrument for each isomorphism in order to experiment.

When playing a note-based instrument, the relative location of the note actuators (keys) to each other is a fundamental feature of the instrument, and can affect learning, playing, and composition. The linear note layout (one semitone next to another) is the *de facto* standard arrangement for western 12-tone music, and the piano, guitar, and violin are the most common popular instruments[1]. Single-note instruments such as brass and woodwinds do not constitute a "layout" in this context since a combination of actuators (and additional controls such as breath) produces a single note, rather that having all notes available at once. Alternate note layouts such as the Jankó keyboard [17] have been proposed in the past, however they remained obscure, mainly because of the expense of construction and the limited number of people who knew how to play them.

In the last thirty years, there has been a resurgence of interest in alternate note layouts for the 12-tone western scale (as well as for microtonal contexts) with devices such as the Thummer [14] and C-Thru AXiS[2]. Many alternate layout instruments are based on the concept of musical isomorphism (see below, and detailed in Maupin [10]) which promotes quicker learning, an intuitive connection to musical harmony, and a more compact arrangement than a traditional linear piano keyboard [11]. Like the Jankó, however, these new instruments have not become commercially successful despite the features and benefits.

1.1 Musical Isomorphisms

A *musical isomorphism* is a regular arrangement of note actuators on a surface such that each musical construct, (for example, a major chord) has the same shape no matter the tonic of the construct. Bass guitars and Mandolins are examples of rectangular isomorphic layouts, since each fret is the same harmonic distance from the previous fret (a semitone) and each string is the same harmonic distance from the previous string (a perfect fourth for bass guitar, a perfect fifth for mandolin). The result is that any "shape" on the fretboard is the same harmonic construct, regardless of the tonic. This is not the case with a guitar, however, because not every string is the same distance from the previous string, so a single shape can create different musical constructs, as shown in Fig. 1. Similarly, a piano is not isomorphic because not all white keys are the same harmonic distance apart, (although they are the same physical distance apart) and a single harmonic construct can have a number of different shapes, depending on the tonic of the construct. An isomorphic key layout arranges the notes by their harmonic relationships, and the result is that any given shape will have the same harmonic construct regardless of the starting tonic, as shown in Fig. 2.

This paper presents a discussion of the current state of development of isomorphic instruments, and enumerates a series of problems with the current state of development. Two new musical instruments are presented which are shown to be able to employ any isomorphic layout, a significant improvement over the current state of single-layout isomorphic instruments, as well as rapidly switch between layouts and inform the user of the current layout through note actuator labels. The design and construction of these two instru-

[1]`http://www.musictrades.com/census.html`

[2]`http://www.c-thru-music.com`

NIME'13, May 27 – 30, 2013, KAIST, Daejeon, Korea.

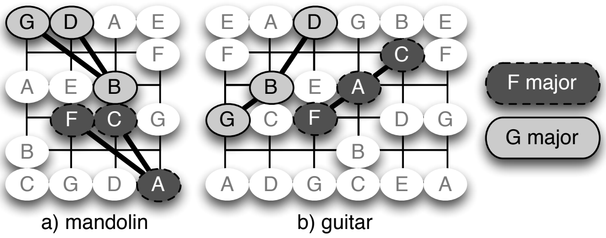

Figure 1: isomorphic and anisomorphic stringed instruments: (a) the mandolin has same-shape triads; (b) the guitar has different-shape triads.

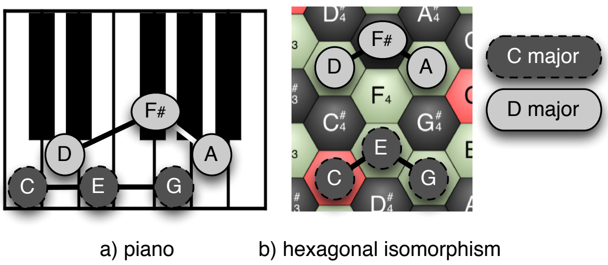

Figure 2: isomorphic and anisomorphic keyed instruments: (a) the piano has different-shape triads; (b) a hexagonal isomorphism has same-shape triads.

ments are presented in detail, as well as the advantages of having multiple layout available and of displaying more informative note actuator labels.

The first instrument, *Musix*, is a tablet/smartphone app developed for the iOS platform, which allows the user to choose from a set of standard isomorphic layouts or create their own. The instrument contains internal synthesizers and can be used to drive external synthesizers. The second instrument, the *Rainboard*, is a 61-button physical controller arranged in a compact hexagonal layout, with coloured LEDs under each button, which can represent any hexagonal isomorphism. Musix can also be used as a configuration interface/synthesizer for the Rainboard.

Both Musix and the Rainboard are proving to be valuable research instruments for the ongoing study of musical isomorphisms, the comparison of different isomorphisms, and the benefits and drawbacks of isomorphisms over traditional layouts. By creating both virtual and physical devices, rapid user testing on small and large scales can be realized. Musix and the Rainboard are multi-purpose tools, acting as performance instruments, composition tools, research platforms and musical education devices. They are the first devices to allow users to rapidly switch between different musical isomorphisms in order to compare them.

There are two shapes that allow for isomorphic layouts on planar surfaces: rectangles and hexagons. Rectangular isomorphisms are commonly found in string instruments, as discussed above, and Musix is able to employ both rectangular and hexagonal isomorphic layouts. Hexagonal layouts allow for more complex interval relations (since each note touches 6 other notes) and are more compact than rectangular layouts. For the remainder of this paper, isomorphic layouts will refer to hexagonal shaped isomorphic layouts unless otherwise stated.

2. EXISTING ISOMORPHIC INTERFACES

Isomorphic layouts have been around for hundreds of years, one of the first being based on a tone matrix called the Tonnetz [5], and they have been analyzed for their musical properties [7]. Recently, the idea of isomorphic layouts has been used to create commercial instruments, however, all of the available instruments focus on a single isomorphic layout which the developers of the instrument prefer for one reason or another. Many isomorphic layouts exist and can be rotated or mirrored which can greatly affect the manner in which they are played, however none of the existing commercial instruments allow an easy way to change layouts while providing visual feedback to the user about the new layout. The following is an abbreviated list of commercially available isomorphic instruments.

The AXiS Keyboard.

C-Thru Music produces two different isomorphic keyboards called the AXiS-49 and the AXiS-64, both based on the fixed Harmonic Table layout. The main difference between these two keyboards are the number of keys and additional MIDI controls. C-thru Music has added firmware upgrades to help people use the device with external software, specifically by allowing the keys to be remapped to a different layout. This firmware upgrade demonstrates that users are interested in playing with alternate isomorphic layouts.

Opal.

The Shape of Music[3] creates a keyboard similar to the AXiS called the Opal. The two companies are very closely linked as Peter Davies, who holds a patent [3] on the Harmonic layout, worked with C-Thru Music to create the AXiS. The Opal is a higher end version of the AXiS containing 192 keys and 16 different layouts. It is important to note that, like the AXiS, while the layouts can be changed in software, they do not change the physical appearance of the device.

Manta.

Although not explicitly for music making, the Manta [16] by *Synderphonics* contains a layout of hexagon capacitive touch sensors. Each sensor also has a bi-colour LED mounted behind it to allow for status updates. The device is a general purpose USB controller but could also be used as a musical instrument. It is important to note that the capacitive touch sensors do not detect location, just the degree to which the user is touching each sensor area.

Thummer.

From 2003 to 2006,*Thumtronics* attempted to commercialize the Thummer [12], an instrument consisting of two isomorphic keyboards, one for each hand, akin to the form of a concertina, with a joystick for each thumb to offer additional expressivity. Rather than using the Harmonic Table layout, the Thummer used a Wicki [6]/Hayden [8] layout. Unfortunately, the thumer has not been commercially successful and Thumbtronics has ceased development.

Hex Player.

Hex Player [13] is a virtual isomorphic controller developed for exploring layouts where the pitch of a note is directly related to its vertical location on the surface. One of the primary purposes of the controller is for exploring alternate tunings [12] and microtonality. It does have the ability to experiment with many isomorphic layouts, however, the layouts produced are constrained to a vertical slice of notes with specialized qualities. Although Hex Player introduces some interesting ideas (such as shearing the hexagons) it is not meant to be a general purpose isomorphic explorer.

[3] `http://www.theshapeofmusic.com/`

2.1 Static Layouts

Currently, all physical isomorphic instruments have a static physical layout, in that they are fixed to one specific arrangement of notes, by design. For example, the AXiS-49 is configured for the harmonic table layout; and the traditional concertina uses the wicki-hayden layout. The hexagonally arranged keys on the instruments are coloured or textured to give the user an indication of which keys are which, often by colouring the keys in the same way that the piano keys are traditionally coloured, with the "natural" C-major notes coloured white, and the remaining notes coloured black. This static note identification is limiting for a number of reasons. There are dozens of unique isomorphic layouts, and hundreds of different ways to arrange and orient them. Some keyboards such as the AXiS-49 can remap the keys to a different layout using a midi-enabled computer, but the physical keys are not changed and the user must remap the notes to the new layout in their head, overcoming the existing visual cues that still indicate the original layout. This is like using software to remap your computer keyboard to a new arrangement of letters (*e.g. Dvorak*[4]) without changing the labels on the keys themselves. Each key shows a value, but you get something different when you press it. Some users have physically remapped the AXiS by removing and repositioning the keys, but this is a time-consuming process and does not permit rapid remapping.

3. ISOMORPHIC PROPERTIES

The defining property of a musical isomorphism is the set of interval relationships between notes. This relation defines the shape of musical constructs as well as overall movement when playing note sequences. The ability to modify the layout by changing the harmonic relationships between notes is critical for exploring the space of possible isomorphisms, including rotated and mirrored layouts which share the same interval relationships in a different order or arrangement. Some devices like the Opal allow additional layouts to be selected via hardware; and others, such as the AXiS, can use software to remap the hardware notes to different midi notes, but none of the current instruments provide visual feedback on the playing surface to show the new layout. If any aspect of the layout is changed, the user is forced to ignore all of the markings on the keys and blindly learn the new layout. Additionally, the piano colouring is primarily useful in only two circumstances: (a) the player is already familiar with the piano layout *and* can create a mental mapping from the keys on the isomorphic keyboard to the linear arrangement of a piano; or (b) the player is using one of the natural modes (C-major, A-minor, G-Mixolydian etc.) indicated by the white keys.

A second property of a musical isomorphism (and any discrete-activator-based instrument) is the size of the note actuator itself. Piano keys are between 10 and 12 mm in width, and a piano with smaller or larger keys is more difficult to play. Current isomorphic instruments vary in the size of their note actuators, again based in part on the isomorphism chosen for the instrument. One of the flagship features of the AXiS, for example, is that major and minor chords can be played with a single finger, pressed at the intersection between three hexes. In order to achieve this, the buttons on the AXiS have a major width of 20 mm and an edge length of 10 mm, similar in scale to the keys of a piano. The problem, however, is that because the notes on a piano are arranged linearly, most consonant notes are one or two keys apart, allowing chords to be played comfortably with fingers slightly apart. On the AXiS, however, consonant notes are very close together, often touching, so chords must be played with fingers tightly clustered together, which can be awkward and uncomfortable. Scales played on the AXiS are comfortable because semitones are so far apart in the Harmonic table layout. A different isomorphism would have different ergonomic characteristics based on a given key size.

Additionally, smaller keys mean more keys can be made available given a specific surface. One of the motivations for making smaller keys has been to allow a larger "reach" (more notes that can be played by a single hand at one time), but the compactness of most isomorphic layouts means that a typical reach can be many octaves wide, even with large buttons. There are many arguments for different sizes of keys, and ideally the user would be allowed to change the size of the keys in order fit their abilities. While this is possible in a software isomorphic instrument, hardware instruments are constrained to a single key size.

Isomorphic note layouts are used in several areas of research such as music sight reading [15], music visualization [1], and alternate tunings [12]. The use of isomorphic layouts for microtonal music goes back to the late 1800's with the generalized keyboards developed by Bosanquet [2]. Early musicians needed a way to lay out more notes on a keyboard yet retain some of the familiarity of the more popular keyboards [9]. Although isomorphic keyboards have long been used for enharmonic research and performance, significant quantitative research using 12-tet layouts has *not yet* been published. Hayden has evaluated many 12-tet layouts and claims we can ignore many of the hundreds of possible layouts due to mirrored and rotated orientations, reducing the set to only 9 interesting layouts [18]. Although many layouts have strong relations, each must still be considered for its ergonomic properties. For example, a piano rotated to be vertical rather than horizontal would provide a completely different playing experience.

4. NEW DEVICES

The motivation to create Musix and the Rainboard came from our ongoing experimentation with existing isomorphic instruments, as described above. Each commercial device has its advantages, but we wanted to experiment with a wide variety of isomorphic layouts in rapid succession. Our first effort was to create isomorphic experimentation software (Musix) on a touchscreen device. A software solution is easier to prototype and refine since it does not require design, constructing or refining the design of a physical mockup, and the touch screen allows direct interaction with the isomorphic layout by the user. The use of a touchscreen allows the user to obtain much more information about the layouts (such as notes and interval direction) than from static instruments. Visual layout feedback and dynamic layout generation makes Musix unique among both tablet apps and physical isomorphic instruments, however, touch screen instruments lack tactile feedback: If you can't feel the note before you play it, you need to keep your eyes on the screen and this is not ideal.

Once the interaction characteristics of the tablet app were refined and understood, we began constructing a physical device (the Rainboard) with the same reconfigurable characteristics of the tablet app in order to overcome the limitations of touch screen devices. The Rainboard is unique among isomorphic instruments in that it is the only one which dynamically changes the colours of each key to provide visual feedback to the user. The Rainboard uses MIDI for setting layout information as well as for synthesizing audio. A special version of Musix is used to provide an interface to the Rainboard for rapid manipulation of layout

[4]http://www.andong.co.uk/dvorak/

parameters and colouring settings. This connection is made via MIDI over the standard Apple USB adaptor (from the "camera kit"). Event information from the Rainboard (such as a key presses and expression controls) are sent to the iPad to have the audio synthesized by a MIDI-enabled app such as NLog Synth Pro[5] or Sampletank[6]. The USB midi interface on the Rainboard can also be connected to any standard usb-enabled MIDI synthesizer or computer. Although still in the prototype stage, the Rainboard is proving to be a popular instrument and has been seen by almost three quarters of a million people through various youtube channels[7] and blogs[8].

4.1 Musix Pro

Development of Musix began in early 2010 and the application was released to the public in the fall of 2010. In late 2012, we released an updated version (Musix Pro) containing a number of additional features including rectangular layouts (in addition to the hexagonal layouts present in the original version of Musix); scale colouring; and alternative note labelling. The application allows users to generate any possible isomorphic layout (with adjacent note intervals restricted to an octave or less) by selecting two intervals for adjacent notes. Two intervals are sufficient to fully specify an isomorphism since opposite-direction intervals will be the complementary interval in the opposite direction, and the third pair of intervals is the sum of the previous two by a triangle identity. (for more details see Maupin [10]). The user also has the ability to change the size of the notes, scale mode, tonic, note colouring, and note text labelling. The generated layouts are also fully-functional musical instruments which can be played by touching the screen, with audio being generated either by an internal FM-based synthesizer, or by an external MIDI synthesizer.

The initial release of Musix and subsequent release of Musix Pro (Fig. 3) has advanced the use of isomorphic layouts for interfacing with new expressive instruments. As of April 23rd, 2013 the app has been used in 132,218 unique sessions with an install base of over 23,789 devices.

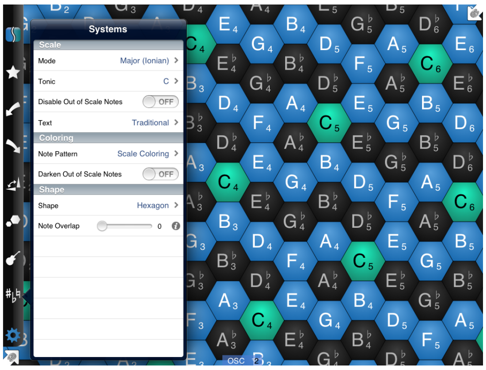

Figure 3: The Musix interface.

4.1.1 *Touch to Hexagon Algorithm*

Since Musix Pro is a musical instrument, it is critical to reduce latency (the time from when the user activates a control to when a sound is produced). This is complicated by the fact that the interaction areas are generated in real time, can be moved to any location on the screen, and it is possible for thousands of hexes to be visible at once. To reduce latency, we developed a constant-time algorithm to map a touch location to a unique hexagon on a grid.

The algorithm works by giving all hexagons a grid coordinate. The grid is initially laid out by starting with the note at the top left corner. The screen is then divided into 4 columns per hexagon width and two rows per hexagon, as shown in Fig. 4. Each touch is mapped to a grid location, and the grid numbering is used to identify the hexagon. If the column is not divisible by three, the hexagon can be uniquely identified by row and column number. If the column is divisible by three (i.e. $x \mod 3 = 0$), the touch must be disambiguated. In even rows and odd columns (after mod 3), the column is divided by a positive-sloped line. In odd rows and even columns, it is divided by a negative sloped line. The hexagon can then be disambiguated by calculating which side of the line the touch is on. Each operation is either a modulus or a comparison, and so the algorithm completes in constant time.

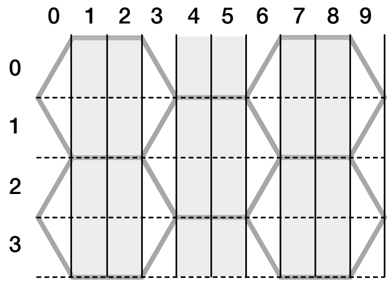

Figure 4: Hexagon identification algorithm. Columns divisible by 3 must be further examined, other columns are trivial.

4.1.2 *User layout customization*

Musix Pro contains a set of the most commonly used isomorphisms, including Wicki Hayden, Harmonic Table, Linstrument, and a number of layouts of our own design ; each with its own advantages and disadvantages. Since one of the goals of Musix was to allow users to experiment with a wide variety of isomorphic layouts, we developed a system that would allow the user to produce any isomorphism by selecting the appropriate intervals. The user can assign any interval (up to an octave) in each of two directions, and the system will generate an isomorphic layout with those intervals. Not every layout is "complete", meaning some user selections may result in an isomorphism that does not contain every note in the western 12-tone scale. We call such layouts "degenerate" since they are mathematically incomplete, but we do not prevent the user from experimenting with such layouts. For example, if the user selects an ascending major second on each of the two available directions, the third interval will zero and the layout will not generate semitones.

4.2 Rainboard

The user response to Musix has demonstrated that isomorphic layouts are of interest to a large audience, but the lack of tactile feedback and limited playing area of touch screens can be a problem for using Musix in performance. In order to overcome these issues, a physical isomorphic instrument named the Rainboard was developed (see Fig. 5).

When designing the Rainboard, providing visual information about the current layout was essential and was the feature missing from existing instruments. Musix allowed us to display text labels for each note actuator, but displaying text on a physical button is a problem. There are

[5]http://www.temporubato.com
[6]http://www.ikmultimedia.com/products/sampletank/
[7]http://www.youtube.com/watch?v=EKkXLZJDNrA
[8]http://hackaday.com/

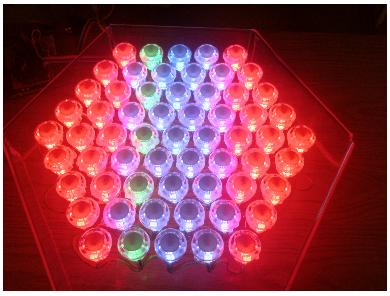

Figure 5: Top view of the Rainboard in a Wicki/Hayden layout showing a major scale.

solutions like button-sized OLED screens which would allow us to display whatever we want on each button, but these are prohibitively expensive (for comparison, see the Optimus Maximus[9] computer keyboard). Instead, we chose to use an RGB-LED integrated into each button, with the buttons in a hexagonal layout. The RGB LEDs can be used to change the colour of each button independently, showing the user which layout is currently active, the button to note relationship, and the harmonic relationships between the notes. There is some learning involved, for example, the user must learn that one colour of notes is in the scale and another is out of the scale, or that keys of a particular colour correspond to a particular tonic note, but the same learning is required for any new instrument.

In order to provide an effective, efficient and expressive user interface for layout configuration, we employed a software solution. Since Musix was already configured to allow the user to easily design and experiment with isomorphic layouts, we used Musix as the layout generator for the Rainboard. Musix communicates with the Rainboard using a MIDI channel over USB, similar to that used by the HIDUINO [4]. The Rainboard uses an Arduino Uno R2 with the onboard ATMega 8u2 running custom firmware allowing it to behave as a MIDI client device.

The Rainboard has 61 arcade-style buttons and 61 RGB LEDs. In order to interface these buttons and lights with the arduino, additional hardware is required. We use a 64 button shield[10] to receive and interpret button-press information, and a Serial Peripheral Interface (SPI) bus to drive the LEDs as a chain. An accelerometer integrated into the body of the Rainboard gives rough velocity information. The body of the Rainboard is cut from a sheet of acrylic and hot-folded. When a button is pressed, the button shield interprets the button press and sends it to the Arduino, which maps the button ID to a midi value. The accelerometer is then sampled to determine a velocity for that note, and the note and velocity are packaged and sent over MIDI. At the same time, the Arduino maps the button ID to a LED ID and turns the LED to white to indicate the button was pressed. An animation then starts and creates a ripple effect that emanates from the pressed button and updates the surrounding LEDS at 30fps. If multiple waves occur they interact with each other. The Rainboard also has a a linear touch sensor on one side, which can be applied to any midi parameter, and which we have chosen to map to pitch bend.

4.2.1 Polling Accelerometer Data

In an early prototype of the Rainboard, each key resulted in a MIDI note of a constant velocity, and we wanted a way to add expressivity in the form of per-note velocity controls. The arcade buttons we chose have only one actuator, so we couldn't use the double-action method: the time differential between two actuators on the same button giving the speed of the press and hence the velocity of the note. Instead, we used an accelerometer (Freescale MMA8452Q, sampling at 200hz and communicating over I^2C) installed in the center of the Rainboard. To detect the velocity of a hit, the acceleration orthogonal to the playing surface is collected in a rolling buffer, and when a button is pressed, the average of the absolute values of acceleration 2 samples before and 5 samples after the button press is used to infer the velocity of that press. The mapping can be modified using scale parameters available through the Musix interface. The I^2C connection between the accelerometer and the arduino is much to slow to be polled every loop, so a mixture between interrupt and polling was used: An interrupt flag on the accelerometer is polled in the main loop of the arduino. The accelerometer raises this flag when new data is ready, and a buffer's worth of data was then transferred from the accelerometer to the arduino.

4.2.2 Using the LEDs as a display surface

A grid of RGB LEDs can be used to display global information as well as local information. We use the LEDs in a number of ways to indicate information about the layout and the current state of the device to the player. When the Rainboard first powers-up, an animation is played to take each LED through the full range of colours. This performs two functions: First, it indicates a successful software startup of the device, and second, it draws attention to any LEDs that may not be functioning properly.

When the user selects a new layout through the Musix configuration system, the LEDs on the Rainboard display that layout to the user. There are a number of options for colouring schemes that can be used to indicate the layout to the user. The primary colour scheme differentiates between in-scale notes (coloured blue) and out-of-scale notes (coloured red). Using the Musix software, the user can select any root key and any scale/mode. Musix currently includes support for the 12 western tone centers, and allows the user to choose between one of 32 modes, ranging from the standard church modes, to blues, jazz, and world modes. For example, if the user selects C-ionian, the notes are differentiated the same as they would be on a piano (with white keys coloured blue and black keys coloured red). An alternative display mode colours each tone, for example C would be red, C♯ would be orange, etc. We experimented with 12-category colour sets that could be displayed by the LEDs and distinguished as separate colours, and fixed on two, shown in Fig. 6: "Pastels", which uses brighter colours by interpolating between Yellow, Magenta, and Cyan; and "Perceptual", which uses colours slightly further apart in the green-blue space, since western colour perception has fewer namable categories of green, and more namable categories of red (including orange and salmon).

4.2.3 Displaying the Wave

Although the focus of the development of the Rainboard was reconfigurable isomorphisms, the visual nature of the instrument has been a strong point of attraction when showing it to others. Specifically, individuals who have played the Rainboard have commented on the visual effect of the "wave" emanating from each pressed note, and have indicated that this wave is a significant aesthetic feature of the instrument. There are three key components to make the wave move through time: the start location of each wave, the time passed since wave start, and an increment timer. The timer establishes the frame-rate of the wave, and we

[9] `http://www.artlebedev.com/everything/optimus/`
[10] `http://spikenzielabs.com/`

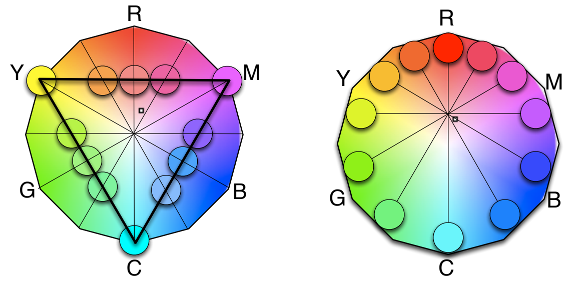

Figure 6: Colour wheel selections for 12-tone scales. (left) Pastels; (right) Perceptual

have set this at 30 fps. Each propagating wave has an effect on three concentric rings of buttons at a time, and takes four timer counts to move on to the next distance. The wave does add computational load to the Rainboard, and as a purely visual effect it was debated whether or not it would be included, but the reaction has been so positive that rather than removing it, the code was optimized to the point that multiple waves had only an incremental additional computational cost.

4.2.4 Keeping up with Sysex

Musix communicates with the Rainboard via midi in order to send new colour layouts and new note information, and rather than encoding the layout information in MIDI messages, we created custom sysex messages to communicate new layout and colouring information in batch. Because these sysex messages are relatively large compared to standard midi messages (378 bytes total for a completely new layout and colouring), there were occasionally problems with updating, when a byte would be lost in the transfer, causing a failed update. In order to allow these updates to happen, we disable non-crucial functions during a sysex update. These included accelerometer updates, slider updates, wave updated, and eeprom updates, and these processes are reactivated when the sysex message ends or a button is pressed. Combining this with optimizations of midi processing code and the sysex midi library, we were able to process each byte in about 600 cycles, allowing us to process sysex messages of any length.

5. CONCLUSIONS AND FUTURE WORK

Isomorphic note layouts promise many beneficial features yet the hardware that supports isomorphic layouts are static and provide limited visual feedback for a user playing them. Musix Pro and the Rainboard have been created to allow users to generate, analyze, and play isomorphic layouts with the advantage of visual feedback.

5.1 Microtonal and Modal support.

Although the Rainboard currently implements 12-tone equal tempered scales, it has always been our intent to support microtonal scales and user-configurable modes. Although our study of isomorphism was based in 12 categories, the same mathematics can be extended to any number of categories with the same result. As such, it is possible to create isomorphisms of 19-tone scales using the same hardware and software as the 12-tone scales currently implemented in Musix and the Rainboard. Further study of colour selection will be required for (for example) 19-tone scales, since it is difficult to distinguish between colours of the same hue and different intensity using the LEDs currently employed.

6. ACKNOWLEDGMENTS

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