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THROUGH THE EYE OF THE NEEDLE: COMPOSITIONAL APPLICATIONS FOR VISUAL/SONIC INTERPLAY

Lindsay Vickery
Edith Cowan University
WAAPA

ABSTRACT

This paper explores the relationships between sound and its visualisation, focusing upon the issues of representation and interpretation of music through both performative and machine processes. The discussion proceeds in the context of recent works by the author exploring the representation of sound and musical notation and their relationship to and with performance: *murmurs trapped beneath the bark* [2014], *in nomine tenebris* [2014], *detritus* [2015], *trash vortex* [2015], *acid fury* [2015], *here, apparently, there was time for everything* [2015], *between-states* [2015], *the miracle of the rose* [2015], *residual drift* [2015], *...with the fishes...* [2015] and *inhabited matter* [2015]. Issues examined include: resonification of spectrograms, visualisation of spectral analysis data, control of spatialisation and audio processing using spectral analysis data, and reading issues related to scrolling screen score notation.

1. INTRODUCTION

In 2013, through exploration into the development of notation that would be capable of capturing the nuances of complex sounds, I became interested in the possibility of using the spectrogram of a sound, more or less annotated, as the source for musical notation. The immediate question was what resolution would a spectrogram need to be in order to capture all the nuances that the ear can detect?

The eye and the ear sense vision and sound in entirely different ways. In the simplest sense, putting aside the processing that occurs at a later point to create the auditory scene, sound is mapped in a broadly linear fashion with the cochlea capturing frequencies from high to low with a resolution of roughly 20ms. The eye in contrast combines data from a range of different sensors – colour through three cone cells and luminosity through rod cells. The result is that vision is not mapped in a linear fashion: if it were, the light spectrum would appear as a continuum from purple - the brightest (highest) colour to red the darkest (lowest colour). The arrangement of rods and cones gives rise to anomalies such as the non-sequential perceptual "brightness" of colours such as yellow, cyan and magenta in the colour spectrum. Additionally, in order to focus on a score with a "gaze frame" of roughly 4cm^2 the eye must fixate the fovea – the only part of the eye densely enough packed with cones to show the required detail – for periods of time in the order of 200 - 400ms. Sound is akin to a rapidly changing column and vision to a slowly changing field.

Using this logic, in order to attain the detail that is sonically perceptible, a visual score would hypothetically need to be changing at a rate of approximately 40cm/s. (My previous research has suggested reading becomes uncomfortable beyond a rate of approximately 3cm/s (Vickery 2014b).

Musicians are capable of performing nuances at extremely minute durations, but between the sound and the performance lies the notation. I have come to refer to this restriction as "the eye of the needle".

Peter Ablinger explores this issue in his "Phonorealist" works such as the *Quadraten* series, in which spectral analysis data from recordings is "reconstituted in various media: instrumental ensembles, white noise, or computer-controlled player piano" (Barrett 2007). A key issue at the heart of *Quadraten* is representation or analogy made between "real" sounds and their reconstituted counterparts. The "eye of the needle" problem obliges a loss of resolution and this loss can become interesting in itself.

> The reproduction of "phonographs" by instruments can be compared to photo-realist painting, or - what describes the technical aspect of the "Quadraturen" more precisely -with techniques in the graphic arts that use grids to transform photos into prints. Using a smaller grain, e.g. 16 units per second, the original source approaches the border of recognition within the reproduction. (Ablinger 2011)

This paper examines some developments in this work exploring the relationships between sound and its visualisation, focusing upon the issues of representation and interpretation of music through both performative and machine processes. Some initial projects exploring this issue were discussed in an earlier paper (Vickery 2014). The discussion proceeds in the context of recent works by the author exploring the representation of sound and musical notation and their relationship to and with performance including *in nomine tenebris* [2014], *detritus* [2015], *trash vortex* [2015], *acid fury* [2015], *between-states* [2015], *the miracle of the rose* [2015], *residual drift* [2015] and *...with the fishes...* [2015], that have resulted in new approaches to notation and new possibilities for composition and sound processing.

2. SONIFICATION/VISUALISATION/ (MANIPULATION)/RESONIFICATION

In 2013 I began a project to construct means to interchange data between visual and sonic media: to create a continuum in which sound could be visualized and then resonified. A patch, *Sinereader,* was created in *MaxMSP* to resonify greyscale spectrogram images (Fig. 1). In the patch each vertical pixel of a greyscale version of the spectrogram of a sound is mapped to one of 613 independent sinewave generators. In the patch a .png file of the spectrogram is loaded into a jit.qt.movie, it is then played through jit.matrix and jit.submatrix that send an image of one pixel width to the jit.pwindow. Data from the submatrix is split into a list of 613 values in jit.spill and these values are represented in a multislider. The vertical pixels are scaled logarithmically according to the vertical resolution of the spectrogram and each mapped to an individual cycle~ object. The greyscale value of each pixel is scales and mapped to the amplitude of each `cycle~` object. In addition to being a transcription tool, the patch can also be controlled externally as an "instrument" using *MaxMSP Mira* app for iPad.

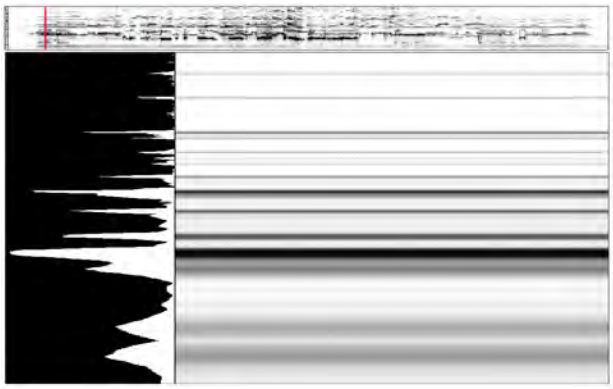


Figure 1. The *Sinereader* patch developed in *MaxMSP* to resonify spectrograms. The complete spectrogram with a "scrollbar" indicating progress through the image is displayed at the top of the image, the greyscale value of each vertical pixel in a one pixel segment is displayed on the bottom right and the resulting amplitude is displayed on the bottom left.

This particular form of resonification is not the only possible route and even in the case of the Sineplayer itself there are other potential end points that have not yet been explored: for example sonification through granular or wave table synthesis. However, even within this fairly straightforward resonification process there is much potential for exploration.

In *in nomine tenebris* [2014] a new step was added to this process: a spectrogram of Giacinto Scelsi's organ work *In Nomine Lucis* [1974] was processed in the visual domain using the software *Photoshop* and *Illustrator* to stretch, warp and distort the spectrogram image (Fig. 2). The image was then resonified and used as the basis for a score for five acoustic instruments. Scelsi's original quite static work provides a spectrally and somewhat morphologically defined sonic substance from which the new work is fashioned, new sonic morphologies are wrought on the material, formal proportions are manipulated and a new work is created sharing a kind of spectral DNA with the original.

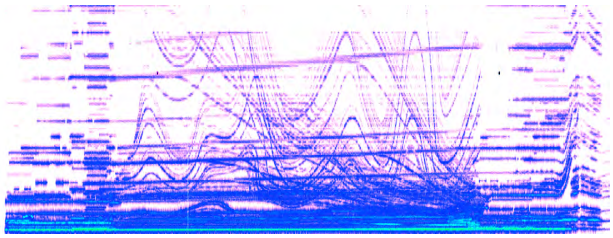


Figure 2. An excerpt of the manipulated spectrogram of Scelsi's *In Nomine Lucis* used to create *in nomine tenebris*.

acid fury [2015] explores what O'Callaghan terms "Category 2 Musical Mimesis" through the transduction of a found sound recording (of chaotic noise and a distant power tool) into a sound object (and score) of "some acoustic similarity to the source sound, but distant enough that it requires other extra-musical contexts to identify" (O'Callaghan 2012). Again the spectrogram is re-synthesised using the *Sinereader* patch to produce a sound object morphologically almost identical to the original recording, and yet distinct in an acousmatic sense.

Between these two approaches, *residual drift* [2015] (a homage to the 50th anniversary of Varèse' death), takes a spectrogram of a recording of *Ionisation* that was processed in *Illustrator* to generate a score and accompanying pre-recorded electronics. Spectrograms are probably least effective at visualising percussive works, and this deficiency was exploited by choosing a resolution for the spectrogram that would render features such as snare drum rolls as continuous pitches. Because the spectrogram was restricted to a limited frequency band (the range of the bass flute C2-C4) its resynthesised audio was reprocessed by analysing the recording using the `sigmund~` object and using the detected pitches to generate "false harmonics" by ring modulating the audio multiple times to add higher but related upper frequencies.

The final version of the electronics part incorporates three versions of the sonification: processed by *Photoshop*, processed by *Illustrator* with added false harmonics and a version featuring a spectrogram of just the upper harmonics of the recording (which were excluded in the image used to make the score). The "high harmonics" version prominently features the imprint of *Ionisation*'s characteristic sirens.

3. NOTATION FROM SPECTROGRAMS

Two important consequences of the emergence of Electroacoustic music upon instrumental music were the development by Lachenmann of "Musique Concrete Instrumentale"

> (t)he term refers to that of Pierre Schaeffer's musique concrete. Instead of instrumentally using mechanical everyday actions as musical elements I go about it by understanding the instrumental sound as information

> about its production, therefore rather the other way round - by illuminating instrumental sounds as mechanical processes. (Lachenmann 1996: 211-212)

and by Grisey of "instrumental synthesis"

> Grisey calls 'instrumental synthesis', where a recorded sound is orchestrated based on an analysis of its frequency content over time (either by the visual aid of a spectrogram or, as is often the case in contemporary efforts, increasingly sophisticated and diverse software analysis tools). (O'Callaghan 2015)

These two expansions of the language of instrumental music opened new fields of possibilities, but also new problems for the representation of complex sounds for live performers. Lachenmann's solution, for example in *Pression* [1966], was often to turn to tablature – that is to define the actions of the performer rather than the sound to be produced. Grisey often retained aspects of traditional notation but adopted the proportional duration approach of Earle Brown and Berio (for example in *Partiels* [1975]). Both options have trade-offs in precision and neither solve the underlying problem, that there are limitations upon how much notational detail can be delivered in real-time to a musician.

Aaron Cassidy's increasing unease with the complexity of his gesturally polyphonic tablature style scores, (such as *What then renders these forces visible is a strange smile…* [2007-8]) has led to his proposing a "unified multi-parametric notation system" in which "multi-planar, multi-dimensional movements are reduced to a two-dimensional notational image (principally through the use of color)" (Cassidy 2013).

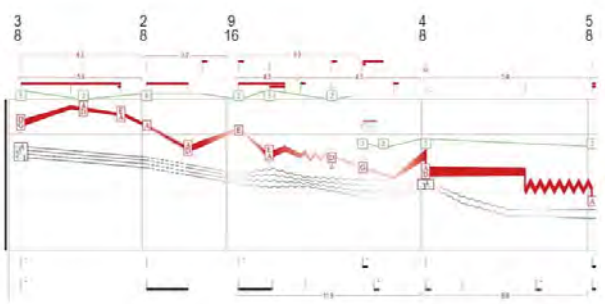


Figure 3. *Aaron Cassidy's* "unified multi-parametric notation system" *in Second String Quartet*, Violin I, mm.1-4.

Another solution might be to draw from the discipline of cartography and create digital scores that can be viewed in multiple modes (in the way a map can be viewed in satellite or terrain mode) allowing the composer to define the sound in one mode and the action in another. Modern cartography has also developed means to "zoom-in" on details while maintaining a fairly constant graphical density, for example using software to display no more than 10 "semantically meaningful units" per cm^2 (Bertin 1967). Such a system would allow a performer to "zoom in" on detail of a complex notational passage, commit it to "muscle memory" and then "zoom out" to a level of notational signification that is actually readable at speed.

My own recent work has tended to focus the representation sound to be produced by the musicians rather than the means. An early approach to this problem was *unhörbares wird hörbar* [2013] in which a score highlighting important sonic features was created from a "spectral trace" in which the notation was drawn directly onto the spectrogram. In *in nomine tenebris* [2014], parts for five instruments were created by directly colouring and annotating features of the spectrogram itself (Fig. 4.). This allowed performers to acoustically recreate minute and continuous changes in pitch, dynamic and timbre by following the height, thickness, shape and shade of the original spectrogram. The players performed the work from scrolling scores synchronised in the *Decibel Scoreplayer* (Wyatt et al. 2012).

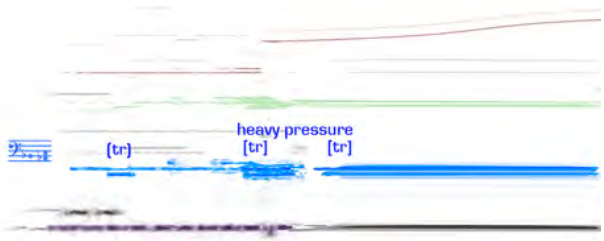


Figure 4. The opening of the cello part *for in nomine tenebris* [2014].

In *acid fury* colour-coded parts for the eight instruments were made from direct transcriptions of a spectrogram of the recordings (Fig. 5.). Here the correspondence between the recording and the instrumental lines is extremely difficult to perceive as they are extremely rapid and simultaneous – the "noisy" sections (it actually sounds reminiscent of Ornette Coleman's *Science Fiction* [1971]) and the effectiveness of the work is almost entirely based on the precise coordination of the transitions between chaos and relative stillness facilitated by the networked scrolling score.

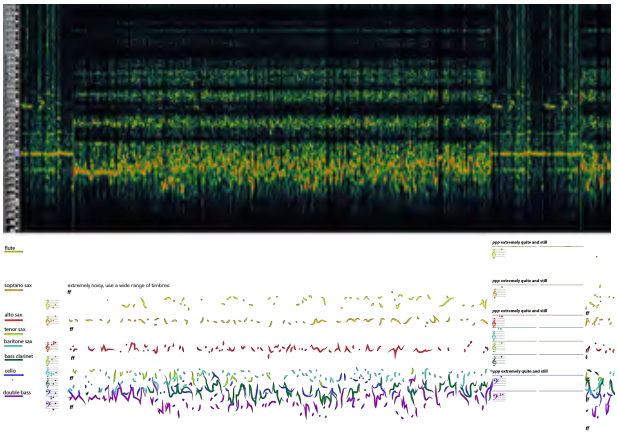


Figure 5. Spectrogram of found-sound recording (above) and annotated graphical transcription (below) of *acid fury* [2015] (excerpt).

Sonic Visualiser software offers the possibility of annotating a spectrogram directly in a MIDI layer. In the work *here, apparently, there was time for everything*

[2015] the initial aim was to create a notated score created from a MIDI transcription of a spectrogram of "no-input bass clarinet"[1] feedback that was processed by complex variable-speed delay. The process of "pruning" the MIDI transcription and "orchestrating" specific pitches to instruments (soprano saxophone, electric guitar and harp) was begun (Fig. 6), however the problem of imposing a temporal grid to the unmetered music and the desire for the musicians to perform in synchronisation with the source recording led to a return to the "spectral trace" approach to transcription.

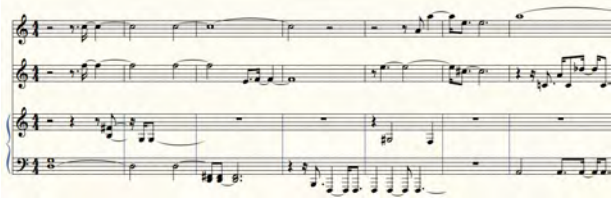


Figure 6. "Orchestrated" MIDI transcription of *here, apparently, there was time for everything* [2015] (excerpt).

This work, featuring textures far closer to those accommodated by traditional notation than *unhörbares wird hörbar* introduced a new problem: horizontally, the spectral trace is temporally proportional and performing with precision can be achieved through a scrolling score, however, it is also vertically proportional – each pitch occupies a distinct vertical spatial position. Because the source audio had no glissandi and was less timbrally divergent than my previous spectral trace works, a vertically proportional stave was the most appropriate to represent the pitches. The issue of representing the chromatic scale on a staff has occupied many minds for some time (Morris u.d), and resulted in systems using varied lines, spacings and noteheads. The system I developed attempt to more-or-less retain the topographical layout of the traditional stave, while adding coloured lines to accommodate non-natural notes (Fig. 7).

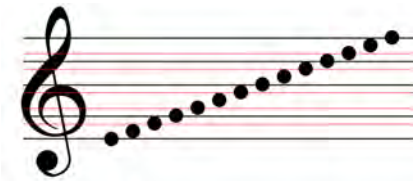


Figure 7. Proposed vertically proportional stave showing a chromatic scale from E3 to F4.

Fig. 8 is the opening of the scrolling transcription of *here, apparently…* in addition to the proportional stave, note stems/beams are used as an indicator of phrase grouping and circular noteheads are adopted. Stems are always located to the left of noteheads as it aids in reading synchronously in a scrolling score. Although I personally prefer the proportional stave version, for the first performance – due to the small number of rehearsals - a scrolling non-proportional stave version was also created.

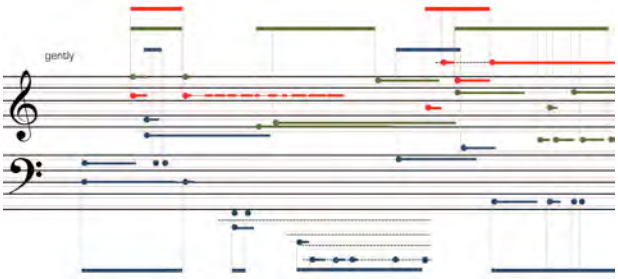
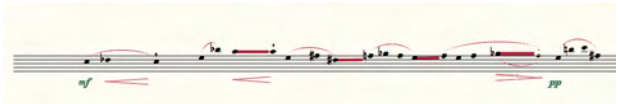


Figure 8. Vertically proportional stave transcription of *here, apparently, there was time for everything* [2015] (excerpt).

Despite a certain elegant schematic quality to the score, I still feel the level of abstraction from the spectrogram's descriptive shapes and timbres, removes too much musical information for the performers.

In *between-states* [2015] the initial concept was also to construct a traditionally notated score for bass flute and bass clarinet from a spectrogram of a mosaic of transformations of acoustic bass flute and bass clarinet recordings. The transformations were then edited leaving the most interesting outcomes still in their original temporal position - and therefore all relating back to the source acoustic recording. The process of creating a traditionally notated score involved annotating the spectrogram as a MIDI-layer in the software *Sonic Visualiser* and then exporting the MIDI-file and audio to *Finale* notation software for score editing.

a.



b.

c.

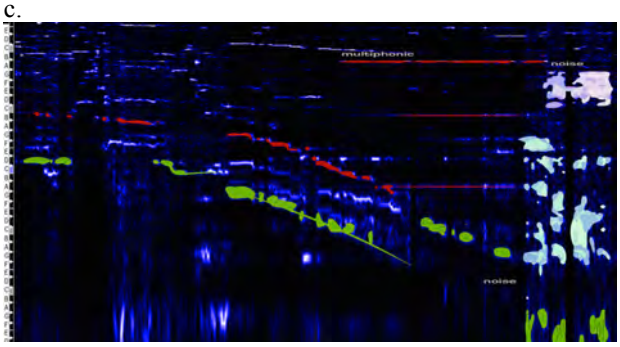


Figure 9. a. notated score, b. spectrogram score and c. annotated spectrogram score (excerpts) for *between states* [2015].

In the initial attempt I was unable to develop a satisfactory accommodation between the degree of detail in the score and the scroll-rate required to read it: if it was over-detailed it had to move too quickly to

[1] A play on the concept of the "no-input mixer", a microphone is player in the bell of a bass clarinet and amplified just to the point of feedback. The feedback can then be initiated and "shaped" by closing or opening keys on the instrument without any other impulse from the performer.

accurately read (Fig. 9a). For the first performance a simplified spectrogram score (Fig. 9b) was used with a pitch-guide fixed at the left of the score. The pitch-guide replaced the single-line "playhead" that is used in most scrolling scores in the *Decibel Scoreplayer*. I had used the same approach to read Percy Grainger's *Free Music* in the Macintosh version of the score player (and this had later been coded into the *iOS* version by Aaron Wyatt). The pitch-guide had the advantage of providing more detail to the performers more "morphological" information about the sonic shapes and could also be scrolled more slowly than a conventional score. However in this version each player was allowed to choose which shape they would render with their instrument.

A final version of the score (Fig. 9c.) identified sounds to be performed by each performer (bass flute - red, bass clarinet - green) and contains text annotations and hue variations to represent different timbres. Since the parts are more defined, the full (unsimplified) spectrogram was re-added to the score giving the performers a greater indication of the context in which their sounds are heard.

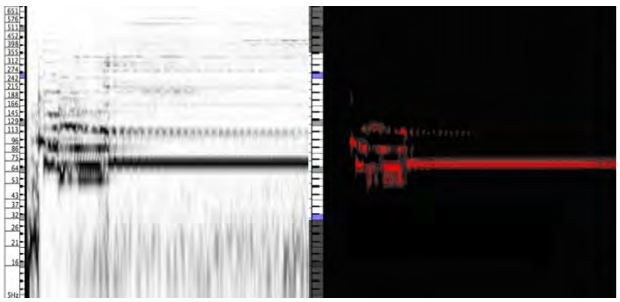


Figure 10. The opening of the *Ionisation* spectrogram (left) and the score of *residual drift* (right).

In *residual drift* the "representation sound to be produced by the musician" approach is explored to the fullest extent. The first few seconds of the *Ionisation* spectrogram and the score of residual drift are shown in Fig. 10 (note the "piano roll" style pitch indication is used as a "playhead" for the scrolling score to orientate the performer).

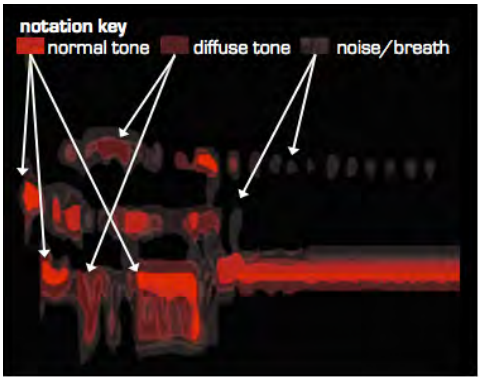


Figure 11. Notation key for *residual drift* [2015].

But the "piano roll playhead" is the only concession towards annotating the score: the performer is given a key classifying three hues with varied timbral qualities (Fig. 11) and then the performer is left to their own devices (along with the resynthesised spectrogram recording that plays synchronously with the score) to determine precisely how the sounds will be actuated.

The notation for *the miracle of the rose* [2015] combined procedures from the spectrogram score with gestural conventions. The work is based on a passage concerning the time-altering nature of solitary confinement from Jean Genet's novel *The Miracle of the Rose* [1946]. In it Genet considers the mastery of time through the performance of gestures with infinite slowness - that "Eternity flows into the curve of a gesture". A collage of time-stretched recordings of the text by Australian/French artist Emmanuelle Zagoria – becomes the gesture that is curved in time. The spoken phrases are transcribed for the two percussionists into gestures exploring their cadence and timbre via varied instruments and notational approaches.

In Fig. 12 the notation for player 2 (which occupies the lower half of the page), indicates the amplitude of the sound (the vertical height), the timbral richness (hue), onset of event (stem) and direction of the bow (beam). The notation was created using software that I created for the project *Lyrebird: environment player* that was originally "intended to visualise sonic features of a 'field recording'" (Vickery 2014). In this software the amplitude and frequency of the single strongest detected sinusoidal peak is represented by the size and vertical height of the rectangles drawn on a scrolling LCD object (in this case *jit.lcd*) and, brightness, noisiness and bark scale data derived using Tristan Jehan's `analyzer~` object are used to determine the luminance, hue and saturation of each rectangle. This allows for the Scoreplayer to visualise timbral features of a recorded sound.

In the upper half of Fig. 12 the notation for player 1 indicates muted cymbal strikes (speech rhythms transcribed from the spectrogram). The changing position of the strike is indicated by the direction of beam. In both parts the thin beams indicate the movements of the performer's arms between actions. The score is intended to be projected behind the performers allowing the audience to see the ritualistic gestural coordination between the performers and the score.

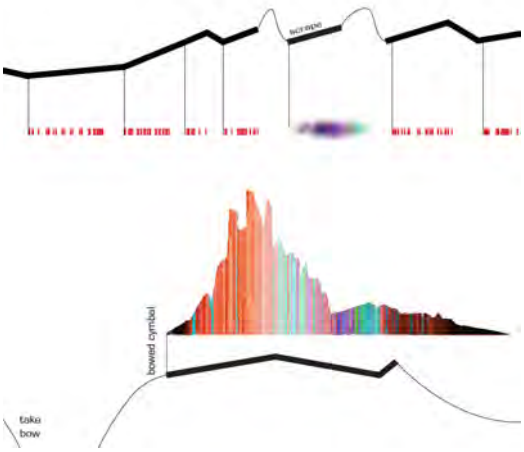


Figure 12. Excerpt from the score of *the miracle of the rose* [2015].

In Fig. 13. player 2 is bowing 5 different keys on the vibraphone, while player 1. is lowering a medium-sized chain onto the keys of a second vibraphone. The red note-heads and the downwardly inclined beams indicate lowering the chain onto the keys and orange note-heads (and upwardly inclined beams) indicate lifting the chain off the keys (both actions produce sound). Again the contours are transcribed directly from a sonogram of the accompanying recording.

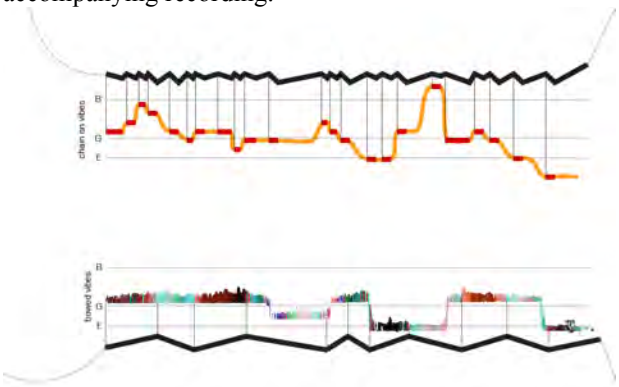


Figure 13. Excerpt from the score of *the miracle of the rose* [2015].

These works explore varied aspects of what O'Callaghan terms "mimetic instrumental resynthesis":

> Not only do these works use 'extra-musical' source materials as the starting point of their analyses, but they also attempt to preserve aspects of the source sound through the transcriptive process to engage in a mimetic discourse. (O'Callaghan 2015)

In particular the works allow for the contrast and interaction of instrumental and machine forms of sonification.

4. AUDIO PROCESSING FROM SOUND AND IMAGE

Many of the possibilities opened up by the processes described above have been enhanced by developments afforded by the *Decibel Scoreplayer* namely: synchronised networking, communication with external computers via OSC, audiofile playback, cross-fading of layers, random playback of score "tiles" and "nesting" of scoreplayer types (Hope et al 2015). The ability to interchange audio and visual representations of a work and to precisely synchronise them with live electronics provides a controllable work environment, including performers and electronic sound, that is not unlike that only previously available to Acousmatic composers working with recorded sound alone. The arrangement comes very close realising the "computer controlled performance environment" proposed in my 2011 paper "The possibilities of novel formal structures through computer controlled live performance".

The realtime transcription of field recordings into a symbolic score for an improviser to perform with or around in *Lyrebird: environment player* has been previously discussed (Vickery 2014). In *murmurs trapped beneath the bark* [2014], however, the source audio is a processed recording of a clarinet improvisation. Its ambiguous resemblance to real-world natural sound led me to term this an "artificial filed recording" and indeed the score produced by *Lyrebird* here has itself been visually processed in *Illustrator* to further the analogy with the recording (Fig. 14). This work, and this process opens up the possibility of creating hybrid real/mimetic sound works interchangeably combining field recordings and their machine and human emulations.

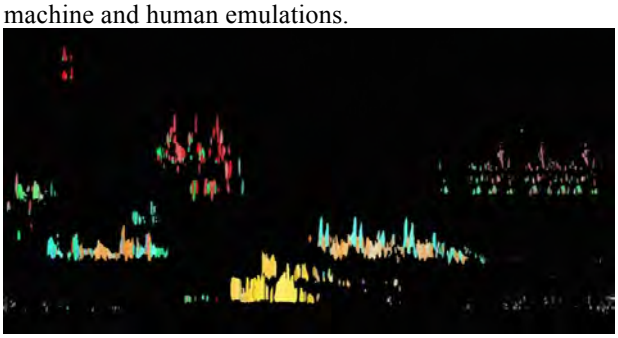


Figure 14. Detail from the score of *murmurs trapped beneath the bark* [2014],

Both *trash vortex* [2015] and *detritus* [2015], for example, feature scores comprising three layers: a graphical score, a rhizomatic path and an image collage (Fig. 15). The "path" layer periodically (and indeterminately) becomes transparent causing the graphical score to appear to "submerge" into the background collage - making it more challenging for the performers to read. The score (in the Decibel Scoreplayer) sends messages about the "path" layer's status via OSC to a *MaxMSP* audio processing patch, which in turn alters the audio processing of the live instruments to reflect the state of the score.

Figure 15. *trash vortex* [2015] three layered score: a graphical score, a rhizomatic path and an image collage.

My work in progress, *split constant* takes the opposite approach, repositioning score fragments in the Scoreplayer via OSC messages from the computer to align the performer with varied audio processing strategies.

In *in nomine tenebris* the contours of four of the instrumental scores are used to determine the spatialisation of the audio over 8 speakers (Fig. 16).

The data was transcribed by tracing the contours of the instrumental parts into four `function` objects. The data is then retrieved by inputting the position of the audiofile as reported by `snapshot~` (or score as reported by a *Tick* message received from the Scoreplayer over OSC).

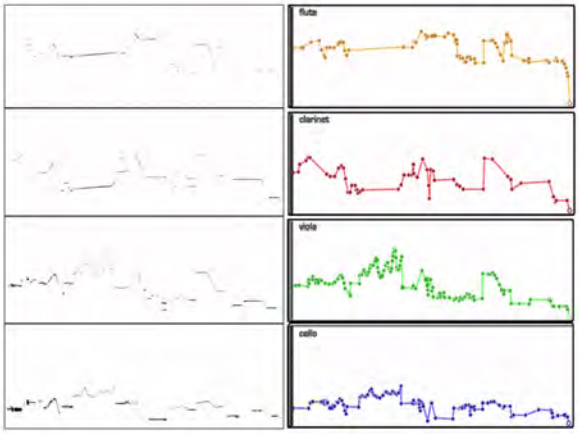


Figure 16. Contours of four of the instrumental parts for *in nomine tenebris* transcribed into four `function` objects.

The contour data also controls real-time spectral envelope warping of the acoustic instruments using Eric Lyons' `mindwarp~` in order to stretch instrumental spectra as the pitch of the instrument rises. *acid fury* in contrast, uses analysis of the found sound recording using data derived from Jehan's `analyzer~` object to spatialise the recording over 8 speakers in real-time. Similarly, *residual drift* employs real-time analysis of the noisiness of the live instrument to control the amplitude of the signal – allowing for inharmonic sounds to be favoured over harmonic ones.

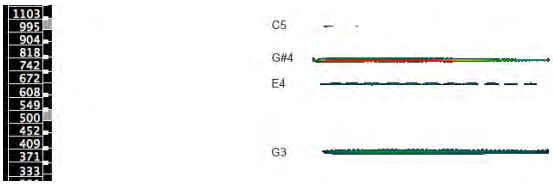
Similarly, *inhabited matter* [2015] and eight channel acousmatic work uses data derived from realtime analysis of its own structure to drive the spatialisation. The source audio in this case processed machine sonifications of the score of an earlier work *nature forms I.* This re-interrogating of materials is perhaps implicit in this project that emphasizes the interchangeability of audio, image and notation and, as noted, is also a feature of a number of other works discussed in this paper.

The score for ..*with the fishes*.. [2015] was built in a series of tableaux: oil rigs, flood, nuclear leak, deep sea, jellyfish/methane, submerged city, trash vortex. The tableaux were joined into a long image and then a score for viola, cello and double bass was then added on another layer. The score contained several references to musical objects: a recurring ship's bell and several passages from Debussy's *La Mer* [1905].

At an early stage of development of the work the instruments were recorded separately performing the notation and also performing passages with only the visual images from the tableaux. Once all of these elements had been created and had fixed temporal positions – the position of the scrolling score and the position of the recorded performances – they could be further compositionally developed through a range of interactions. The temporally fixed notation and audio allowed the process to proceed in a manner akin to manipulating audio in a Digital Audio Workstation: processing strategies could be auditioned; data could be derived from the score and used to control audio processing, pre-processed audio could be added and so forth.

At the simplest level the sound of a ship's bell was aligned with notation derived from a spectrogram of the same ships bell (Fig. 17) and short processed passages from Roger Désormière's classic 1950 recording of *La Mer* were aligned with the short quotations from the work.

a.



b.

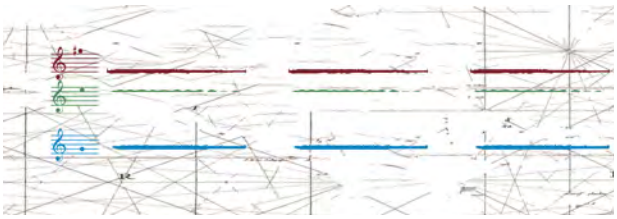


Figure 17. a. Spectrogram of ship's bell and b. notation of ship's bell in the score of ...*with the fishes*...

Like *in nomine tenebris*, contour details from the background image were also mapped into `function` objects to control manipulation of the live performers using a range of processes including degrading the signal, pitchshift/delay and spectral manipulation (Fig. 18).

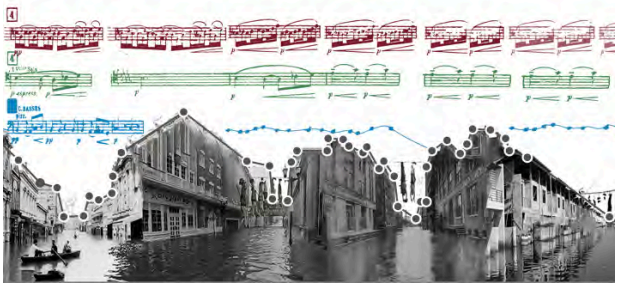


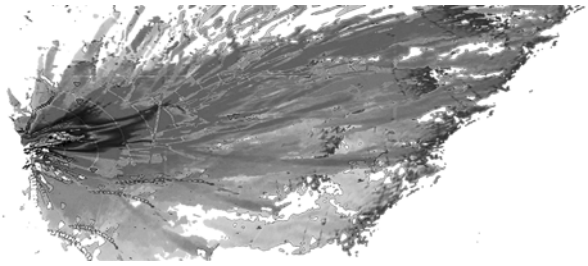
Figure 17. The *MaxMSP* function object mapped to contours of the score background image to control spectral manipulation of live performers and pitchbend spectrally "frozen" (with resent~) loop of Debussy's *La Mer* in ...*with the fishes*...

Audio files of the musician's performances of passages of visual images were then cross-processed against sonifications of the same images created in the *Sinereader* using Eric Lyons FFTease objects: namely resent, ether, thresh, shape, bthresher, pvwarp, pvgrain, disarray, taint, vacancy, burrow, codepend.

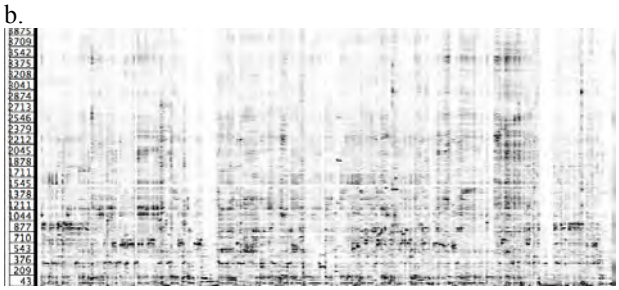
The processing included convolution with sonifications of the score image and the performance of the same image by the musicians to produce hybrid sounds combining both machine and performer

realisations of the images. In Fig. 19 the original image (a.) is compared to a sonogram of instrumental reading of image a (b.) and the spectrogram of the convolution between sonifications of the image and its performance by the musicians (c.).

a.



b.



c.

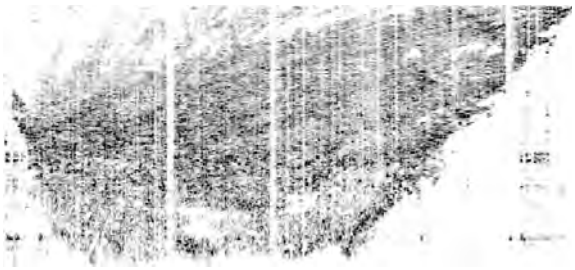


Figure 19. a. Image of Fukishima radioactive leak b. sonogram of instrumental reading of image a. and c. spectrogram of convolution of instrumental reading of the image and sonification of the image in *...with the fishes...*

5. CONCLUSION

These works explore the possibilities inherent in interchanging data between visual and sonic media. The processes involved including transcription of sound to image/notation, image/notation to sound, image to audio processing/spatialisation and audio to audio processing function interchangeably within a temporal framework. The imperfections in the transcription processes are intriguing in themselves as they throw into relief the distinctions between the various forms of representation. The implied circularity of processes opens the potential for re-interrogation of materials through continuous transmutation through the "eye of the needle" of transcription. These implications include the exploration of audio artifacts or "found sound" recordings as discussed but also extend to the exploration of field recordings and natural sound.

The efforts to extend notation discussed here are part of an ongoing project to better capture nuances of sound such as timbre, temperament and envelope morphology using shape and colour parameters (hue, saturation and luminosity). These experiments are further discussed in Vickery (2014a, b and c.)

Many of the processes described here are made possible through synchronisation of image, notation and audio afforded by computer networking, allow for the composer to operate simultaneously and interchangeably in both media. The inherent limitations of the analogy "that image and sound can be equivalent" can themselves be a rich field of investigation.

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