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Multidimensional Data Sets: Traversing Sound Synthesis, Sound Sculpture, and Scored Composition

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MULTIDIMENSIONAL DATA SETS: TRAVERSING SOUND SYNTHESIS, SOUND SCULPTURE, AND SCORED COMPOSITION

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ABSTRACT

This article documents some of the conceptual developments of some various approaches to using multidimensional data sets as a means of propagating sound, manipulating and sculpting sound, and generating compositional scores. This is not only achieved through a methodology that is reminiscent of some of the systematic matrix procedures employed by composer Peter Maxwell Davies, but also through a generative signal path method conventionally termed *Wave Terrain Synthesis*. Both methodologies follow in essence the same kind of paradigm - the notion of extracting information through a process of traversing multi-dimensional topography. In this article we look at four documented examples. The first example is concerned with the organic morphology of modulation synthesis. The second example documents a dynamical *Wave Terrain Synthesis* model that responds and adapts in realtime to live audio input. The third example addresses the use of *Wave Terrain Synthesis* as a method of controlling another signal processing technique - in this case the independent spatial distribution of 1024 different spectral bands over a multichannel speaker array. The fourth example reflects on the use of matrices in some of the systematic compositional processes of Peter Maxwell Davies, and briefly shows how pitch, rhythm, and articulation matrices can be extended into higher-dimensional structures, and proposes how gesture can be used to create realtime generative scores. The underlying intent here is to find an effective and unified methodology for simultaneously controlling the complex parameter sets of synthesis, spatialisation, and scored composition in live realtime laptop performance.

1. INTRODUCTION

The idea of traversing data sets is well established in the realms of sound synthesis and computer music. One only has to consider the concept of *wavetable lookup*, and we find this method is the basis of generating digital oscillators, audio sampling, *Waveshaping Synthesis*[1], audio analysis via *FFT* or *wavelet* methodologies and the subsequent resynthesis of this data, *Graphical Synthesis*, *Convolution Reverb*, *Wave Terrain Synthesis*[2], *Head-Related Transfer Functions* (HRTF's) for the binaural treatment of existing sounds, and *Multi-Impulse Response* techniques found in the *MIR-Project*[3]. Table lookup procedures for sound synthesis developed not long after the birth of the microcomputer in the mid-1970's, and it was in 1978 that Rich Gold first coined the term *Wave Terrain Synthesis*. There have been many advantages to the table lookup procedure - it is considered to be computationally efficient as processing requirements are consistently low, and the procedure allows for storing and reloading tables of data. These data sets might consist of either arithmetically generated values, statistical information, and measurement data, provided the data range is adequately sufficient. For example we may use "samples" of real world data, be it audio, video, or any other collection. Extending the dimensionality of the table lookup procedure allows for describing the complex non-linear behavior of electronic components and other complex phenomenology such as the localized perception of sound in a binaural setting using HRTF's.

Investigation into the wide variety of multi-dimensional data sets for use with *Wave Terrain Synthesis* presented many possibilities.[4] One of the main attractions to *Wave Terrain Synthesis* for the purposes of this research is that the system of traversing these data sets can be intuitive and effective to control, especially when mapped to gestural controller input.[5] The fact that the system also is so adaptable for varied applications as the examples will demonstrate, is also leading toward a hope that this research may find an organic, efficient, and unified methodology for the simultaneous control of the parameter sets associated with sound synthesis,

1 Le Brun, M. 1979. "Digital Waveshaping Synthesis." *Journal of the Audio Engineering Society* 27(4): 250-264.

2 Gold, R. 1979. "A Terrain Reader." In C. P. Morgan, ed. *The BYTE Book of Computer Music*. Byte Publications, Petersborough, NH.

3 The MIR-Project http://www.vsl.co.at/en/65/73/500/320.vsl

4 James, S. 2005. Developing a Flexible and Expressive Realtime Polyphonic Wave Terrain Synthesis Instrument based on a Visual and multidimensional methodology. *West Australian Academy of Performing Arts, Western Australia. 2005.*

5 Mills, A. and R. C. De Souza. 1999. "Gestural Sounds by Means of Wave Terrain Synthesis." *Congresso Nacional da Sociedade Brasileira de Computação* XIX. http://gsd.ime.usp.br/sbcm/1999/papers/Anderson_Mills.html

sound sculpture and manipulation, and generative scored composition.

As a means of clarification, the term sound sculpture is used here to describe the physical act of sculpting a terrain surface with physical input much like Dan Overholt explored with the *MATRIX* interface.[6] Since the terrain largely affects the resulting sound, the perceived effect here is such that the performer is "sculpting" the sound gesturally via this process.

2. SOUND SYNTHESIS MORPHOLOGY

The concept of morphing sound synthesis is a concept that arose during the course of my Masters thesis. Initially I was more concerned in the thesis to observe the characteristic traits and topographies of conventional sound synthesis processes as it could inform and develop a further understanding of the many other kinds of topographies commonly used in *Wave Terrain Synthesis*. It was only later it occurred to me that this would open the possibility for both an organic and uninhibited way to efficiently morph between different forms of sound synthesis. In this example we take three forms of modulation synthesis and map the associated parameter spaces, keeping in mind that the audio input source will be sinusoidal in most cases. These three synthesis methods discussed are *Ring Modulation*, *Frequency Modulation*, and *Waveshaping Synthesis*.

It is immediately apparent why *Frequency Modulation Synthesis* creates more sidebands and spectral complexity when one observes the number of undulations found in its associated parameter space in Figure 3. This is significantly more than that of the *Ring Modulation* (Figure 2) and the *Waveshaping* parameter space (Figure 4). The terrain structures are generated in MaxMSP utilizing the Jitter matrix processing library. This library allows for traversing not only 2-dimensional matrices, but higher dimensional structures which may be created using the *jit.expr* object (Figure 1).

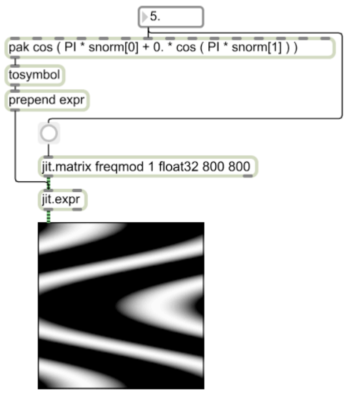

Figure 1. *Frequency Modulation* parameter space curve as generated in MaxMSP

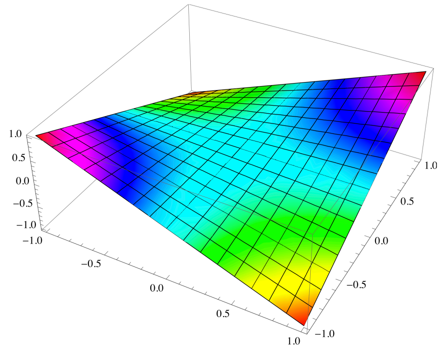

Figure 2. *Ring Modulation Synthesis* parameter space determined by the equation $f(x,y) = x_t . y_t$

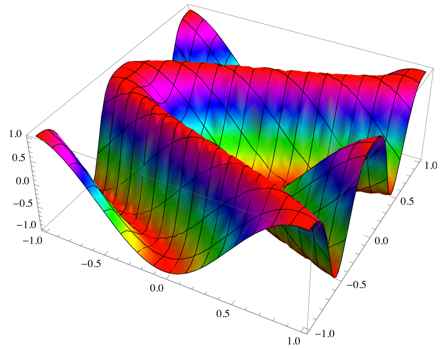

Figure 3. *Frequency Modulation Synthesis* parameter space determined by the two dimensional equation $f(x,y) = \cos\left(\pi x_t + I \cos\left(\pi y_t\right)\right)$ where $I = 3$

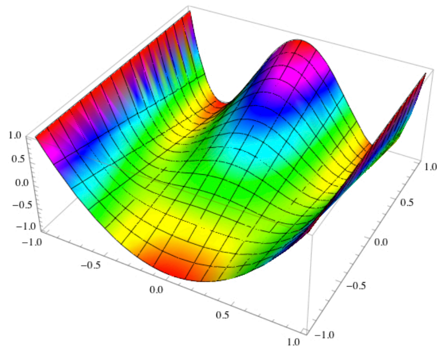

Figure 4. *Waveshaping Synthesis* parameter space determined by the two dimensional equation $f(x,y) = 0.5\left(y_t + 1\right)G_x - 0.5\left(y_t - 1\right)H_x$ where *G(x)* and *H(x)* are two Chebychev Polynomials

[6] Overholt, D. 2002. "New Musical Mappings for the MATRIX Interface." *Proceedings of the 2002 International Computer Music Conference*. http://www.create.ucsb.edu/~dano/matrix/ICMC2002.pdf

Previous research has shown that many of the curves used will result in greater levels of spectral complexity. James has suggested that depending on the way the methodology is perceived, *Wave Terrain Synthesis* could also be described as multi-dimensional *Waveshaping Synthesis*.[7] The potential for using terrain surfaces that exhibit random and "noisy" topographies translate to a resulting waveform contour that exhibit these same sorts of characteristics. Previous research has investigated many different terrain curves ranging from finite solutions to constrained Algebraic, Trigonometric, Logarithmic/Exponential, Complex, and composite mathematical functions, to data extracted from analyses of global seafloor and land topography[8], digital image files, video[9], perlin noise functions, elliptic functions, recurrence plots, OpenGL NURBS surfaces, fractal and iterative structures, and video feedback.

The concept of morphology in matrix terms involves the interpolating between two or more different pre-defined states. In terms of signal processing, this can be achieved most simply by a linear crossfade. The *jit.xfade* object in MaxMSP is used to perform this (Figure 5).

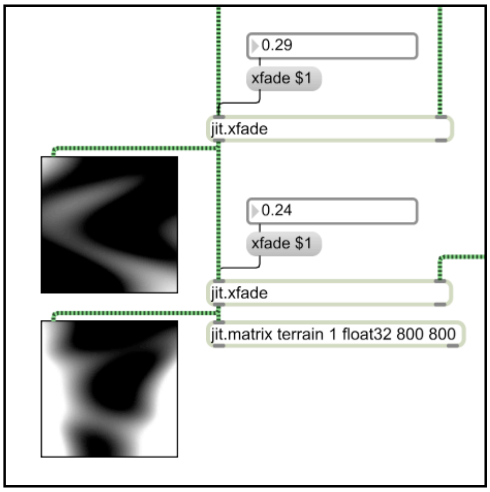

Figure 5. The use of *jit.xfade* to morph between terrain structures

Another useful modulation to explore in this process is the spatial distortion and contortion of a terrain structure through the process of 2D wavetable lookup; this is sometimes referred to as *spatial remapping*.

As one would find in any *Wave Terrain Synthesis* model, the multidimensional data set needs to be traversed with a trajectory signal that is often comprised of two independent audio signals. Previous research into *Wave Terrain Synthesis* has largely focussed on highly periodic trajectory structures as a means of traversing a terrain. Although other kinds of structures have been used including quasi-periodic orbits such as pseudo-phase space plots, chaotic orbits and random orbits.

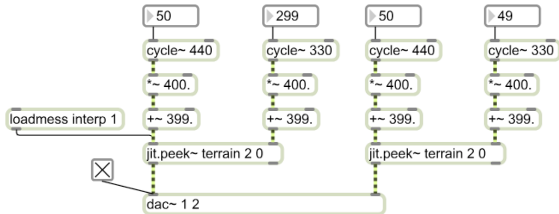

Figure 6. Two periodic trajectories created using the combinations of sine tones of varied frequency

In this example, and in keeping with the generative methodology used for generating terrain curves, the trajectories used followed periodic structures such as elliptical curves and orbits attributable to the *Harmonograph*. These have been described by the parametric equations:

$$x(t) = A_1 \sin(tf_1 + p_1)e^{-d_1 t} + A_2 \sin(tf_2 + p_2)e^{-d_2 t} \quad (1)$$

$$y(t) = A_3 \sin(tf_3 + p_3)e^{-d_3 t} + A_4 \sin(tf_4 + p_4)e^{-d_4 t} \quad (2)$$

Just as one can spatially distort a terrain structure, geometric transformations can be applied to the trajectory resulting in further modulation possibilities - some of these transformations include phase distortion or pulse width modulation and affine transformation which can involve the translation, scaling, and rotation of a trajectory.

An effective physical controller for these kinds of transformations requires a multi-sensory device. Hsu has explored the use of the Wacom Tablet for the purposes of drawing trajectory structures[10], but new technologies are emerging that promise new directions through customisable multi-sensory and tactile control such as the Arduino, as well as mobile and programmable multi-sensory devices such as the Apple iPhone and iPad. Finding effective ways and means of gesture mapping for trajectory motion and how to effectively generate and/or manipulate a terrain surface strikes right at the heart of effectively performing using this method. The choice of physical controller or sensor is critical in being

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[7] James, S. 2005. Developing a Flexible and Expressive Realtime Polyphonic Wave Terrain Synthesis Instrument based on a Visual and multidimensional methodology. *West Australian Academy of Performing Arts, Western Australia. 2005.*

[8] Thibault, B., and S. Gresham-Lancaster. 1992. "Terrain Reader." http://www.mcs.csuhayward.edu/~tebo/TerrainReader.html and Thibault, B., and S. Gresham-Lancaster. 1992. "Songlines.DEM." *Proceedings of the 1992 International Computer Music Conference*. San Jose: 465-466. http://www.mcs.csuhayward.edu/~tebo/Songlines.txt

[9] Dannenberg, R. B., and T. Neuendorffer. 2003. "Sound Synthesis from Real-Time Video Images." *Proceedings of the 2003 International Computer Music Conference,* San Francisco: International Computer Music Association: 385-388. http://www-2.cs.cmu.edu/~rbd/papers/videosound-icmc2003.pdf and Dannenberg, R. B., B. Bernstein, G. Zeglin, and T. Neuendorffer. 2003. "Sound Synthesis from Video, Wearable Lights, and 'The Watercourse Way'." *Proceedings of the Ninth Biennial Symposium on Arts and Technology*. Connecticut College: 38-44. http://www- 2.cs.cmu.edu/~rbd/papers/conncoll2003.pdf; http://www.cs.cmu.edu/~music/examples.html

[10] Hsu, W. 2002. "A Flexible Interface for Wave Terrain Synthesis." *PERformance & NETworking Colloquia*, San Fransisco State University, Department of Computer Science. http://cs.sfsu.edu/news/pernet/02/04-24-02.html and http://userwww.sfsu.edu/~whsu/TERRAIN/

able to effectively map gestural information from a performer. A *Polhemus Stylus* or similar device provides position and orientation information for a single point in space via a stylus tip, whilst a gesture interface can input many positions since the system tracks multiple features simultaneously. Further investigation will involve experimentation with two dimensional and three dimensional motion cameras such as the *Vicon* and *Kinect* interfaces to test their complementarity with the traversal of multi-dimensionality. This is a topic for further discussion at a later stage.

One can also easily see how the concept of morphing synthesis can be extended to three dimensions or more. By extending the matrix dimensionality, it opens up further parameters to be modulated at audio rate by using additional trajectory curves.

3. LIVE INTERACTIVE, DYNAMICAL, AND FEEDBACK-BASED METHODOLOGY

Performing with the *Decibel* ensemble at *Createworld* 2009 in Brisbane we performed one of my own pieces that involved live alto sax and a MaxMSP patch that reprocessed this live acoustic instrument in various ways. The reprocessing involved a *Wave Terrain Synthesis* patch that would generate dynamical terrain surfaces. In this model the rate of dynamic terrain evolution can be adjusted; effective rates can be achieved of up to 30 frames a second.

One of the attractions to this kind of model was a fascination with evolutionary and dynamical systems.[11] As opposed to the purely generative system found in example one, this second example explores more of an organic system where the structure of the contours are determined by real-world acoustical events, thus creating a relationship between the acoustic instrumentalist and the computer. Rather than the laptop performer determining the structure of all elements, terrain and trajectory, they are not in complete control of the terrain surfaces derived from the live audio input stream.

This model was inspired by Di Scipio's research,[12] who has used iterative structures for generating terrain curves. Di Scipio describes some of the sounds produced to be reminiscent of boiling water, cracking of rocks and icebanks, the sound of wind, various kinds of sonorous powders, burning materials, certain kinds of insects, thunder, electrical noises, sulphureous or volcanic events, and the sound of wind flapping against thin but large plastic plates. With higher order iterates the audio would be reminiscent of a large fire, rain or hail, or frying oil.

In this example, instead of using iterative based structures, this model draws a terrain based on the audio input. A low-pass filter is applied to the audio input in order to control the topographical complexity of the terrain surface itself, allowing the laptop performer to control the resulting spectral complexity of the synthesized sounds generated. As a means of introducing further complexity, sounds produced by the instrument are fed back via software and blended with the live input in order to introduce further complexity in the evolution of the terrain dynamics.

The terrain surfaces are recurrence plots generated in realtime based on the audio input. Recurrence plots are normally used to reveal non-stationarity of a series as well as to indicate the degree of aperiodicity in a signal.

$$\|f(t) - f(\tau)\| < r \tag{3}$$

For the purposes of creating smooth contours for *Wave Terrain Synthesis*, we look at the use of the recurrence plots without the Boolean stage. In other words, we are interested in a Recurrence Plot of a function f (t) that is described:

$$f(t,\tau) = |f(t) - f(\tau)| \tag{4}$$

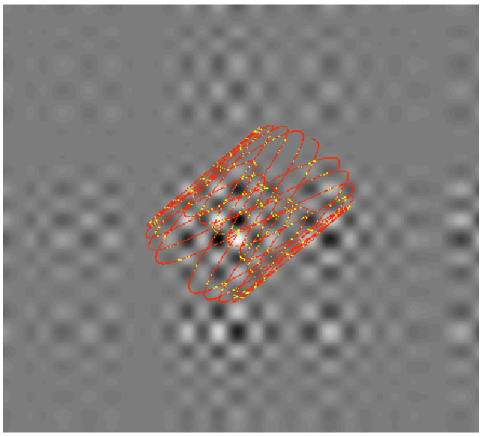

Figure 7a. A recurrence plot terrain generated using live audio input with the trajectory superimposed

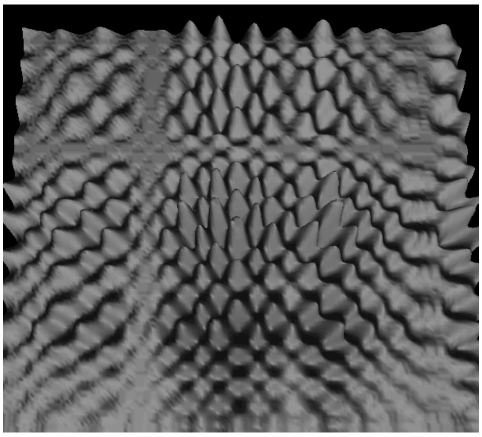

Figure 7b. The same recurrence plot in Figure 7a plotted in 3D

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11 James, S. 2003. "Possibilities for Dynamical Wave Terrain Synthesis." *Converging Technologies, Proceedings of the Australasian Computer Music Conference*: 58-67.

12 Di Scipio, A. 2002. "The Synthesis of Environmental Sound Textures by Iterated Nonlinear Functions, and its Ecological Relevance to Perceptual Modeling." *Journal of New Music Research*. 31(2): 109-117.

The trajectories for this instrument were generated by "collecting" fragments of musical phrases by the instrumentalist. By using an attack and release detection mechanism, the phrases are catalogued and replayed in a different order to which they have been originally performed. There is also a pitch detection algorithm used to determine a pitch set used to generate long drone-like passages with the *Wave Terrain Synthesis* instrument.

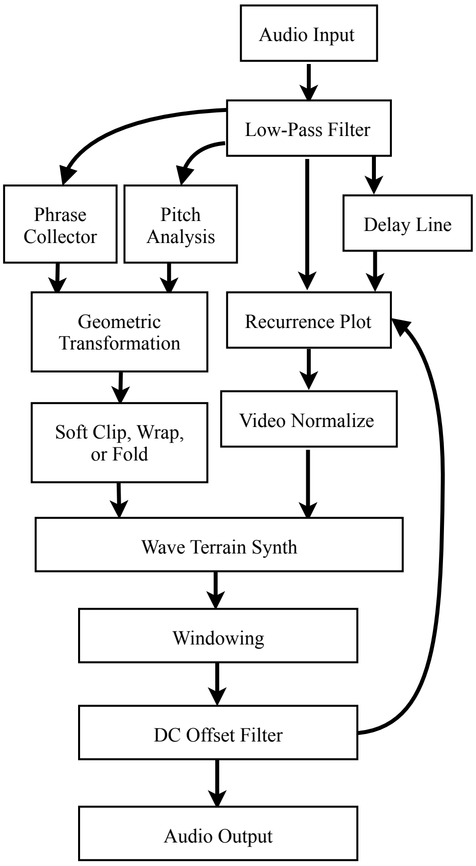

Figure 8. A schematic describing the instrument design

4. SPATIAL SCULPTURE

In the concluding paragraphs of my masters thesis I concluded that *Wave Terrain Synthesis* methodology could be used for the control of another process. In this example we will be looking at the use of *Wave Terrain Synthesis* methodology to control the discrete independent spatialisation of 1024 spectral bands and has been described *timbral spatialisation.*[13] This methodology may be adapted to any multi-channel speaker configuration, for example 4, 8 or 16 channels. In this example the performer uses *Wave Terrain Synthesis* as a bridging system for controlling the complex parameter sets associated with timbral spatialisation, allowing the performer to sculpt the localisation of many individual frequency bands with a comparatively small number of control parameters.

The process is achieved using a windowing technique that scales the relative amplitudes of each spectral bands, which are themselves dependant on the topographical nature of the terrain curve. A flat terrain contour translates to spectral uniformity in all loudpeakers. However as the terrain tips around on one axis the spectral distribution starts to separate so that higher frequencies moves across to one side of the spatial field, and low frequencies to the other.

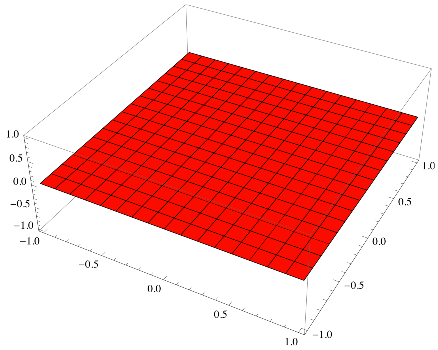

Figure 8a. Signal equally spectrally distributed out to all loudspeakers

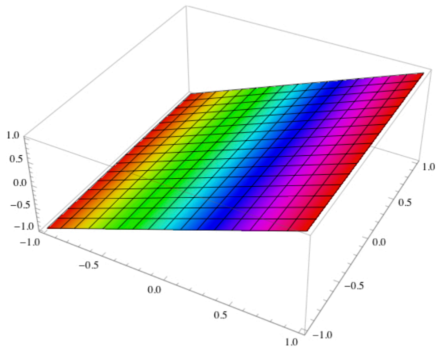

Figure 8b. Signal is distributed out to the loudspeakers in such a way that the sound spectrally shifts from low to high frequency across the room

More interesting results can be achieved with non-linear and curved terrain surfaces. The introduction of undulating terrain surfaces create very effective evolutional characteristics, and a sense of emersion in terms of the spatial listening experience., even when the source sound is a mono static oscillator.

One can see that there is an obvious benefit in this case to keeping the trajectory elliptical and to map each corner of the terrain with its relative spectral distribution. In this way the trajectory can be rotated about the polar plane causing a shift in azimuth for all spectral components and their associated localisation.

Spatialisation can also be influenced at audio rates by geometrically influencing the trajectory signal by rotation, scale or translation, or by spatially contorting

13 Normandeau, R. "Timbre Spatialisation: The Medium is the Space." *Organised Sound, 2009. Vol. 14. Issue 3.*

the terrain surface using the *jit.repos* object. Chaos and randomisation can also be introduced in this way.

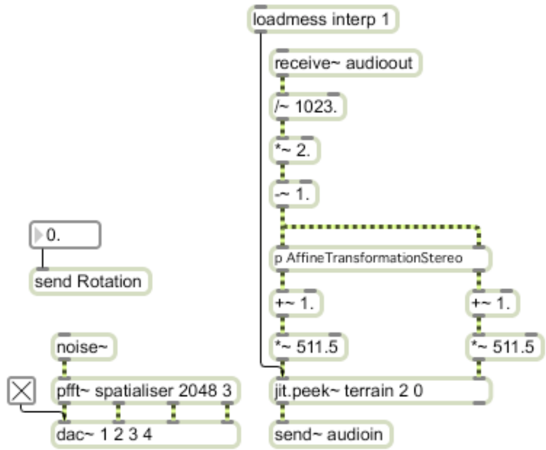

Figure 9a. The main patcher design for the spatialiser

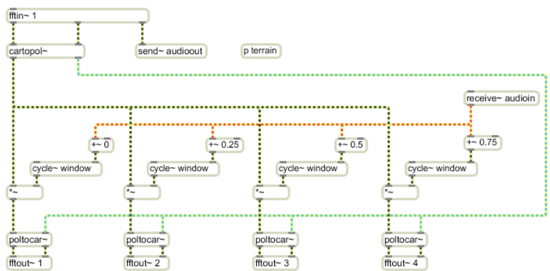

Figure 9b. The sub-patcher showing the spectral manipulation applied

5. SCORED COMPOSITION

Peter Maxwell Davies documents a use of pitch matrices and rhythm matrices in the composition of many of his works. in this way he is able to take a source melody and manipulate this with the contour of another. The different permutations that occur through this process create complexities in terms of harmonic and melodic material, thus also influencing the overall tonality.

Davies is known for his use of magic squares as a source of musical materials and as a structural determinant in his works. This is evident in Davies' compositional workings for *Ave Maris Stella* (1975), Symphony no. 3 (1984) and Symphony no. 6 (1996) to name but a few. In Davies' *A Mirror of Whitening Light* (1977) he took 8 notes from the plainsong *Veni Sancte Spiritus* which is arranged into an 8x8 square and then re-arranged according to the magic square of Mercury.

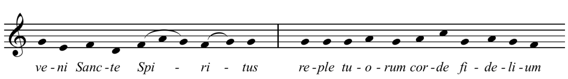

Figure 10a. Plainsong melody *Veni Sancte Spiritus*

Figure 10b. Davies' pitch series from *Figure 10a*

G 1	E 2	F 3	D 4	F♯ 5	A 6	G♯ 7	C 8
E 9	C♯ 10	D 11	B 12	D♯ 13	F♯ 14	F 15	A 16
F 17	D 18	E♭ 19	C 20	E 21	G 22	F♯ 23	A♯ 24
D 25	B 26	C 27	A 28	C♯ 29	E 30	D♯ 31	G 32
F♯ 33	D♯ 34	E 35	D♭ 36	F 37	A♭ 38	G 39	B 40
A 41	F♯ 42	G 43	E 44	G♯ 45	B 46	B♭ 47	D 48
G♯ 49	F 50	F♯ 51	E♭ 52	G♯ 53	B♭ 54	A 55	C♯ 56
C 57	A 58	B♭ 59	G 60	B 61	D 62	C♯ 63	F 64

Figure 10c. Pitch matrix derived from *Figure 10b*

Peter Maxwell Davies has then generated melodic and harmonic material by traversing the matrix using zig-zag formations, diagonal lines, and spiral formations. One can see how the fundamental process here can be attributed to *Wave Terrain Synthesis*, but instead of extracting audio signals from a matrix, we are retrieving pitch, rhythm, or articulation data. Alternatively, the matrix data could be used for determining higher level constructs in generative composition such as Markov Chains and formal grammars.

Implementing the traversal of pitch, rhythm, and articulation matrices requires a slightly different approach in procedure, as the traversal should refer to specific cells rather than smooth gradations between cells as is found in *Wave Terrain Synthesis*. These constructs can be triggered and manipulated through the use of gesture, determining not only the pitch, rhythm, dynamic, and articulation sets used, but also the context of this material, whether it be harmonic, melodic, or largely textural. The question here is how does one effectively categorize these gestures, and distinguish between these many varied kinds of materials - chords, melody, fast-fluid material, and various kinds of layers and densities.

As is found in many of the systematic compositional procedures documented by Milton Babbitt, here we focus on other permutational and matrix transformational procedures such as matrix inversion, matrix multiplication, and other procedures involved in multi-signal processing. Rhythm and articulation maps are either kept synchronised with their original respective pitch, or can be processed independently through their own concurrent procedure.

C 8	A 58	B♭ 59	F♯ 5	D 4	D 62	C♯ 63	G 1
G♯ 49	F 15	F♯ 14	E♭ 52	G♯ 53	F 17	C♯ 10	C♯ 56
B♭ 47	F♯ 23	G 22	E 44	G♯ 45	E♭ 19	D 18	D 48
G 32	D♯ 34	E 35	C♯ 29	A 28	A♭ 38	G 39	D 25
B 40	B 26	C 27	F 37	D♭ 36	E 30	D♯ 31	F♯ 33
F 17	B♭ 47	B 46	C 20	E 21	G 43	F♯ 42	A♯ 24
E 9	A 55	B♭ 54	B 12	D♯ 13	F♯ 51	F 50	A 16
F 64	E 2	F 3	B 61	G 60	A 6	G♯ 7	C 57

Figure 10d. The pitch matrix found in *Figure 10c* re-ordered according to the magic square of Mercury

Matrices in Jitter can also reflect structures greater than two dimensions. So for transpositional pitch matrices this allows for pitch transformation over two or more melodic contours. This research will investigate how effective this might be in terms of modulating tonality.

In terms of scoring these musical structures in realtime, there are currently two music scoring systems developed for MaxMSP: *MaxScore* and *Lilypad* embedded in MaxMSP. This research project has been using *MaxScore* due to its support for complex metric structures and rhythmic tuplets.

6. CONCLUSIONS

The focus of this paper has been to observe four different applications of a similar methodological paradigm, and how such a model can be used for significantly different outcomes. The purpose is to encourage interest in this area, and to throw further questions. The underlying intent here is to find an effective and unified methodology for simultaneously controlling the complex parameter sets of synthesis, spatialisation, and scored composition in live realtime laptop performance.

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