# ARTIFICIAL SYNAESTHESIA

## Digital Media Master's Project Design Document

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Demo Link: http://dwig.lcc.gatech.edu/projects/Swaminathan/project.html

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Visualizing the effects of certain atypical neurocognitive syndromes using digital interfaces

**II. Committee**

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Dr. Ashok Goel
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**III. Abstract**

Atypical neuro-cognitive syndromes produce effects for people that are not often understood by neuro-typical people (due to the different neurological conditions). To fully understand the experience, there should be some form of simulation that demonstrates these effects. We can use the affordances of Digital Media and perform such a simulation depending on the perceptive systems involved in the cognitive process. If there are visual and auditory elements involved, we can simulate the mapping of one sense onto another. One example that illustrates this type of mapping would be a kind of music equalizer that maps the audio signals of the song to a visual representation in the form of an equalizer. To develop such a project, I analyzed existing work on synaesthetic media experiences in order to develop a solid form of mapping. The next step was to computationally abstract the underlying cognitive process (of an atypical syndrome involving music perception) and built an interface through which people can experience the effects. I created an "Artificial Synaesthesia" device that performs such an interactive mapping and displays a visualization that allows users to gradually realize the result of

the different mapping process. Through this experience, I hope to provide another perception of music for people by revealing to them the result of atypical cognitive processing (Synaesthesia) of music.

## IV. Theory and Related Work

Synaesthesia is a neurological condition that occurs due to a cross-activation of different sensory systems. As an example, cases can involve people seeing either certain numbers as being specifically colored or having certain kinds of sounds affecting your taste. The experiences are usually perceived as being very natural among synesthetes unless someone points the uniqueness out to them or they read about it (Cytowic and Eagleman, 2009). One specific type of Synaesthesia is an auditory-visual synaesthesia, where an influx of sound signals will generate visual percepts for the person and the visual percepts can differ and be unique for each individual that possesses this type of Synaesthesia.

### Current Research

There has been lots of scientific research as well as artistic projects in this field of research, which include work by artists such as Marcia Smilack and Michael Fratangelo. The most relevant ones related to my project are the computer-realized video works and recordings by Brett Battey, Visual Magic projects by Nancy Herman and Bloom by Brian Eno. There use certain types of artificial synaesthetic devices like the feelSpace device and the scoreLight project. My approach will have a digital media and neuroscientific focus to it, mainly using research by Richard Cytowic, Vilayanur Ramachandran and Oliver Sacks.

Oliver Sacks observes the unique effects that music has on the emotional centers of our brain and also how the re-creation of musical memories in the mind has the capacity to sometimes make it indistinguishable from an external music source (Sacks, 2008). He cites instances of multiple patients suffering from or enjoying different music-related conditions that either hinder or enhance one’s perception and processing of music. Sacks talks about most of these cases to illustrate that unlike other forms of communication, music has a very distinct form of processing in our brain. He goes on to state that whereas certain kinds of language skills can only be learned at infancy, learning musical skills doesn't have a particular age barrier.

Richard Cytowic (Cytowic and Eagleman, 2009) found that the effects of Synaesthesia are automated perceptual experiences that cannot be particularly controlled or stopped. He also points out that most of the sensory perceptions have simple mapping mechanisms – such as specific numbers having an assigned color to them. He goes on to say that Synaesthesia might have links to the limbic system (associated with emotion), and that a lot of Synaesthetic effects might have an emotional construct attached to them.

Ramachandran and Hirstein say that the inadvertent act of making correlations between information from 2 different sensory systems has a rewarding effect and generates a satisfying sensation, which is not hindered by the level of abstraction of these correlations. Sensory substitution studies like the ones used in the feelSpace experiment suggest that forms of Synaesthesia can also be acquired. This acquisition is not always immediate and might require regular reinforcements of perceptive exercises but it is possible.

Combining the work of all these scholars, it is clear that synaesthetic experiences are concise in their cognitive appearance (Sacks, 2008, Cytowic and Eagleman, 2009). Its perceptive attributes and be clearly mapped out (Cytowic and Eagleman, 2009) and taught through sensory substitution techniques to neuro-typical people (Ramachandran and Hirstein, 1999). These techniques will be applied to build the artificial synaesthesia application.

**The problem and my proposed solution**

The main problem I am addressing is that of music perception and those digital artifacts that can be used to explore that particular realm of study. Everyone has a certain capacity for the perception of music that has evolved with our ability to learn languages (Sacks, 2008). Even though it can be said that people process music in a more or less similar cognitive way and describe it in terms of metaphors, I think the perception of music itself can be experienced in different ways (as shown by synesthetes) and in turn can have a novel effect on the processing of music. The problem here is that majority of people do not have synaesthesia and have no way to experience music the way that synesthetes do. Any particular way to experience music is only a position on a much larger scale of media experience and neuro-typical perception should not be seen as the only possible option. To provide a means in which a different perceptive experience of music could be offered, we need to first identify the cognitive aspects associated with Synaesthesia.

The functionalities of certain parts of our brain are often identified by atypical characteristics in our regular cognitive processing. Certain atypical neuro-cognitive syndromes reveal anomalies in our cognitive systems. For example, a particular type of disorder that induces auditory hallucinations in a person's mind could be the result of a faulty part of the auditory system in that person's brain (Sacks, 2008). Studying the role of this faulty part in the atypical auditory system could reveal anomalies that are not otherwise present in typical systems (Ramachandran, 1999).

These anomalies can then help us understand how different parts of that particular cognitive system work by analyzing its functionalities in different people. In fact, these anomalies have shown to display a great capacity for expressing metaphors through cross-modal relations (Cytowic and Eagleman, 2009). As the capability of people to learn new aspects of musicality does not diminish at a later age (Sacks, 2008), I think it is possible for people to acquire different perceptive experiences of music at different ages. In order to build a context in which that would be possible, it is important to investigate the effects of these atypical syndromes by replicating the process and letting people experience their effects in a digital form, specifically the effects of music perception. By providing some context and experiencing different viewpoints, it will help us understand what we consider being "normal" perception by observing the results of an atypical process; and by using digital media and user interaction design, we can further realize this by including a participatory element and enhance the experience further within that context. Artificial Synaesthesia can be induced by taking in the real information of one sense (in this case - sound) and mapping it onto another sense through the use of a computational process that performs these cross-modal wirings. The application will then visualize the process of hearing with your eyes, by mapping sound to visual elements.

This application will be a visualization of the underlying processes of synaesthesia. To include participation, the visualization will be interactive and could be described as an Artificial Synaesthesia application. It will run on a procedural version of the underlying cognitive process, and by interacting with the visualization in real-time, the different cross-sensory processes can be experienced. Participants do not only visually map the sounds onto images but also learn to map their interaction (playing an instrument) onto a synaesthetic visualization (images instead of audible music).

There exist Artificial Synaesthesia devices (audio -> visual) but I've found that they are usually of two types. The first type mimics the visual synaesthetic effects and manifests them in the form of a visualization or generative art installation with no interaction (e.g. Synaesthesia App: http://logarithmic.net/pfh/synaesthesia). The other type is usually a generative application that creates visuals based on the viewer's input (e.g. Brian Eno's Bloom & Trope: http://www.generativemusic.com/). Both types do share the intention of showing the effects of synaesthetic processes to people who do not experience them, but not particularly intending to change the viewer's perception. My application includes both these aspects in its approach as it involves procedural generation of the visualizations as well as participation simultaneously.

The generated display will have elements reacting to the music as well as to a viewer's input. The viewer can play along with the music using a MIDI instrument such as MIDI keyboard, to which the visual elements will change in real-time. Through this play-along approach and matching up the visual elements from the audio piece, I am hoping to cultivate an approach to listening to music that involves a visual experience rather than a typical auditory one. The neurological components required for such an experience is present in all of us, but the ability to make the connections between those components is present inadvertently in Synesthetes (Hubbard and Ramachandran, 2005). Neuro-typical people can make these connections, or at least to an extent that might result in changing their current perception of music (Cytowic and Eagleman, 2009). I think this can be achieved by having neuro-typical people actively participate and reinforce these cross-modal senses in an environment catered to such experiences. My application will act as a proof of concept prototype, that acts as framework, attempting to do just this by combining real-time feedback and procedurally generated visuals.

I will be building an interactive visualization tool that is built on a computational abstraction of the cognitive process involved in this cross-modal wiring. The interaction involved in manipulating this visualization allows for new mappings for the users when they encountered the new music perception. The participant will first experience the visualization of a music piece and try to manipulate certain elements of the mapping process like an emotion related color scheme (eg: Light Blue associated with ambient sounds). Through this interaction of experiencing changes in the visualization, the mapping process of processing music related information for the participant would change.

I will use the work and research mentioned above to focus on taking a neuroscientific approach in building a prototype that would try and change a person's mapping after they have experienced the effects of the application. The processes running the application will be based on the different neurological conditions associated with music.

**Related Work**

There are Artificial Synaesthesia devices that perform certain kinds of information mapping depending on their intended function, and are often generative art works. This is true for Synaesthesia artists that specifically cater to an audience that can relate to the artistic expression as well as to neuro-typical people that would perceive the art as a form of surrealist work.

**FeelSpace:**

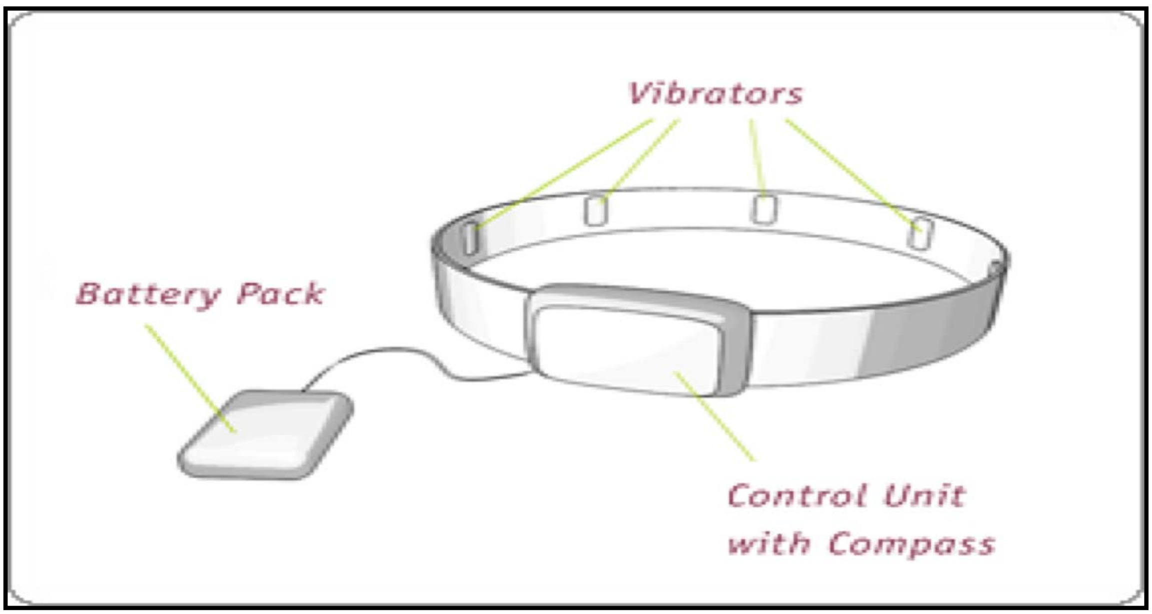


*Figure 1: FeelSpace Device Components*

A project more closely related to the one I propose to create (although involving different sensory mappings) is the feelSpace device. It tries to create a mapping between our spatial and directional systems to our touch senses, so the person can improve their navigational skills. The device uses vibrations to help people manage their spatial orientation in an environment. The vibrations are induced through a belt that is worn by the user. This device aims to explore the effects of long-term stimulation (specifically with regard to orientation information).

http://feelspace.cogsci.uni-osnabrueck.de/en/technology_01.html

**ScoreLight:**

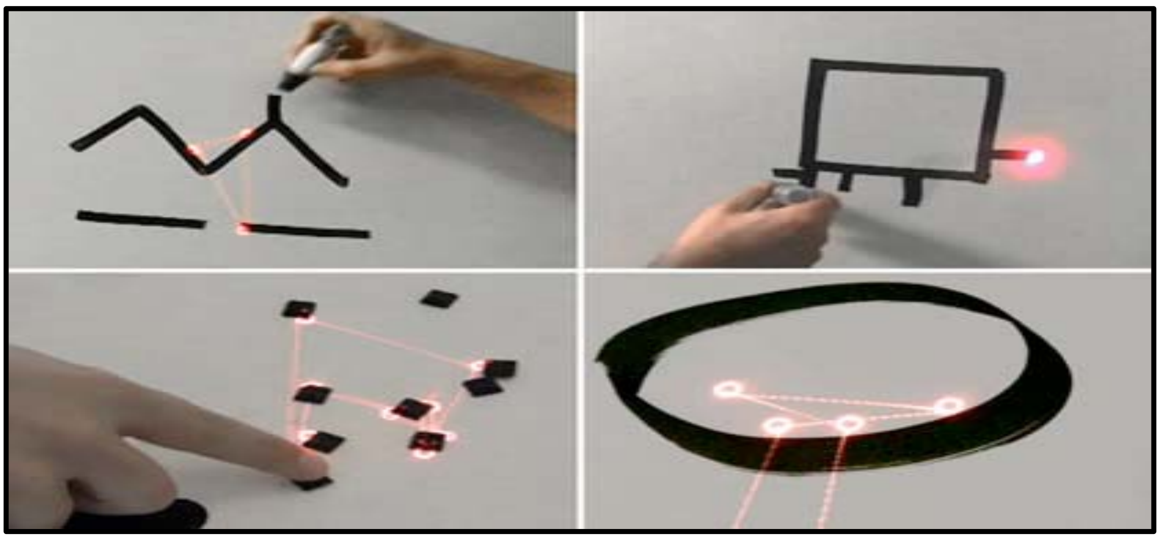

*Figure 2: ScoreLight working with shapes*

This device analyses different shapes (using a laser) and generates pieces of noise that are proportional to the contours of the shapes, and hence performs a shape to sound artificial synaesthesia. This device is conceptually different to the one I propose to make because the sensory mappings are different, and it doesn't attempt to alter the viewer's perceptions of either of the senses (shapes and sound) involved in the process.

http://www.k2.t.u-tokyo.ac.jp/perception/scoreLight/

**Trope:**

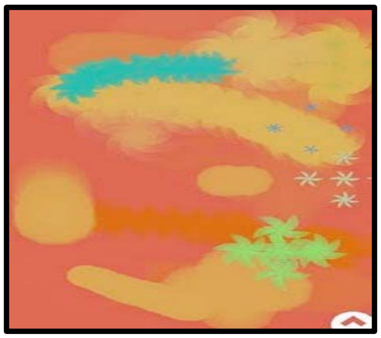

*Figure 3: Trope by Brian Eno and Peter Chilvers*

Bloom (a precursor to Trope but with the same idea in mind) is, “Part instrument, part composition and part artwork, Bloom’s innovative controls allow anyone to create elaborate patterns and unique melodies by simply tapping the screen.” It most resembles my application in terms of a computational approach to generative music playing. My application is conceptually different in that it will have a procedurally generated visualization that the viewer’s interaction will accompany. It is also not clear on what basis the visual elements where chosen to represent the sound pieces.

My Artificial Synaesthesia device would create a mapping of sound to visual senses in a way that affects the viewer’s perception of sound after experiencing the device, by adding different dimensions (like the emotional affectations of music) in the computational abstraction of the cognitive process. My primary goal is the realization of an interactive visualization that simulates a new cognitive process. The motivation is to provide a proof-of-concept prototype that could lead users to create new mappings and “learn” to see music in a synaesthetically inspired way. It is very difficult to achieve this mild rewiring in order to change one’s perception of music, but based on Ramachandran and Hirstein’s idea of the satisfactory emotions involved in cross-modal binding, I do not think it is impossible to at least generate a novel experience for the person, so he is more aware of his own cognitive process, post-artificial-synaesthesia experience, while listening to music. I will thus simulate the mapping process by creating a procedurally generated visualization. If feasible, I will also test the application for the possibility of new wirings that may have been created after extended use of the visualization.

## V. Project Construction

### Research and Design

From August to October, I researched and studied about the cognitive processes behind of synaesthesia and music perception. I specifically looked into the visual and auditory aspects of synaesthesia through the works of Richard Cytowic and Oliver Sacks. While noting the specific workings and processes of music perception and synaesthesia, I was also learning different methods of creating music visualizations; keeping this research in mind, I went about designing the application.

My final deliverable will be a single-user application. It will process music signals and produce an interactive visualization. The interactive elements can be used to manipulate selected attributes of the visualization generation process. As shown in the system diagram (Figure 3), the music signals (input) will be segmented into different categories during the music analysis process, and then based on an algorithm, mapped into different visual elements.

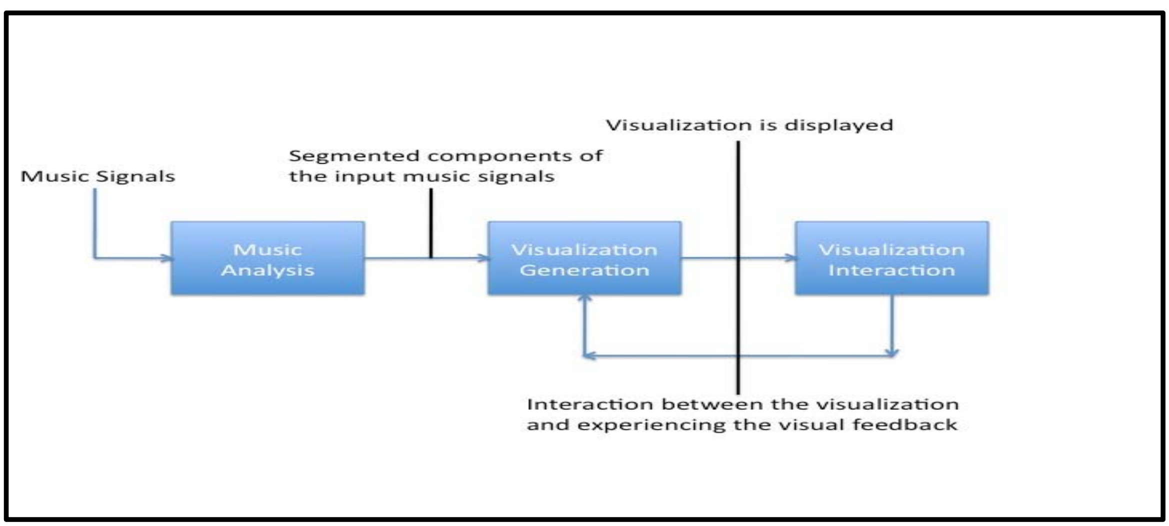


*Figure 4: System Diagram for the Application*

The mapping process in the algorithm will be based on an abstraction of certain atypical cognitive processes that take place during music perception. These processes could involve different components of the cognitive system such as emotion, shape generation, color generation etc. These components will be integrated into the process that generates the visualization.

The interactive elements will be used to manipulate how and to what extent these individual components are used in the algorithm that generate the visualization. Through this interactive and visual experience of music perception, we can manipulate the process behind which the visuals are generated. As mentioned in the FeelSpace example, it is possible to acquire mappings between two different senses by reinforcing the sensations through participation. Making correlations between two different sensory systems induces a rewarding effect that cements those cross-modal experiences (Ramachandran and Hirstein, 1999). Using these concepts, I will be utilizing the participatory element to cement cross-modal experience provided by the music visualization.

**Determining Visual Elements**

Before getting into the process of determining visual elements, it is important to have a specific system diagram to understand where the individual components that I am going to discuss, are situated within the context of the project.

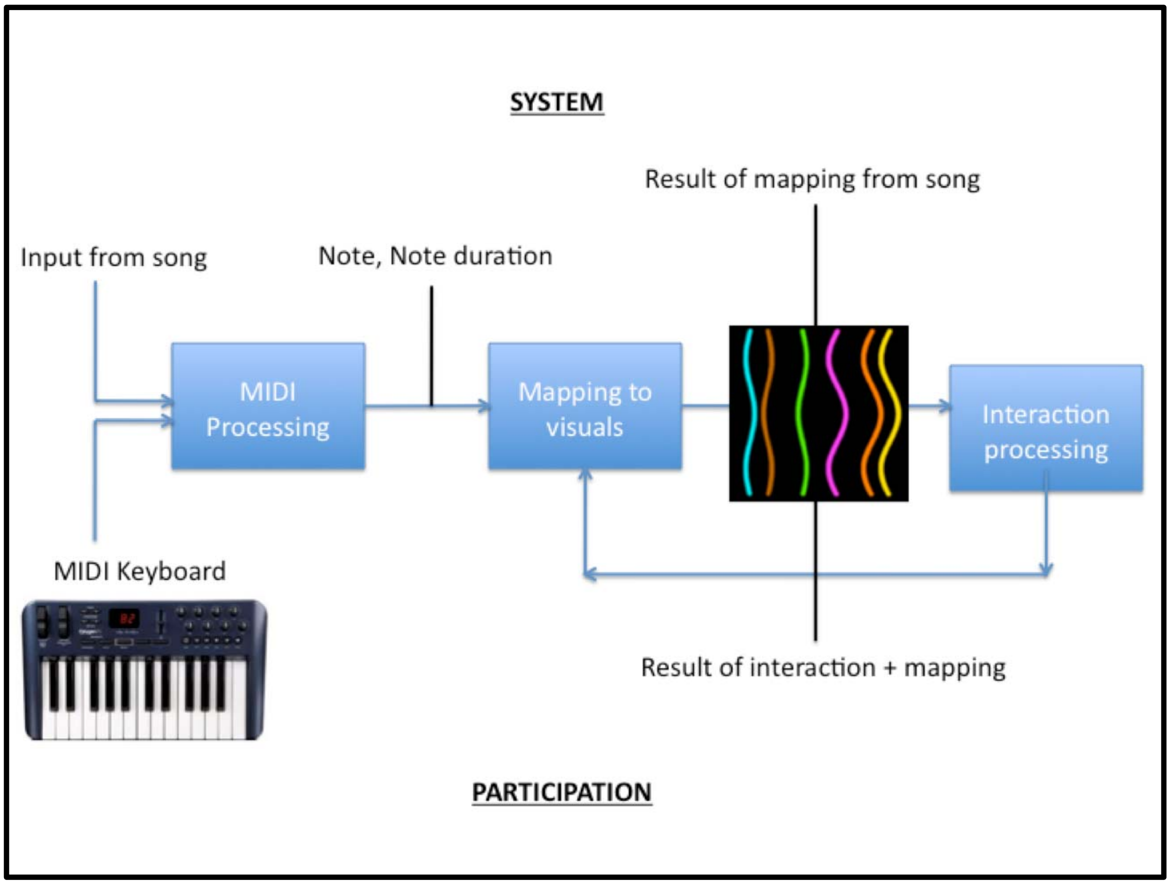


*Figure 5: Participation and system process*

Now that we have an illustration showing the relationship between the participatory and system processing aspect of the project, we can start focusing on the individual components of the project.

The first step in building this visualization entailed determining the visual characteristics of the elements that are to be displayed. The characteristics include color, shape, movement and duration. These visual properties vary according to the auditory properties of the audio piece. They are assigned based on key, duration of the note and intensity of the note that I extract from the MIDI (Musical Instrument Digital Interface) file. I chose MIDI because it's easy to handle in Processing. The attributes of the MIDI file that can be read are its pitch and velocity, and they determine the properties of the visual elements. The correlation between the MIDI attributes and the visual elements is based on the cross-modal relations (auditory/visual) found in synesthetes. The relations I use are correlations found in subjects as studied by Richard Cytowic.

The sound to color and sound to shape correlations vary (Cytowic and Eagleman, 2009), but there are common overlaps that occur across different synesthetes. These studies have also been informed by Ramachandran (Ramachandran and Hubbard, 2001) and Sacks (Sacks, 2008) in their description of synaesthesia and the various cases experienced by synesthetes. I have selected the common overlaps to best represent the mappings as part of the artificial synaesthesia experience. I assign different colors for keys and one shape for all the notes that are arranged linearly corresponding to the structure of a scale. I have chosen vibrating strings after looking through all the common associations made by synesthetes (as mentioned above) associated with different instruments. Hence, the choice of the oscillating shapes of the strings corresponding to a piano.

The keys -> colors associations are as follows:

A – Pink

A# - slightly less saturated Pink

B – Orange,

C – Gold

C# - darker Yellow

D – Grey

D# - Silver

E – Sky Blue

F – Brown

F# - Dark Brown

G – Green

G# - Dull Green

*Figure 6: Colors assigned to different keys*

The colors listed above will be the colors of the individual strings represented by their respective key. As the intensity of the note fades off, the colors will fade into black as well. The strings will also be placed adjacent to each other and arranged to represent an octave on a keyboard start from middle to C to it's next octave, with the colors repeating for the next 12 notes. This spatial arrangement according to melodic structure is often noted by synesthetes as being a common visual experience while listening to melodies (Cytowic and Eagleman, 2009). By the end of November, I had decided on the visual elements of the application and I started exploring for different frameworks that handled music visualization.

**Code**

Being familiar with Processing, I decided to use it as the language with which to build my prototype. After trying out multiple frameworks (jMusic, jEtude, OpenGL) to measure their versatility towards handling MIDI and graphics in real-time, I stumbled across a framework written by Maxime Beauchemin released under the GNU license. It uses the rwMidi library to access MIDI information and the OPENGL library to generate the visuals. The key -> color combinations used in the code is based on the circle of fifths and the physics consists of a ball bouncing to-and-fro on the vertical axes of the display. The ball eventually fades off as the duration of the note comes to an end.

*Figure 7: Screencap of original code*

As there is no documentation for the code and due to my unfamiliarity with real-time graphics programming, real-time audio processing or writing physics algorithms that link the two together, I started familiarizing myself with the framework by manipulating various aspects of the code and learning their functionality.

The first part of the code I actively started working with was the MIDI processing. I had to change aspects of the code so the application accepts multiple devices instead of just one. I also had to go through documentation for studying the MIDI format to figure out how to catch the pitch and velocity of the file. I spent the next couple of weeks studying the documentation of OpenGL and rewriting the code completely to understand how it was integrated into the existing code to see if and how it would best suit my visual requirements. I changed the color combinations of the existing code to the specifications of my visual elements. After setting the attributes of the visual elements, I started work on the physics of the visualization.

As shown in the Figure 6, the original objects were just circles that move up and down. Since the figures needed to be vibrating strings, I rewrote the mechanics of the object's movement in response to the changes in music. As the duration of the note corresponds to the 'velocity' value of the MIDI file, I set the string to vibrate as long as there is a value for 'velocity'.

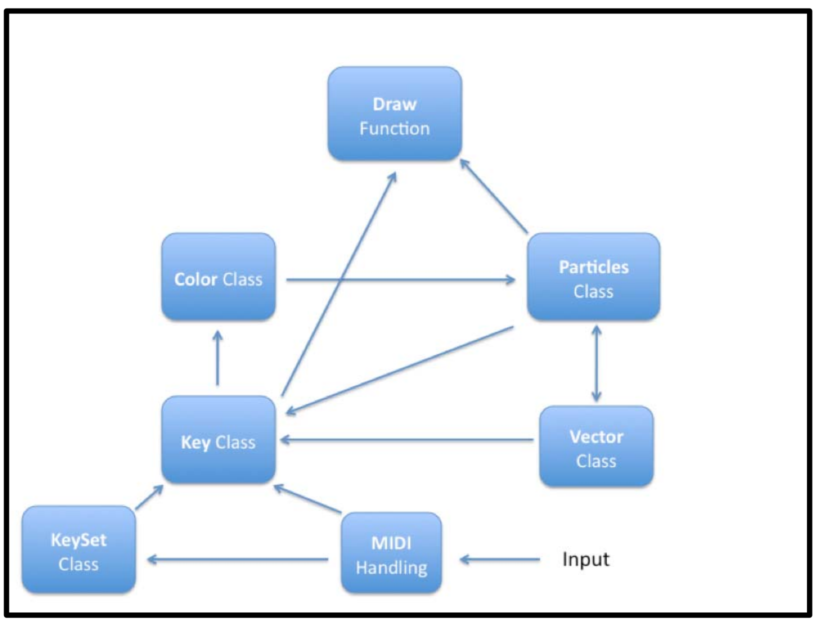


*Figure 8: Schema of Classes in code*

As shown in Figure 7, the code is mainly segmented into classes for particle physics, handling key and color association and MIDI processing. The MIDI input is caught using the rwMidi library and split into main objects – note and velocity. That information is used to assign colors to the respective key and set the ‘duration’ value for the vibrating string. The Particles class that is called persistently in the draw function manipulates the physics of the string to make it vibrate for the duration of the note along with the color assigned to it by the Key Class. The Color class is used to convert the HSB (Hue, Saturation, Brightness) values into RGB. There are also data structures that buffer the particles before they are displayed on to the screen in real-time. I built a working prototype of the application by the beginning of February.

**Bug Fixes and refining graphics**

The application constantly stalled due to the graphics processing involved, so some refinement of the underlying graphics algorithms needed to be changed. The physics of the shapes moving in sync to the audio piece was not running smoothly and some changes in the physics of the mechanics had to be made for the calculations to run smoother. I eventually got rid of running the OpenGL in a 3D Environment and changed the code to remove handling of graphics by OpenGL and reverted back to using the graphics capabilities provided by Processing. I also worked on refining the code for the mechanics of the string so the movement seems more seamless.

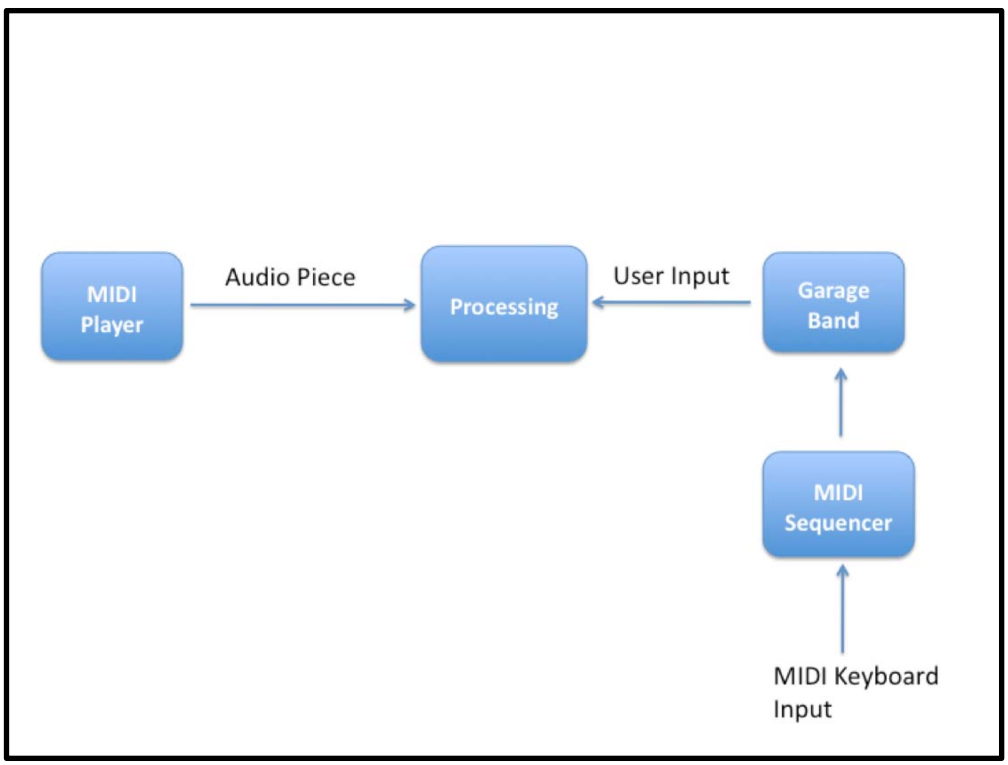


*Figure 9: MIDI software architecture*

Most of the problems occurred while trying to run multiple MIDI devices at once. I came up with the above architecture to most efficiently play with multiple MIDI inputs at once – that is the audio piece and the user's accompaniment. I use a MIDI player that plays the MIDI file and a sequencer that can take in the user's input as MIDI information and then send it through an input channel for Processing to catch. I use a MIDI keyboard for input that sends data to the sequencer on my laptop.

At the beginning of March, while finishing up on bug fixes, I also started collecting all the work that I had been doing in terms of theoretical research and documentation and structuring it along with the chronological progress of my work.

## VI. Conclusions

### Contribution and Future Modifications

There are Artificial Synaesthesia devices that simulate a mapping of different senses but I want to try and change the current perception mechanics of our cognitive systems, specifically for Sound to Sight experiences, and create a novel and learned experience of music perception. Through the experience of Artificial Synaesthesia, I hope to not only create these novel experiences of sensory perception but to also reactivate and change the way people perceive and process sensory information.

The existing devices either display the effects of synaesthesia like perception or ask for the user's input and then generate a visual to show synaesthesia like effects. I use the combination of these 2 types to create the proof-of-concept prototype within a digital media context using research from neuroscientific studies of Synaesthesia.

The main idea is to provide access to a different kind of music perception through a visual medium and allow the user to participate in this system. Using the interactive visualization, I am introducing novel sensory mappings in the user and reinforcing them through participation.

Synesthetes have a hyper connected version of our own perceptive systems. By exploring their sensory mappings as a result of our action, I am hypothesizing that it will change our different sensory possibilities while listening to music. I hope to enrich our own views and perceptions of music through this cross-modal experience, which involves an emphasis on participation, and not just perception.

Using existing studies of Synaesthesia, the application can be used to create different kinds of artificial synaesthesia visualizations to introduce novel experiences for music perception. Some initial emphasis definitely needs to be on at least helping people recognize their type of perception towards music – whether it's cognitively typical. Once that is achieved, there can be various combinations of music -> visual processing that might help in creating a clearer context under which the perception of music can be experienced in different ways.

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Framework: https://github.com/mistercrunch/MidiVisualization

**Links to Related Work:**

Olivier Messiaen:

http://www.oliviermessiaen.org/messiaen2index.htm

Bret Battey:

http://www.mti.dmu.ac.uk/~bbattey/index.html

Nancy Herman:

http://www.nancyherman.com/www.nancyherman.com/HOME.html

Michael Fratangelo:

http://www.fratangelo.com/

Marcia Smilack:

http://www.marciasmilack.com/

Oskar Fischinger:

http://www.centerforvisualmusic.org/Fischinger/

Amy Alexander:

http://amy-alexander.com/

Bill Alves:

http://www2.hmc.edu/~alves/index.html

feelSpace Lab:

http://feelspace.cogsci.uni-osnabrueck.de/en/index.h tml

ScoreLight:

http://www.k2.t.u-tokyo.ac.jp/perception/scoreLight/http://www.k2.t.u-tokyo.ac.jp/

Brian Eno's Bloom:

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