VARIABLE 4: A DYNAMICAL COMPOSITION FOR WEATHER SYSTEMS

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ABSTRACT

Variable 4 is a multichannel sound installation that uses meteorological sensors and a multi-layered array of algorithmic processes to transform weather data into musical patterns in real time. This paper describes the work in detail, outlining its historical context, systems infrastructure and installation specifics. The piece is discussed in relation to sonification and environmental installation, and observations are made on the process of siting a complex sound work in the natural world.

Keywords: installation, algorithmic composition, weather, multichannel, environmental, l-system, Markov chain.

1. INTRODUCTION

Sensor data has become a popular method of controlling the structure and sonic qualities of a sound installation, allowing a composer to closely link their musical work to tangible, real-world processes. Sources of activity such as dance [1], crowd movements [17] and natural ambient sound [6] have been harnessed using analogue to digital interfaces. Weather patterns have been used less frequently in this context, in part due to the lower availability of consumer-grade sensors to read climatic conditions beyond temperature.

This paper describes one such installation: *Variable 4*, a generative sonification of weather patterns, whose behaviour is determined entirely by the current weather conditions at the installation site. In doing so, it reflects naturally occurring cycles of tension and resolution.

Variable 4 takes place in a public outdoor setting, realised not simply as a real-time composition but as an immersive environmental sound work and a platform for exploring the natural world.

This paper provides a detailed outline explaining the principal features that underpin Variable 4. Section 2 begins by explaining the context and broader artistic frame of reference. Section 3 describes the infrastructure of the work including both the software and hardware, and Section 4 details the musical composition of the piece, referring to the global score, conductor model, movement and note-level processes, compositional techniques and spatialisation. Section 5 summarises site specific aspects of the installation; Section 6 provides some aesthetic reflections on the process of creating the installation. Finally, Section 7 evaluates the installation and discusses ongoing development.

2. HISTORICAL CONTEXT

The use of mathematics and algorithmic processes has been intrinsically linked with musical composition for several centuries, traceable to the earliest days of polyphonic music [2]. The motivations for this are manifold [11]: formalising musical structures enables them to be *explored* for better understanding, *automated* to introduce diversity and unpredictability, and *formally related* to other domains of knowledge, such as in the compositional use of natural processes [9].

By employing models inspired by the natural world, the composer has the opportunity to explore the structural linkage of musical composition systems with systems occurring in nature. Prominent examples have borrowed from botany [9], genetics [6] and swarm theory [2]. The pursuit of these explorations provides the composer with the ability to explore and emphasise the relationship between mathematics, music and the environment.

The exploration and consideration of the natural environment has been a fascination for generations of composers working with sound. Through the beginning of Mussorgsky's *Night On A Bald Mountain* and organisations including the World Soundscape Project, established by R. Murray Schafer in the late 1960s [16], to sound installations including Jem Finer's *Score For a Hole In The Ground*[1], composers have sought to explore and accentuate mankind's relationship with their environment.

2.1. As sensor-based installation

As the commercial production of sensor technologies has proliferated, so new pathways for artists to explore have become available. Over recent years works from across many different media have explored the varying uses of sensor data for both control and structure.

1 http://www.scoreforaholeintheground.org/

Whilst in recent years the majority of algorithmic music has involved the exploration of performative interaction with algorithmic systems and their use for the production of score material, *Variable 4* seeks to explore the use of algorithmic processes in an autonomous real-time installation, driven by the chaotic and unpredictable behaviours of weather systems.

2.2. As sonification

Loosely defined, a *sonification* is the translation of a pattern or process into an audible form. By representing data in sound, we may be able to gain insights into structural properties that are not otherwise evident; see Kramer [8] for a full treatment.

Bob Sturm's 2004 sonification work '*Pacific Pulse*' is a particularly absorbing example of environmental sonification, providing the audience with a new level of understanding in the comprehension of the largest ocean on the earth. [14]

In describing *Variable 4* as a sonification of weather data, we seek to contribute to the ongoing dialogue upon the definition of the concept and its use within musicology. In Hermann's 2008 paper, '*Taxonomy and Definitions for Sonification and Auditory Display*' [5], the author more precisely states the definition as follows:

> A technique that uses data as input, and generates sound signals (eventually in response to optional additional excitation or triggering) may be called **sonification**, if and only if
>
> (C_1) The sound reflects *objective* properties or relations in the input data.
>
> (C_2) The transformation is *systematic*. This means that there is a precise definition provided of how the data (and optional interactions) cause the sound to change.
>
> (C_3) The sonification is *reproducible*: given the same data and identical interactions (or triggers) the resulting sound has to be structurally identical.
>
> (C_4) The system can intentionally be used with *different data*, and also be used in repetition with the same data. [5]

In reference to these categories, the installation adheres to (C_1) in that the movements and material contained within are objectively part pre-composed to relate to the input data i.e. a roll of thunder might trigger a low frequency rhythmical motif. Regarding (C_2), the data sensors trigger related material within the score in a systematic way across the score. Regarding (C_4), most methods of sonification we have devised are eminently adaptable for use with different data sources; for example, the mapping of N-dimensional parameters to distinct movements via a nearest-neighbour search (see Section 4).

Category (C_3) requires slightly more consideration. Given exactly identical input data, the score will play structurally in the exactly the same manner (the same clips from the same movements would be triggered). On a more detailed level, the use of chance procedures within the score mean that the audio signal conveyed to the audience is not necessarily an exact replication. The overall sound structure would be the same (if in this instance we consider the sound structure as the tempo, tonality, timbre and general thematic elements of the speaker output), but on a more detailed level, fragments of the sound might differ. In this sense, we diverge from the core tenets of sonification, which presuppose a deterministic mapping from input to sonic output. We argue, however, that as the overall *statistical properties* of the piece remain identical for a given input pattern, this can still be considered a valid form of sonification.

3. INFRASTRUCTURE

The hardware and software infrastructure that underlies *Variable 4* has a number of components, shown in Figure 1. The primary sensing input is the Campbell Scientific BWS-200 weather station[2], with an additional rain gauge and pyranometer for readings of solar radiation. This is connected to a laptop via a serial-USB interface, with an RS-484 "long drop" extender for communications over several hundred metres.

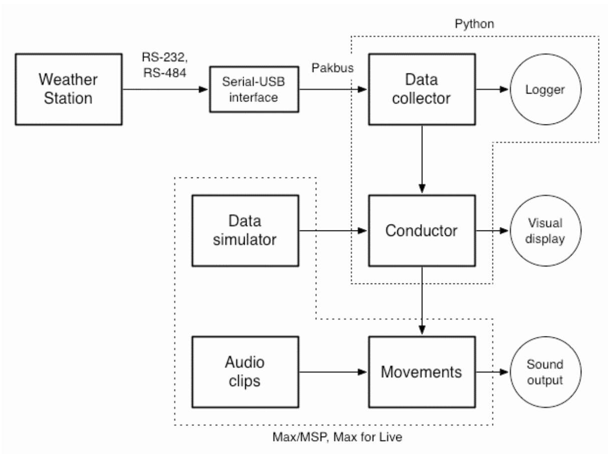

Figure 1

Incoming sensor data is read in real time using a library written in the Python programming language, at the weather station's maximum resolution of approximately 10 readings per minute. Though this rate is too slow for immediate sonification at the sound-object level, it is sufficient for the gradual changes that characterise the score of *Variable 4* and the weather systems themselves.

The following types of data are provided by the weather station. In addition, derivatives are also

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[2] http://www.campbellsci.co.uk/index.cfm?id=1067

calculated by the Python code (change in temperature over time, etc).

Data type	Units	Effective range
Air temperature	°C	[-20..50]
Relative humidity	%	[0..100]
Wind speed	m s^{-1}	[0..30]
Wind direction	°	[0..360]
Rainfall	mm h^{-1}	[0..50]
Solar radiation	W	[0..2000]

Figure 2

The processed data is subsequently made available to the software that performs the bulk of the musical processing. This is a framework developed within *Max for Live*[3] (M4L), a piece of software which bridges the high-grade production values of Ableton's *Live*[4] DAW with the algorithmic and I/O flexibility of Cycling 74's *Max/MSP*[5].

This framework, in turn, has a number of elements, each taking the form of M4L patches interwoven with Python scripts.

- The **conductor** receives the weather data and uses it to determine the overall behaviour of the piece with reference to the global **score** (see following section).
- A number of **movement** elements are identified as groups of audio, MIDI parts and generative elements, grouped together using an internal notation.
- A visual **lattice display** indicates the current position within the score and likely future trajectories.
- A **simulator** enables weather conditions to be emulated using manual controls, overriding the real data input, for testing and development.

In conjunction, these elements handle the data input in real-time and collectively determine the output of the piece. Sections 4 and 5 of this paper detail the musical constituents and notations which these elements are programmed to carry out.

The end audio output from *Live* is distributed using a set of eight KEF Ventura 6 weather resistant speakers. By necessity, *Variable 4* is installed in locations subject to elemental exposure; a sealed ABS composite enclosure and UV resistant rustproof coating provide these speakers with sufficient protection to function in a range of weather conditions.

A related logistical hurdle is the establishment of an audio connection between the processing computer and the 8-channel speaker system. For the Dungeness installation, this distance was over 100m. Using a typical audio cable over such a range would result in such a high resistance as to be effectively useless. Our solution was simply to use a high-fidelity cable with 4mm conductant diameter. Though still attenuating the signal by approximately 18dB, with some drop-off over 10kHz, the audible artefacts are not critically severe.

4. THE COMPOSITION

A key challenge for the piece was to design an infrastructure that could function simultaneously over multiple levels simultaneously: at the level of entire movements; over the segments which constitute each movement; within the finer-grained composition at the level of individual notes; and the spatial distribution of the resultant music over an 8 channel speaker system. We will examine each level of this framework in turn, and subsequently discuss related practical issues.

4.1. The global score

The overarching structure of the piece is notated in a two-dimensional score, mapped onto a hexagonal lattice (below). Each cell corresponds to a single movement, which in turn corresponds to a range of weather conditions and time period.

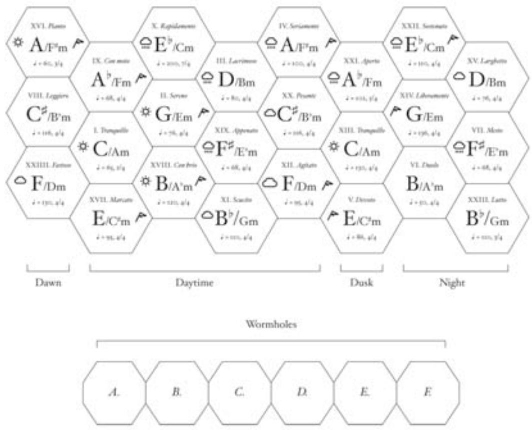

Figure 3

In addition to its corresponding weather conditions, each movement has a number of additional properties: a key signature, from the 24 possibilities in the equal tempered scale (both major and minor); a numeric index; a time period; a metronome mark; and a written tempo.

In designing the score, it was vital to assign similar weather conditions to neighbouring cells; in general, it is most often the case that conditions change gradually, and so should move from a cell to one of its neighbours. A second constraint is at play, however: to ensure harmonic consonance when moving from one cell to the next, the key signatures are connected using the circle of 5ths (and 4ths): the north-easterly cell to a given cell is always its 5th, the south-westerly its major

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[3] http://www.ableton.com/maxforlive

[4] http://www.ableton.com/live

[5] http://cycling74.com/products/maxmspjitter/

4th, and the southerly its major 3rd. By using a hexagonal grid of the given dimensions, these relations wrap neatly across each edge with pleasing harmony.

The time period attributed to a movement is categorised by reference to the installation's time zone as either *Day* (1000-1800hrs), *Dusk* (1800-2200hrs), *Night* (2200-0600hrs) and *Morning* (0600-1000hrs). These move from the west to east of the score.

The use of all 24 possible key signatures in the equal-tempered scale provides wide opportunity for harmonic and idiosyncratic variety when motifs from different movements are combined, and serves as a fitting temporal link between the cyclical motion of both the weather and the duration of the installation.

4.2. The conductor

Navigating across the score to determine the top-level structure of the piece is a single *conductor* process. This moves across the lattice based on the current weather conditions and time period, shifting gradually towards the cell that best matches the real-time sensor data. This match is calculated using a weighted distance calculation between each movement's weather conditions and the sensor data. Conditions that are more psychologically prominent (strong sunshine, heavy rain) are weighted more heavily than those such as wind direction and relative humidity, to tally the perception of the piece's correlation with its environmental surroundings.

As the conductor moves from one cell to the next, a transition begins to take place. At any given time, in consideration of the prevailing weather conditions, material might be triggered from anything up to three movements simultaneously.

The choice of which material is most relevant is accomplished by a ranking system, referencing the current weather data against the data attributed to the scored motifs. The top three movements are considered and material will be triggered if their attached descriptions bear a sufficiently close relationship to both the weather data and other material being considered.

4.3. Movements

Each movement is constituted of a number of *tracks*, each corresponding to a given instrument. In turn, a track includes multiple *segments*, roughly equivalent in length to a few bars. Whilst a movement is playing, segments are moved between using stochastic processes, according to sets of relationships designed at the compositional stage. The dynamic recombinations of these parts generate polyrhythms and composite tonal structures.

By using an internal notation system, the placement of these segments within tracks in the layout of each movement allows them to be identified by Max/MSP, and therefore related to the weather data. For example a sudden increase in humidity might trigger any of four or five clips within the area of the tracks within the movement defined as 'short rhythmical motifs'.

4.4. Note-level processes

All movements of the piece incorporate semi-generative parts, which use a range of algorithmic systems to produce novel patterns on a note-by-note basis. Some of these processes are stochastic or chaotic, ensuring a constant supply of richness and unpredictability whilst remaining within the constraints of the overall trajectory and harmonic mode of the piece.

Techniques used include:

Markov chains [12]: To move between notes, durations or audio segments based on a graph of transition probabilities.

L-systems [9]: To generate extended arpeggiated patterns from branching grammars, based on a parametrised scale according to the current movement or passage.

Combinatorics: To amplify movements based on permutations of their parts.

In general, no one approach was given primacy; our approach was more akin to a creative bricolage, adopting techniques where appropriate to give a rich and diverse sonic outcome.

4.5. Wormholes and transitions

In the typical case, when a transition takes place between two consonant movements, tempo ramps and averages are used to create smooth transitions between material, aided by the use of *Live's* elastic pitch and tempo warping mechanism.

If the weather system changes so quickly that the only option is to move from one movement to one that is harmonically dissonant with it, the piece enters a 'wormhole': an arrhythmic and often atonal bridge, which serves to join two unrelated musical elements. These wormholes were composed specifically for this purpose, incorporating field recordings from the site and microtonal elements.

An additional control mechanism encoded within the score is a 'fatigue' mechanism. This ensures that, even with static weather conditions, the score will always remain in motion. As a movement plays, a 'fatigue' counter rises continually. After it reaches a certain threshold, the conductor begins to be repelled from the corresponding grid cell, and will eventually move towards the next most appropriate movement.

4.6. The score in practice

An example scenario may proceed as follows:

Time: 14:00

Weather conditions: cloudy, moderate wind, cool, low humidity, low solar radiation.

These conditions will result in the triggering of material from movements in the keys of Bb major (XI), G minor (XII) and F major (XII) according to the conductor model. Bb major bears the closest relationship to the weather data in this case, and it becomes the tonality that other considerations are based upon. In this instance, neighbouring movements in G minor (Bb major's relative minor) and F major (its dominant) bear sufficient harmonic and data attributes that material will be playing from these movements in combination.

4.7. Compositional techniques and instrumentation

The compositional process of the musical elements of the piece has relatively traditional roots: the key motifs of each of the 24 movements are scored using conventional notation, with a set of MIDI and audio instrumentation per movement. These instruments are shared and triggered by both the deterministically scored and algorithmically generated elements, giving a shared sound space which ensures some cohesiveness in the piece's output.

The composition of these motifs is objectively linked to both the heritage of the installation site, and to the weather conditions and musical parameters that each movement is linked to. Aesthetic decisions were made with these considerations in mind, correlating audio elements with the weather conditions that seemed most natural: a percussive, clattering sequence recorded on a prepared piano, for example, was matched with a wormhole for rainy periods.

4.8. Spatialisation

Finally, the spatial distribution of the parts over the piece's 8-channel speaker system is also controlled algorithmically. This is closely connected to the current wind direction as determined by the system's weather vane. A number of different panning patterns, containing a combination of generative elements and pre-composed sequences, are determined in relation to the current movement.

Each of the output instruments is allocated a certain abstract spatialisation 'mode': 1-, 2- and 4-channel, and omnidirectional. Instruments are distributed evenly around the surround field, with an appropriate number of channels allocated automatically. As the wind direction and speed alter, channels pan around the listener in real time, ensuring a dynamic spatialisation which has a close, tangible link with the physical surrounds.

5. THE INSTALLATION

Every installation of Variable 4 is site-specific in its nature. Given the wildly differing atmospheric conditions of different geographic locations, and the score's dependence on particular sets of conditions, it is crucial to calibrate it afresh for each new installation. In the months leading up to an installation, historical weather data is collected from the site and, where possible, the records of local meteorologists. This is used to create a statistical model of the weather systems that occur during the time of year that the installation is taking place. In addition, the cultural history of the site informs the composition of the score, with field recordings from the local area often incorporated.

Figure 4

The on-site installation is designed to minimise the visual impact upon the environment as much as possible, with the objective of making the physical presence of sound sources close to invisible. The speaker and data cables are buried in the ground and the speakers themselves are integrated into the natural landscape. In the Dungeness installation, the speakers were buried within the flotsam and jetsam that we found present at the site, providing an added layer of protection from the elements for the speakers.

Figure 5

The first installation took place on the shingle plains of Dungeness, Kent, a site chosen for its elemental exposure, inherent soundscape quality, heritage and atmosphere. The public were invited to visit the installation at any point over the 24-hour period from midday May 22nd to midday May 23rd, creating a situation in which a visitor could explore the piece entirely on their own terms and timescale.

6. AESTHETIC REFLECTIONS

Whilst the algorithmic processes can alone be fascinating in their autonomous activity, they were applied carefully within the score and subjected to close judgements of fit and appropriateness during the composition stage. In many cases, several iterations and combinations of processes, scales and dynamics took place before the deployment of an algorithm was satisfactory. This iterative, reflective process is as described by Tanaka:

> The machine does not replace the composer. The composer must maintain an active artistic interest to coax and mold the machine output into a piece. [15]

A second consideration when siting the installation in an outdoor context is the lack of reverberant surfaces to unify the audio output. Whilst initially trialling the installation with a chain of conventional effects such as reverb and delay, we ended up unilaterally avoiding such effects as their effect sounded comically false when integrated with the natural soundscape.

Moreover, though volume levels were carefully balanced through the development stages of the score using the inbuilt weather simulator, it is notable that a much larger dynamic range became acoustically acceptable. Perhaps this reflects the expectations of dynamic variance within the natural world, unlike our preconceptions of restricted dynamics within a typical audio recording environment.

Serendipity and chance events seemed to play a surprisingly significant role in the audience reception of *Variable 4*. In its context as outdoor spatialised sound installation, external sound events become an intrinsic part of the installation. One audience member at the Dungeness site praised our use of birdsong within the score. In actuality, at that point, the source was a real bird, exploring the telephone wires close to the installation.

McCormack [9] makes reference to the emergence of such unexpected relationships:

> A life experience includes relationships to the environment, interaction with both living and non-living things, social and cultural constructions. We all know that these things have a major effect on a person's internal states. Much creativity also depends on serendipitous and chance events in the external world, both conscious and unconscious. [9]

7. CONCLUSION AND FUTURE WORK

Variable 4 continues to see ongoing development, with a series of installations projected over the coming months across the UK.

The public reaction to the Dungeness installation was one of overwhelming curiosity and engagement. Whilst involving some fairly arcane concepts and technical structures, the straightforward presentation and environment meant that visitors with no awareness of computer music or avant-garde composition could instantly understand the piece. Visitors would also frequently return to the site some time after their initial encounter, to see and hear how it changed alongside the weather.

For planned future installations of Variable 4 we wish to incorporate a series of developments within the hardware and software infrastructure.

- An internet streaming infrastructure will allow us to broadcast a stereo stream of the composition to a dedicated online microsite and over other broadcast media.
- The development of an expanded set of system-based processes, including the incorporation of both established compositional rule-based systems and further generative processes. Those currently under trial include Bach chorales [3], Johann Fux's Gradus Ad Parnassum [13], and genetic algorithms [9].
- The application of spatialisation techniques across the system is to be further developed, both based upon algorithmic processes and through incorporating idea such as those described by Moore [10]
- Over time, the duration of the installation will be increased, enhancing the communicative effect of the sonification upon the public, thus drawing a greater attention to their surrounding environment.

An inherent shortfall with the installation is, as often the case in sound installations, one of accurate documentation. How can one accurately portray through the use of one or more microphones, the effect of a spatialised 8-channel outdoor sound installation, where the environment, the tangibility of the weather and the physical interaction with the speaker system is just as important as the piece itself? We hope to return to this question in a future research paper.

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