Projection and interactivity of musical structures in *Mirror-Rite*

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Mirror-Rite **is a work for 'meta-trumpet', computer and live electronics. The composition is neither notated nor stored, but forms itself as a complex of rule-based structures, transformations and processes around the improvisation of a live performer, its source of both energy and material. This article discusses the ways in which these algorithms deal with interactivity and projection in time, and how the handling of these aspects might permit the assembly of algorithmic elements into a complex dynamic whole, sensitive to (and existing solely within) present circumstances, but demonstrating unity between different performances.**

1. THE SYSTEM

The meta-trumpet is an integrated interactive intrument–interface–composition system, described more fully in Impett (1994). Physical aspects of performance already inherent in playing the trumpet are abstracted and extended to become both control parameters and compositional material. The system has a knowledge of its past history, present state and, by analysis, aspects of the nature of its own behaviour.

2. HARDWARE

Ultrasound receivers around the performer read the position of the instrument constantly in a 2 m^2 virtual screen, from a cluster of transmitters mounted on the bell. Together with the output of an accelerometer, this permits the calculation of direction and acceleration of movement, as well as current position and speed. Information about the player's direct contact with the instrument is provided by two pressure sensors fitted where the fingers close around the valve casing, and mercury switches below the bell to read the lateral tilt of the trumpet. The three valves each contain a magnet, the strength of their fields measured by sensors in the valve caps below. Six switches are fitted behind the valves and next to the left thumb, and are generally used to change the functionality of other parameters in software. Pitch, pitch-bend and volume are derived by an IVL Pitchrider.

3. SOFTWARE

Performance data is processed on two levels – system and composition – behind which run a variable number of independent schedulers. Each scheduler can be switched in and out separately from the composition level, or have its contents transformed in some way without affecting other generated material. Timing information could, for example, be expanded or contracted. This offers a means for the composer to group compositional processes or material into streams of any breadth, while retaining their autonomy of behaviour and keeping track of their origin, as well as to interrupt or resume separate strands of development.

At the first level, performance data is filtered, mapped and stored according to the system configuration given in an initialising function which each composition contains. Continuous parameters are also calculated at this stage, including time-based values such as movement vectors and note density, and other statistical information.

The results are posted as system variables, and filtered events passed on to the appropriate compositional super-function. These are referred to as 'scenes', and organised by MIDI input channel, for each of which any number of scenes can be given. The updated state of the system is further analysed at this stage for locally relevant qualities – recognition of pattern or modality, for example. Scene changes are independent for each input channel, and either can be scheduled initially, or a scene can contain the logic by which a change will occur. All events – system, compositional or MIDI output – are scheduled in the same way.

4. OUTPUT

Live and processed trumpet sound, sampling machines, synthesizers and sound processors, the latter controlled from the computer, are routed through a MIDI-controlled mixer. All performance instructions derive from the event-driven compositional algorithms.

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5. SOUND MATERIALS

The central economy of sounds in *Mirror-Rite* springs almost entirely from the trumpet itself. The first and last sounds are the physical body of the instrument, brought alive by breath or hand, and filtered by the harmonic foundations of the piece (Sound Example 1a/b).

Some are transformed in real time by the processors within the system. Others are transformations that would be impossible or impracticable to perform live – usually because they involve moving backwards and forwards through a sound, rather than dealing with the samples sequentially. Obsession with the idea of 'real time' can cloud this issue. These sounds were produced in the studio – at the Centro di Sonologia of the University of Padova – and are played in the piece by a sampling machine, such that they can be retransformed live in the same manner as the acoustic sounds (Sound Example 2).

These materials are extended in two directions: towards the 'real' world (the 'Tibetan trumpets' in Sound Example 6), and towards greater abstraction (the sustained harmonic background in Sound Example 4).

To this closed, circular space of sounds are added 'gifts' from outside, whose formal function is quite different. In fact their source is closely related, and in the course of the piece, they come within the sphere of direct influence of the player. Or rather, it becomes clear that they form part of his world. The distinction between 'inside' and 'outside' sounds is no longer relevant (Sound Example 3).

6. FORM

Formally, *Mirror-Rite* is essentially a spiral, with an accelerating path in, and a final flat surface on which the music can move freely. The dynamics of time make themselves felt in the first section, rule through the central spiral, and then are taken up into a relativistic total in the last section, as the player both gives in to and takes control over their apparent inevitability. This spiral is divided into four quadrants – scenes, in terms of this environment – through which the player constantly returns. At each return, the logic of the scene resumes from its last endpoint, but the input from the player has moved forward in the meantime. The evolution of each scene is both continuous and discontinuous. On one level they are cross-cut like sections of film; on another the discourse, the drama, has been going ahead constantly in the quasi-linear time in which performer and listender are bound together. The moments of transition are marked by pillars – the previous sound example; the 'gifts' from outside the central exchange. Two opposing Fibonacci series govern the proportions of each scene – the velocity of the path through the spiral – the scale and intersection of these being derived from the present performance. Scene five (the fourth of the central cycle), has its proportions redistributed, to allow a uniquely long development on the first occurrence. This allows the construction of a subsequently constant-length refrain, surrounded by the diminishing proportions of the others.

7. PROCESS

The piece functions as a complex of simultaneous event-driven algorithmic processes. The input for these may come from the live performance (MIDI data), from one module to another, or from itself (via the scheduler, set at an earlier occurrence). Each incoming piece of information is passed through the same structure, using the same syntax, and subjected to a succession of conditions and rules.

The nature of the event which drives a particular module is not directly related to the degree of its awareness of its embedding environment or history, or its implementation. Certain modules exist simultaneously in several realisations, in a pseudo object-orientation which retains the 'narrative' of linear programming. In these instances, several threads of values and identifiers are passed through the schedulers.

In the interests of clarity, this article will use the term 'module' to refer to a particular instantiation of the software which deals with one compositional unit (the boundaries are purely musical), and 'structure' to the material thus generated. 'Process' refers to the means by which this is accomplished. 'Module' is not identical to 'function', because it may exist in several versions, nor to 'object', because its result may be a product of several objects. A 'model' is the paradigm by which a particular structure is generated; the superset of its algorithm.

8. PROJECTION IN TIME AND SPACE

The sonic realisation of a structure or process depends on the definition of each dimension of the musical space in which it is to take place. This is as true of, for instance, a fugal subject appearing in a different mode, in diminution, in a higher, softer voice, as of some fractal microtonal real-time computed structure. Musical spaces so defined are described by Xenakis as 'outside time structures' (Xenakis 1971). The interest in the interactive context is twofold: to realise 'outside time structures' inside time, and to do so with the real-time restriction of one-directional time. In both audio-processing and macro-compositional terms, this simply means not being able to do things that require certain knowledge of what will happen next. To return to the fugue

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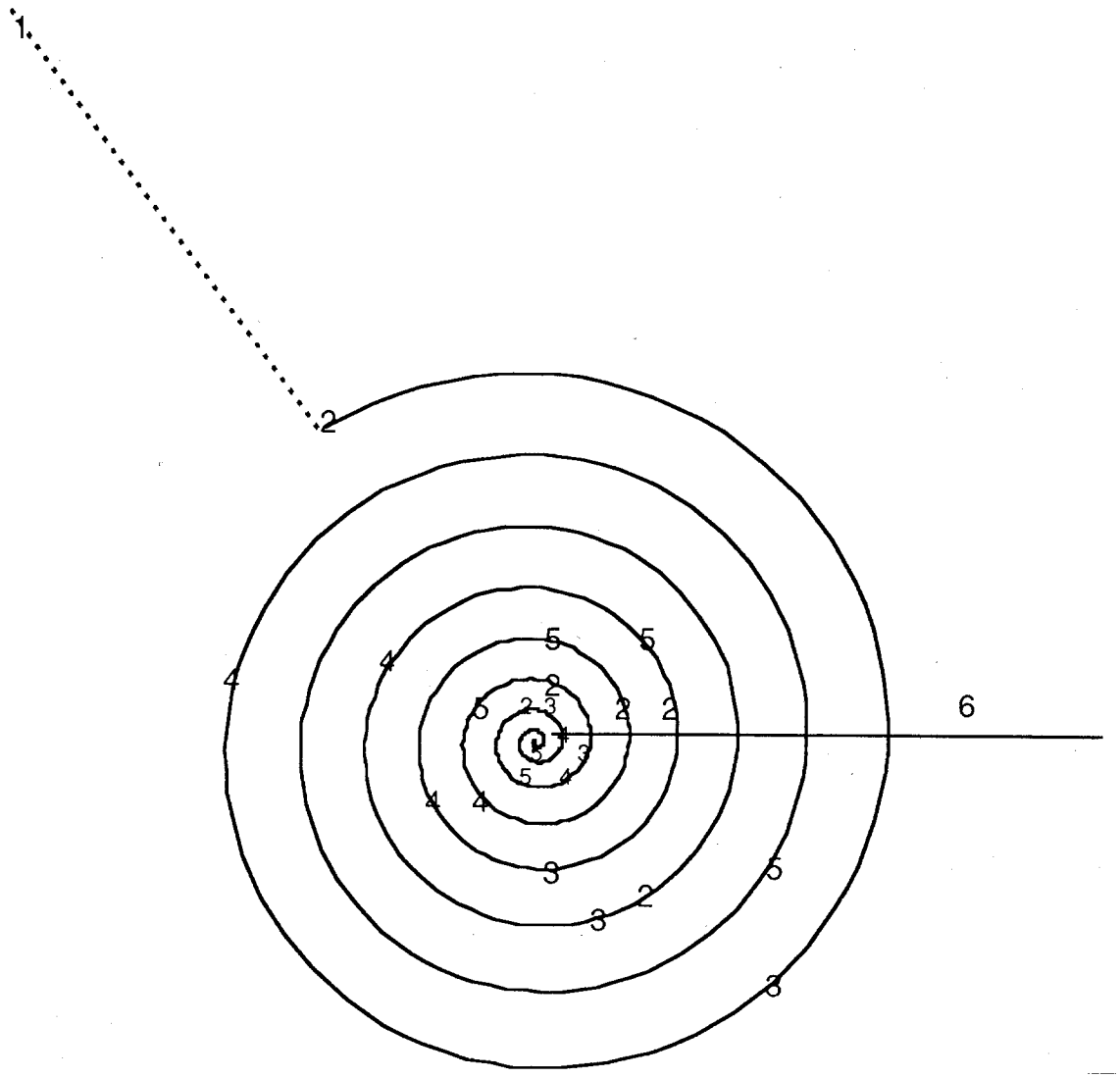


Figure 1

example: at a certain point in the compositional process, the composer might fix certain points of arrival, and work both forwards and backwards. Here, the potential strength and richness of such an approach have to be achieved by other technical means.

It is important to distinguish between the mapping of input performance parameters onto output musical space, and their use as the catalysts, variables and context of the various compositional algorithms. The mapping of performance data directly onto output happens only in certain situations, and then through dynamic 'prisms', continuously shifting or distorting the projection. (Exceptions are the two finger-pressure sensors, which form an integral part of the extended instrument, and whose values are directed straight to the trumpet sound-processor.) Generally, such a relationship serves to give the performer intuitive control over a 'high level' parameter, or as a means of extending the immediate domain of the live instrument. These are powerful tools, and used sparingly. Pitch is never translated directly onto other sounds. Where pitch is the central issue, phrases or structural qualities of input (incidence, density, modality, tendency) are processed.

A rare instance of an input parameter being mapped directly to output sounds (i.e. with no time-based element) is a 'virtual screen' of percussion, heard in the last scene. As the trumpet physically moves into the area of a particular instrument, that sound is triggered with a fine pitch adjustment, filtering and volume proportional to the point, angle and speed of arrival (Sound Example 4).

In an attempt to set out some sort of taxonomy of the various dynamic structures making up the complex system which is the composition, I propose to borrow from Prusinkiewicz (1995). His articulation of the possible space was developed for 'Visual Models of Morphogenesis', but we should not be too

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sidetracked by questions of dimension. Where such models are not entirely abstract in origin, their derivation is generally from the modelling of natural, dynamic, time-based processes, rather than geometric. There is increasing interest in the modelling and analysis of such phenomena in sound rather than pictures (cf. First and Second International Conferences on Auditory Display, Santa Fe, 1992/4). Their algorithmic representation makes them suitable for computer applications such as this. The musical purpose is to allow a complex system of structures and processes to develop internal interaction, and to 'spark life' together with the performer.

Without the performer, we would have a collection of dead algorithms, or at most a system which, given an appropriate seed, could fix its lifeless progeny at startup. The live performance fulfils several roles:

- *Energy source*. Literally. Without input events, there are two possibilities: everything stops, or the current processes continue in their present trajectories and relationships to stasis, chaos or extinction.
- *Nonlinear variable*. Even to structures that analyse their input for patterns, statistical qualities or tendencies, the actual events are entirely unpredictable.
- *Common reference*, *focus*, *history*. All processes have potential access to the same performance information and its history (buffers, analysis), as well as to selected aspects of their own past, and of the state of other modules. Differences of mode and degree of 'self-knowledge' constitute a useful paradigm for the understanding of complex systems in general.
- *Means of information flow*. Standing at the centre of the complex of processes, the reactions of the performer to what he hears constitute a form of dynamic analysis, channelling information on the state of the whole (on various levels, depending on the current focus of attention) back to and between the various structures.

The inverse of this set of functions is the 'sightedness', or field of knowledge of each module, discussed below.

Prusinkiewicz sets out the following characteristics of morphogenetic models, by which they may be categorised:

(1) Structures may occupy a constant space, or the space may expand or contract over time. This transformation may affect the outer boundaries or the internal articulation of the space.
(2) Models may be structure-orientated or space-oriented. That is, they may be considered in terms of the development of the components of the structure, or of the transformation of the embedding space. The first represents the location of each component, the second describes what is located at each point of the space. Contextual constraints – particularly of efficiency of calculation – dictate that the structures in *Mirror-Rite* are essentially structure-orientated. An example of space-oriented composition would be the granular screens of Xenakis (*Analogique A*, 1959, for example).
(3) The developing structure and its embedding space may be discrete or continuous. In this context, apart from the inevitably discrete machine-time, this can be seen in the dynamic periodicity of various structures, the time frames of which are then themselves subject to transformation.
(4) Models may be characterised by their different topologies – linear, branching, network, self-similarity and dimensionality.
(5) Neighbourhood relations between structures may be fixed at the time of their creation, or mobile. Here, the live performance constitutes another nonlinear structure, with which all the others have some form of relationship.
(6) Communication between the modules may take the form of lineage (parent → offspring) or interaction (information transfer between coexisting modules). Within the latter, flow may be endogeneous (between components or instantiation of a model) or exogenous (through the space embedding the model – here the software, but also 'musically' via the performer as discussed above).

9. ALGORITHMIC VISION

Particularly in this physically interactive situation, the last of these captures the crucial aspects of the flow of control information during the morphogenesis of the various musical structures, and we will use this as the prime means of articulating their differences. From this point of view, Bell (1986) observes three major types of model:

(1) *Blind*. The 'parent' or generating module controls the whole structure, independent of the remainder of the structure, or of its embedding environment.
(2) *Self-regulating*. The developing structure organises itself, using communication between existing components.
(3) *Sighted*. The structure is aware of its environment.

In practice, there is a continuum of 'sightedness', and within each module, different dimensions display varying degrees of knowledge and dynamism. The one common dimension is time. The 'time-sightedness' of a structure might appear directly related to its being plotted at the moment of creation, or rescheduled and calculated step-by-step. Only a structure fixed in every dimension can be planned in its entirety at one moment, and even then the space onto

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which it is projected may be transformed: the time frame of that area, for example, or the tuning of an instrument.

10. BLIND STRUCTURES

The decaying complex of bell sounds heard in Sound Example 3 is a compact instance of a near-blind structure. Only three parameters take account of the 'outside world', it looks (in principle) only at the current note event, and the entire passage is scheduled at the moment of its generation, such that only changes to the relevant scheduler or to the configuration of the output devices (in this case sampler → processor → mixer) could alter the course of events. The sound events are determined by a Gaussian distribution using offsets and multipliers derived from the delta time, pitch and volume of the last appropriate input note, folded about the current time. Searches for 'appropriate' values have to be made where conversion errors or unusual events in performance would negate the musical sense of a structure.

The second scene contains a falling structure of sharp, percussive sounds which has a slightly richer relationship with the input. Pitch input in certain occurrences of this scene is analysed for interval patterns derived from the player at an earlier stage. The pattern recognition mechanism is simple: if a new note event forms the first interval of the pattern with the previous note, a flag is set. Subsequent intervals confirm the match or otherwise, until a complete pattern is found. When a match triggers this module, the previous phrase of input is 'verticalised', transposed by a sequence of values stored in the module, and the result further pitch-filtered by a harmonic grid, again derived from the pitch input. The tempo of the structure is inversely proportional to the speed of movement of the trumpet within the performance space, and its volume is the average of that of the triggering pattern.

This approach is developed further in Sound Example 5 (Scene 5), where the drum sounds constitute a self-similar structure, the seed of which is the previous phrase of improvisation. The input is represented as an ordered series of vectors, which are further applied in with transformations of scaling to each point (note event) thus generated. The scaling factors for time, pitch and volume are derived from the density, range and intensity of input, and the position of the instrument at the moment of generation. The first two factors are always <1.0 to ensure the 'mortality' of the structure. In this case, the triggering mechanism is a rotational flick of the trumpet, armed only during this scene and in the absence of certain other structures. This is the only module that reasons in geometric terms, for the purposes of efficiency (it does generate a fundamentally two-dimensional structure), and to avoid compound semitone-averaging errors. Figure 2 is a simple notated example of the relationship between input and generated structure in this module.

11. SELF-REGULATING STRUCTURES

Three modules, each generating two simultaneous structures of shawm-like sounds (actually a cross between Tibetan oboes and granulated trumpet), follow the trumpet input in rotation in Scene 2 (Sound Example 6). As their self-regulation increases, so does their degree of autonomy. The first retains a perceptible note-to-note relationship with the input; each note of input is delayed and its velocity changed within a range proportional to the volume of that note. The length of the note is that of the previous note of input. The two structures thus use the same pitches and note lengths, but staggered and overlapping differently. With protracted loud playing, therefore, the relationship of input to output is increasingly likely to be stretched in time.

This separation is widened in the second module of the sequence, which increases the offset and range of a Gaussian distribution of event delays in each structure, according to the horizontal position of the trumpet within the performance space. Two new continuing linear structures are thus generated which convolve the improvised line in time, with a degree of complexity determined by physical movement.

These structures are taken as the source material for the third module, which continues independently of the live note events, rescheduling itself at each stage (still in two separate structures) and looking at the new situation in which it finds itself. For pitch material, each structure works its way through an array filled from the output of the previous module, selected by Brownian motion within a sequentially shifting, expanding and contracting window of possibilities. The note lengths and delta (inter-onset) times are taken from the present input, working backwards relative to the current note event in ever-increasing cycles. These time values are then subject to a multiplier proportional to the radius of movement of the trumpet. This relates intensity of activity of the structures to intensity of physical activity, allows the structures to fold in on themselves in time, and avoids projection into infinity.

The central module of the fifth scene (Sound Example 7) generates four simultaneous structures, each with their own voice and controls, together constituting a dynamic refrain. Which of these is currently aware of the player depends on the spatial position of the trumpet. A switch command triggers the module (or rather, its instantiation for that space) to store the previous phrase of improvisation.

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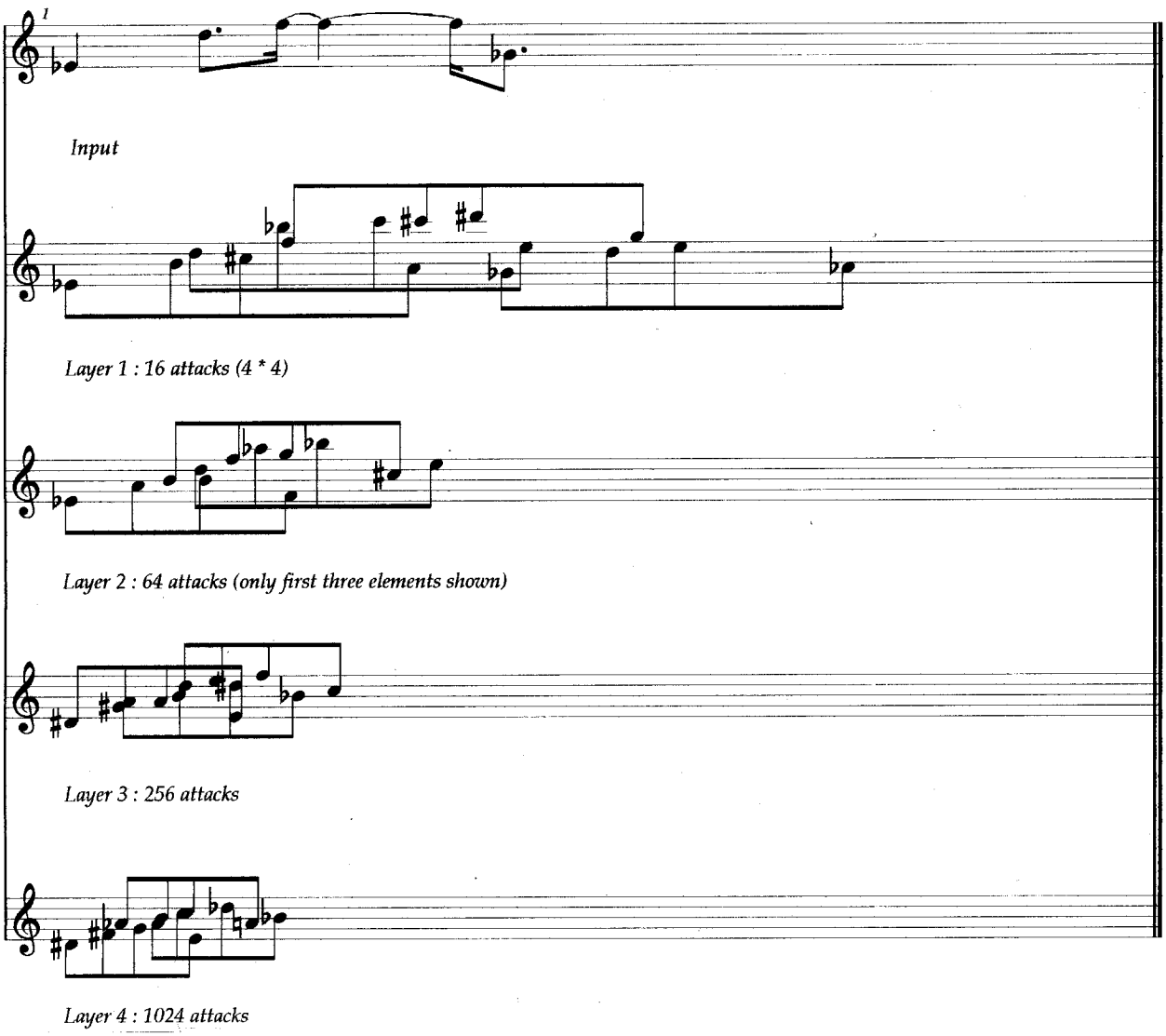


Figure 2

Another phrase is stored at the next command, and the time-distance, note-length, pitch and velocity differences are calculated. Increments for each parameter are derived to transform the second phrase gradually into the first, which process begins immediately, scheduling itself phrase by phrase. When the original is finally restored, a further command will continue the process, and thereafter toggle between continuation and halting. The reduction or expansion of intervals in all dimensions, and pitch-range reflection allow the material to turn itself 'inside-out', continuously changing the relationship of the structures to each other – generating new polyphonies – and to the original models. Figure 3 illustrates this process for a single voice, in music notation. The dynamic refrain thus generated is heard punctuating the spiralling acceleration of the other scenes in Sound Example 8. The complexes of bell-like sounds superimposed constitute an expanding spiral of the same formal process, but in this instance calculated 'backwards' in time from a common landing point. This represents the first three layers, with pitch and time scaling factors of 0.75, in a direct input $\rightarrow$ output space projection. Movement during the performance of the structure might transform the pitch space within a range from one semitone to six octaves.

12. SIGHTED STRUCTURES

Sound Example 9 illustrates a complex of three modules from the third scene, which view the continuing note input relative to a common reference – an extended note sequence (of 43 elements, in this example) derived from the improvisation by a set of constraints during the introduction to this scene – and constantly revise their reactions in the light of changing circumstances. Input is searched for the next element of the sequence (a sort of virtual theme).

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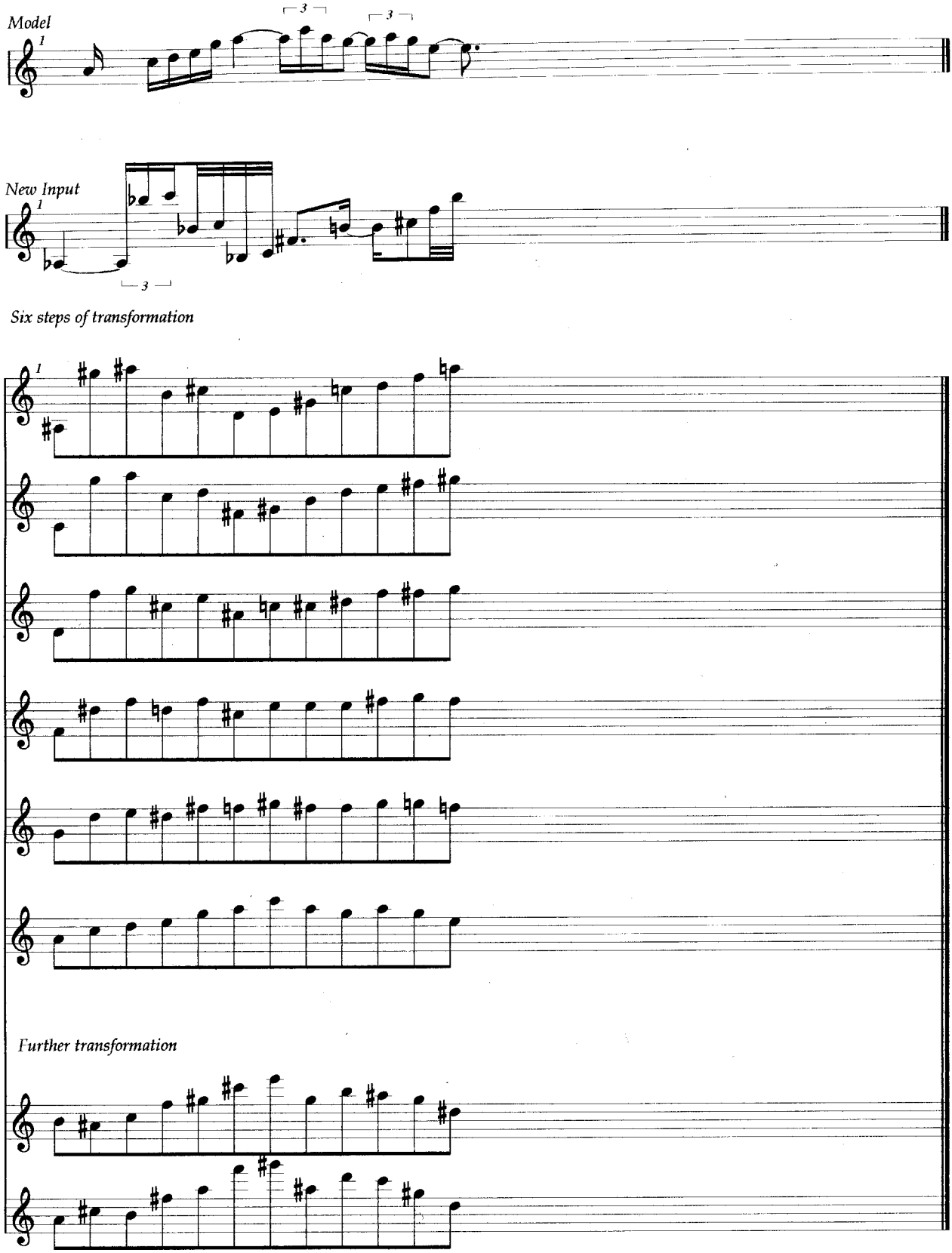


Figure 3

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The trumpet's material from the previous 'hit' to this is looped, time compressed, and played by the zither-like voice with a tempo multiplier controlled by one pressure sensor, and transposition by the other. Velocity is proportional to the radius of the spatial movement currently inscribed by the instrument. If it reaches zero, the structure dies; otherwise it continues until replaced.

The sustained synthetic sounds track the passage of the trumpet through the reference sequence, with an intensity (number of voices, transpositions, volume) relative to the density of activity of the improvisation. Certain movements of the trumpet add voices to the rules for new triggers, with a transposition based on the relationship of the last note played to the previous reference note, and a delay calculated on the same basis. A polyphony thus develops, which becomes richer as the new reference points overtake the accumulated delayed voices.

A similar principle governs the transposition of the whole body of sound (apart from the 'zither'). A complex polyphony would clearly be unworkable in this case. Instead, the transposition module develops its own accelerating sequence of temporal divisors (based on the previous time between triggers, and the time between those and new transposition instructions, reduced each time by the same ratio), and transpositions. Level and position are controlled by spatial movement, allowing the performer to work directly with the density of sound.

The final Sound Example (10) is again of a complex of modules, which demonstrate particularly the characteristics of self-analysis, communication between structures, and the transformation of the musical space onto which a structure is projected.

The sustained background is a product of the position of the trumpet and the notes played – a filter, in effect. A harmonic grid covers the 2 m^2 performance space, in which a different pitch corresponds to about 8 cm of movement along either axis. This harmonic matrix is predetermined, and relates to the harmonic structure of the composition as a whole. As a new note is sensed, its resonance within this framework is calculated: harmonic and sub-harmonic relationships to the current position on the matrix are weighted in proportion to their harmonic proximity, and the whole complex is sounded accordingly (see figure 4). A similar process is repeated for the four neighbouring positions, their weights further adjusted for the greater distance.

The two periodic structures in the foreground (santur and stone-marimba sounds) work in complementary ways. Both are generated by projecting a bifurcating logarithmic map structure ($i = c^*i + (1 - i)$) onto time–pitch space. In the first case, the multiplier c is related to the horizontal position of the trumpet, and the initial value of i to the last note played. The situation is reversed in the second structure. New values are triggered by a new note event in the first instance, by a change of position in the other. The time frame (distance between iterations) is controlled by the vertical position of the trumpet: at ground level almost continuous, at 2 m between 7 and 10 s (the tempo relationship of the two structures is proportional). Switches turn the structure on and off, and their 'sight' can be restricted by closing the flow of information from one or more sensors. The output of each structure is buffered, such that at every new event they can analyse their own output for periodicity. If a pitch cycle of period 3–7 is found, chordal accents are added to the output.

Movement into one of two sectors of space at certain angles triggers the streams of noisy percussive sounds. Lines of Brownian motion begin from the pitch, velocity and spatial position of the last trumpet note, moving in a random walk in each of these dimensions, reflected by certain boundaries and absorbed by others. Each structure thus generated is aware of the continuing pitch input, and of the output of other such structures. According to another set of boundaries, if two lines meet in any dimension (i.e. the present structure and either another structure or the trumpet), either an additional line is generated from that point or the whole complex moves towards absorption.

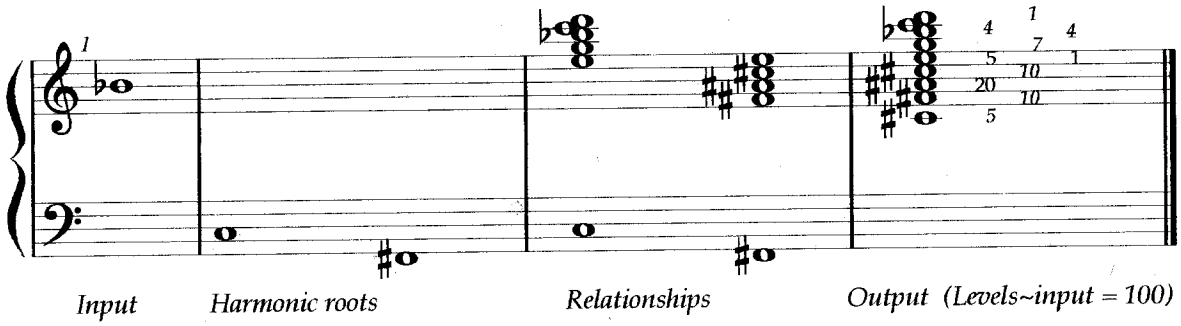


Figure 4. Harmonic roots C3 and F#1, input note Bb4. Note the reduced weighting (0.5) of the C 'filter' because of the one-octave sub-harmonic relationship of the input pitch to the 7th harmonic.

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13. CONCLUSION

These examples illustrate practical solutions to the issues of the terms in which a musical algorithm or process might be expressed, the role of and mechanisms for interactivity, and how the structures thus generated might be projected onto musical space, particularly in the temporal dimension. A possible taxonomy of the attributes of such models has been proposed, and they have been considered in a context which demonstrates how the interplay of relatively few variables and simple models can form a complex system sufficiently rich and dynamic to challenge both composer and performer.

Mirror-Rite was awarded second prize at Ars Electronica '94. It is available on CD on Attacca (Amsterdam) Babel 9476.

REFERENCES

Bell, A. D. 1986. The simulation of branching patterns in modular organisms. In *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences* **313**: 143–59.

Impett, J. 1994. A meta-trumpet(-er). In *Proc. of the ICMC*. Aarhus: ICMC.

Prusinkiewicz, P. 1995. Visual models of morphogenesis. In C. Langton (ed.) *Articial Life*: *an Overview*. Cambridge, MA: MIT Press.

Xenakis, I. 1971. *Formalized Music*. Bloomington: Indiana Unversity Press.

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