Sonification of Fish Movement Using Pitch Mesh Pairs

Andrew Mercer-Taylor
Columbia University
Department of Computer Science
ajm2209@columbia.edu

Jaan Altosaar
Princeton University
Department of Physics
altosaar@princeton.edu

ABSTRACT
On a traditional keyboard, the actions required to play a consonant chord progression must be quite precise; accidentally strike a neighboring key, and a pleasant sonority is likely to become a jarring one. Inspired by the Tonnetz (a tonal diagram), we present a new layout of pitches defined using low-level harmonic notions. We demonstrate the potential of our system by mapping the random movements of fish in an aquarium to this layout. Qualitatively, we find that this captures the intuition behind mapping motion to sound. Similarly moving fish produce consonant chords, while fish moving in non-unison produce dissonant chords. We introduce an open source MATLAB library implementing these techniques, which can be used for sonifying multimodal streaming data.

Keywords
Sonification, computer vision, generative music

1. INTRODUCTION
In Tonnetz, a pitch layout first devised by Leonhard Euler [3] and widely used in modern neo-Riemannian theory [2], pitches are placed on the vertices of a triangle mesh such that all triangles correspond to a major or minor triad. We refine this definition by loosening the constraint on the quality of the triads to permit all diatonic triads (major, minor, or diminished). We also add the constraint that adjacent triads can differ by only a single whole step. The resulting pitch chain is aligned with a second pitch chain to reflect the resolution of diminished fifths. We capture register using an additional dimension, creating pitch meshes.

To produce a consonant chord, a user may select any sufficiently narrow cluster of pitches from a pitch mesh. To produce a functional change in harmony, the user just switches the cluster to the opposite mesh. Because of this flexibility, a musical instrument based on the pitch mesh pair system could be particularly valuable to children and those with impaired fine motor skills.

We use our system to create music from video of an aquarium such that clusters of fish moving in the same direction produce consonant, diatonic chord progressions and changes in direction produce changes in harmonic function. We also demonstrate sonification of Van Gogh's *The Starry Night* and randomly generated input.

2. PITCH MESH PAIRS
2.1 Definition
For any diatonic triad (major, minor, or diminished), there are exactly two other diatonic triads that are attainable by moving a single voice by a whole step. For example, from the G major triad we can reach the E minor triad or the B diminished triad. Ultimately, this operation generates a loop of 18 of the 36 possible diatonic triads (assuming octave and enharmonic equivalence). Since each triad shares two pitches with the previous one, this can simply be represented as a chain of pitches a major or minor third apart (Figure 1).

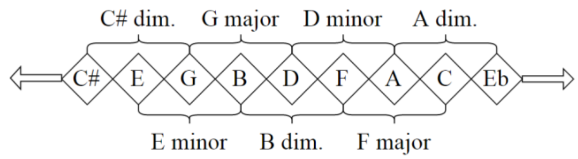

Figure 1. Section of pitch chain generated from G major.

From Figure 1, it is clear that the neighborhood of five triads centered on B diminished all belong to the key of C major. These five triads all have dominant or subdominant harmonic function according to German harmonic theory, which classifies them as dominant parallel (E minor), dominant (G major), incomplete dominant seventh (B diminished), subdominant parallel (D minor), and subdominant (F major) [5]. Notably absent are the two diatonic triads having tonic function in C, the tonic parallel (A minor) and the tonic (C major). However, both of these triads can be found in the pitch chain generated from the C major triad itself. In fact, this second pitch chain will contain exactly the 18 triads absent from the first. We graphically align these two pitch chains such that each major third is positioned between the diminished fifth that resolves to it: for instance, C and E are positioned between B and F.

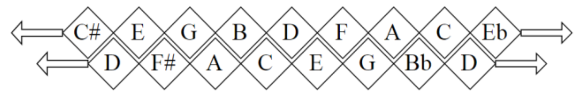

Figure 2. Section of aligned pitch chain pair.

To introduce register, we generalize our notion of a pitch chain to that of a pitch mesh consisting of vertically stacked pitch chains in parallel octaves (see Figure 3). We align pairs of pitch meshes as we aligned their respective pitch chains.

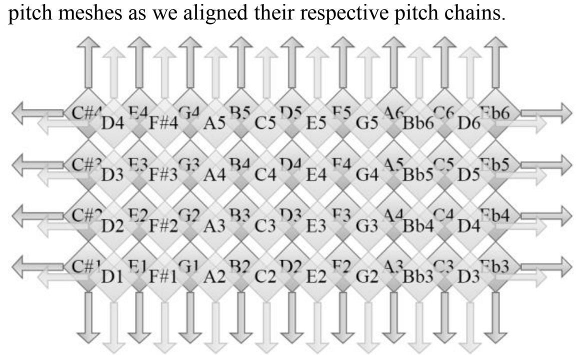

Figure 3. Section of aligned pitch mesh pair.

2.2 Some harmonic properties
In a pitch chain, two adjacent pitches produce a diatonic third, three produce a diatonic triad, four produce a seventh chord, five produce a ninth chord, and so on. Larger clusters are generally more dissonant.

Any cluster of seven pitches on both chains of an aligned pitch chain pair is a diatonic scale (see Figure 2). Furthermore, when traversing the aligned pitch chain pair beyond a diatonic region, one encounters chromaticism only in the form of predictable modulation about the circle of fifths. While ascending, sharps are added or flats are removed every three pitches (including pitches on both chains). We observe that chords from slightly beyond a diatonic region are closely related to the key of that region. For instance, F# diminished, the triad built on the first pitch below the diatonic region of C major, is the incomplete dominant seventh chord of the key of G major and thus a secondary dominant in C major.

Finally, we observe that shifting a cluster of notes from one pitch chain to the other produces a progression from a chord of tonic function (that is, the tonic or the tonic parallel) to one with dominant or subdominant harmonic function, or vice versa. On the other hand, shifting a cluster along a pitch chain may not produce a significant change in harmonic function.

3. SONIFICATIONS

3.1 Aquarium

We use the pitch layout defined above as the basis of the sonification of a video of fish swimming in an aquarium. The video is resized to 64x32 pixels to reduce computational demands and susceptibility to noise. We compute dense optical flow at intervals of 0.2 seconds and search the results for local maxima in magnitude, which we assume correspond to fish in motion (the aquarium background is immobile). Whenever a sufficiently large local maximum is detected, a note is triggered (rapid repetition of the same note is filtered out). An aligned pitch mesh pair is projected across the video. One of the meshes is selected based on the horizontal direction of the optical flow at the maximum, and the pitch in that mesh which is nearest the location of the maximum determines the pitch of the triggered note. The velocity of note is proportional to the magnitude. Notes are synthesized in Ableton Live. The link to the demo video is in Section 5.

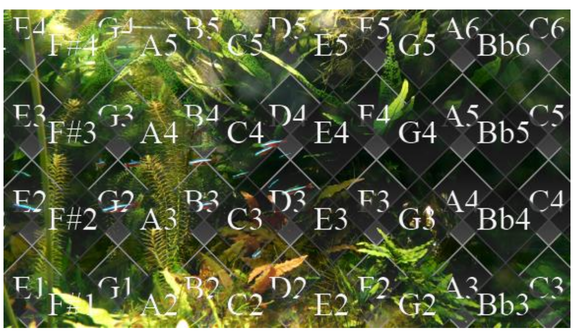

Figure 4. Visualization of aligned pitch mesh pair projected onto aquarium video. Fish velocities greater than a threshold trigger the respective pitch at their location.

This strategy means that when fish move in sufficiently narrow clusters in the same horizontal direction, they produce consonant sonorities. We observe that this type of collective movement is common behavior in fish. (Fish swimming in opposite directions are likely to produce dissonance, while changes in direction, especially of an entire cluster at once, produce changes in functional harmony.) By increasing the horizontal scale of the projection, we allow broader clusters to sound consonant and thus increase the consonance of the music produced. However, this means reducing the number of accessible chords and key areas, which sacrifices some harmonic possibilities. Translating the projection horizontally causes the music to be transposed (potentially between modes).

Furthermore, the vertical position of a fish loosely corresponds to the register of the notes it triggers. This effect can be increased or decreased by changing the vertical scaling. Vertically translating the projection causes the music to rise or fall in register. The above parameters for threshold and vertical or horizontal scaling ensure a variety of harmonic possibilities from the same data.

The generation of music from the movement of fish has been the subject of several previous works. These include the Quiet Ensemble's "Quintetto" [4], which translates the vertical positions of five fish in separate vertical tanks into sound, and the Accessible Aquarium Project [6], which studies sonification as a tool to improve the accessibility of aquariums to visually impaired visitors. The closest precedent to our approach is that of "Musica Sull'Acqua" [1], which maps the position, velocity, and appearance of fish in an aquarium to a range of musical parameters with the intention of producing an aesthetically pleasing experience. In contrast with our focus on the selection of harmonically plausible pitches, "Musica Sull'Acqua" determines the pitches of triggered notes by mapping the vertical position of a fish linearly into a predetermined scale.

3.2 The Starry Night

We transform an image of *The Starry Night* into the HSV color space and shrink it. We then sweep across the image from left to right, pausing for a fraction of a second on each column of pixels. Every pixel with sufficiently high saturation and value triggers a note. The saturation value specifies a horizontal location on the pitch mesh pair, while the height of the pixel specifies the vertical location and either the first or second pitch mesh is selected based on whether the hue is closer to blue or yellow. The nearest pitch on the selected pitch mesh determines the pitch of the triggered note, and the value of the pixel determines its velocity. The demo video is linked in Section 5.

3.3 Random input

We generate a random, geometrically distributed number of samples from a bivariate Gaussian distribution with variable mean. The first or second pitch mesh is randomly selected, and each sample triggers the nearest pitch on the selected mesh (with a small probability of using the opposite mesh instead). Note velocities are selected randomly. We pause for a fraction of a second, randomly adjust the mean of our Gaussian distribution, and repeat. This video can again be found in Section 5.

4. REFERENCES

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5. SOURCE CODE AND DEMO

MATLAB code for these demonstrations is available at:
https://github.com/andrewjmt/fishmusic
Demo video available at: http://youtu.be/HzsFGQyIpuc