Transformation and mapping of L-Systems data in the composition of a large-scale instrumental work

Nigel Morgan

Interdisciplinary Centre for Computer Music Research
University of Plymouth, Drake Circus, 206 Smeaton Building
Plymouth, Devon, PL4 8AA, United Kingdom
n.morgan@netmatters.co.uk
http://www.nigel-morgan.co.uk

Abstract. *Heartstone* is a 20-minute composition in seven movements for wind, brass, percussion and solo piano. It was the composer's first extended work using production tools for modeling processes of organic development, in particular those associated with Lindenmeyer Systems, originally created as an artificial means of studying plant growth. Composed in 1992 its extensive revision prior to publication in 2007 prompted a re-assessment of the aesthetic fitness of its original algorithmically-generated content and of the approach taken in the transformation and mapping of data into a viable performance score. The *poesis* of *Heartstone* is revisited, its ways and means examined from a position informed by the experience of a further 15 years of algorithmic computer-assisted composing.

Key Words: L-Systems, Computer-Assisted Composition, Data Transformation and Mapping, Sound and Visual Equivalence.

1 Background

Heartstone took shape as a concept in the late 1980s at a time when the scientific revolution surrounding Chaos theories was well under way. Fractals, dynamic systems and strange attractors grabbed public media attention and interest. The idea that complexity was more or less about the interaction of very simple particles and individual parts resembling the whole seemed so novel. This certainly contributed to the interest in the simulation of process in natural phenomena through mathematical means. For the creative artist the maths had an engaging and elegant simplicity that required only the most rudimentary of programming skills [1]. In music there was an early divergence into two strands: chaotic systems as sonic generators of digital audio; fractal generators and processors of musical events usually operating in the MIDI domain. For composers wishing to create a linkage between such generative systems and the symbolic encapsulation of musical parameters present in Common Music Notation (CMN) there were difficulties: how did one compose with and make musical sense of data output that usually appeared as unbroken symbolic or integer streams and was more usually observed in 2D representations by the eye rather than the ear? Music Festivals staged well-documented encounters between scientists and composers that often debunked notions that new musical structures analogous with the striking computer-generated images of this chaotic and self-similar world might appear [2]. Composers who did pursue making music from generative systems were often reluctant to reveal just how the transformation and mapping from data to score had actually taken place [3]. It looked as though composers could get at the ingredients, but were going to have difficulty working out a recipe.

2 Context

In the late 1980s the production tools supporting event-based music composition rarely stepped beyond Boolean editors. This was enough to tempt some composers to look further. Evolving and consecutive variation-making laced with Gaussian or Brownian randomness and the random walking of Marchov Chains proved sympathetic with Minimalism and the New Tonality movement [4]. In the author's own work a series of digitally-mediated compositions for chamber ensemble called *Touched by Machine?* explored these techniques and genres [5]. But engagement with mapping representations of natural phenomena into music became possible through experimentation with a language-based environment for music composition that demonstrated a potent mix of unpredictability, recursive patterning and logic. This exploration took place against a backdrop of activity by a small number of researcher-composers known to the Author, notably Kevin Jones [6] and the late Jan Owen-Thomas [7].

A commission for a large-scale work for wind, brass and percussion from a UK conservatoire provided the author with the opportunity to find out how effectively musical structures might be transformed from very specific sets of primitives and processes associated with the modeling of artificial life-forms. If there is one medium that seems to call out to composers to use computer-assisted means of composition it has to be that of the large wind ensemble. Such ensembles revel in broad timbral and dynamic effects, complex organ-style registrations and intricate textures made up of layers of oscillating figures.

3 Inspiration and Starting Points

The title *Heartstone* comes from a short poem that includes a description of a plant-like form embedded in a fossil within a stone. The stone is described as displaying self-similar features with the chalk and flint landscape in which it was found. This provided a lively context for the use of Lindenmeyer-Systems [8]. Usually called L-Systems they demonstrate that many plants have recursive patterns and these can be represented through simple grammars (made from strings of text). The composer and educator David Worral has identified the L-System as being an ideal entry point for composers wishing to explore methods of creating powerful sound and image structures from simple material [9]. Experiments with the rewriting and recursive processes in L-Systems certainly showed that is was possible to make musical phrases appropriate to performance by wind, brass and percussion instruments.

4 Interpretation of Symbolic Data

Any composer working with the output of recursive generative algorithms is likely to encounter problems of interpretation of symbolic data. The L-System for example encourages the use of formal grammars that can be expressed in terms of alphabetic symbols. Wishart has suggested that initial visual scanning of such output is likely to make a more cognitive impact than hearing an auditory stream of sonic events [10]. Furthermore, the production of symbolic lists is common within pre-compositional activity where some form of symbolic abstraction is a common mode of representation [11]. In composing *Heartstone* it was the search for definition formulae that was fundamental to being able to use L-Systems to generate new and lively material. The example code below in Fig.1 illustrates how by adopting the symbol '= to represent a virtual rest it was possible to generate a symbol stream that could be interpreted visually as a collection of phrases punctuated by silences. Research by Cook [12] in the construction of a guided tutoring environment for reflection about intention in the composition act suggests that composers instinctively regard such collections of elements in a symbol stream as embodying a default note length reading the symbols and rest-symbols as a list of equal 'beats and spaces'.

```
(defsym a '(b c))
(defsym b '(b b a d))
(defsym c '(c c d a = ))
(defsym d '(a = = b c))

(gen-notrans a 1)
 --> (a b c)
(gen-notrans a 2)
--> (a b b b a d c c c d a =)
(gen-notrans a 3)
--> (a b b b b a d b b b a d a b c d a = = b c c c c c d a = c c c d
a = d a = = b c a b c =)
(gen-notrans a 4)
--> (a b b b b b a d b b b a d a b c d a = = b c b b b b a d b b b a
d a b c d a = = b c a b b b a d c c c d a = d a b c = = b b b a d c c
c d a = c c c c c d a = c c c d a = d a = = b c a b c = c c c c d a =
c c c d a = d a = = b c a b c = d a b c = = b b b a d c c c d a = a b
b b a d c c c d a = =)
```

Fig. 1. The definition of symbolic lists (a, b, c, d) and the generation of symbol streams by applying the material to L-Systems processes of varying iterative depths. The above example demonstrates how addition (rather than substitution) has been used in the generation of L-System data. This approach leaves a trace of the entire growth pattern, preserving the hierarchy of symbolic elements.

5 Defining rhythmic character

Although a symbolic pitch stream is able to give some approximation of a musical continuum simply mapping this stream by matching symbols to rhythmic values does not in itself guarantee satisfactory results, particularly in melodic and heterophonic contexts. A more oblique strategy is employed for *Chert*, the opening movement of *Heartstone*. Here a library is constructed containing 4-bit binary combinations of 1/16, 1/8 and 1/4 (semi-quaver, quaver and crotchet) values and their equivalent rests. A function to pick these entries is employed, with the L-System data providing a template structure. The picking-function creates a set of replacement rules by which the symbols are each allocated a corresponding entry from the library. Fig. 2 below shows the result of applying the symbol output at the second level of recursion:

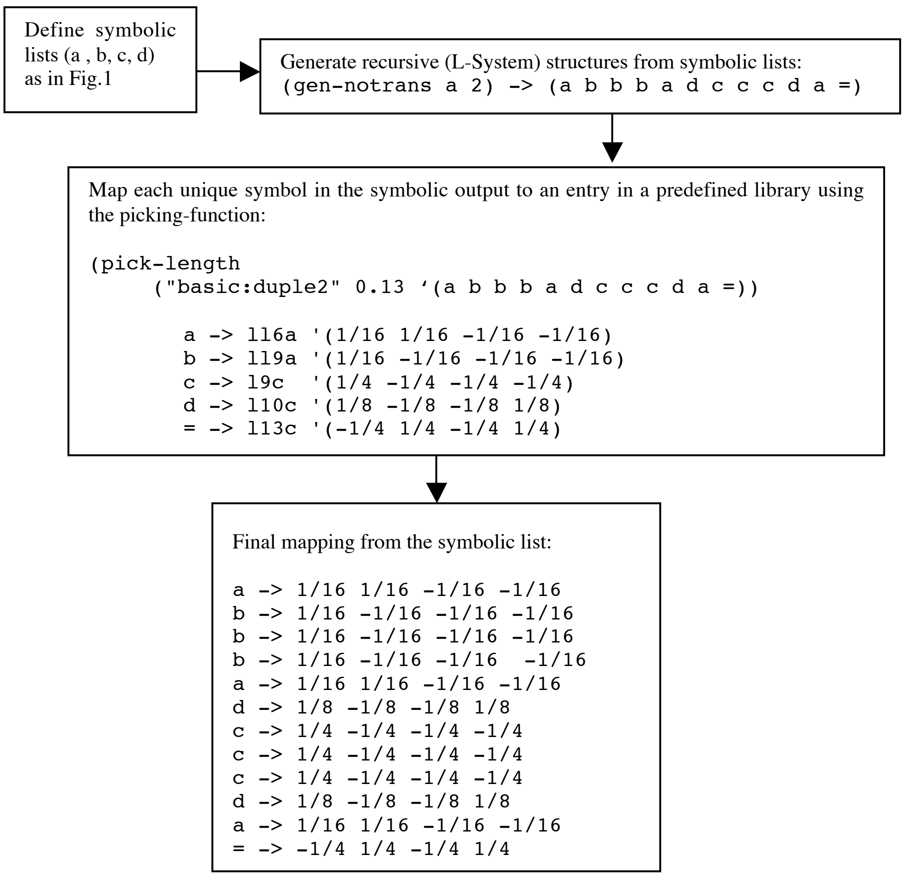

Fig. 2. Flow-chart illustration of the process used to map symbolic data to rhythmic structures.

Chert is constructed in three sections. The first two introduce choirs of wind and brass. Each choir plays in two parts only with the number of ‘picked’ rhythms are constrained to a template (a b c d =) as above. This has the effect of producing a march-like texture. The piano underpins and amplifies this heterophony; its own process based on expanding Fibonacci patterns that are then transposed at each iteration. In the third section eight separate rhythmic parts are generated for wind and brass instruments. Unique rhythmic schemes, based on a wider symbol range (a to l), are picked for each of the wind and brass instruments. This results in lively dance-like section in 8-part counterpoint.

6 Tonality Mapping

It seems apparent from studies of computer-assisted scores for human performance that the mapping employed to define pitch from symbolic or integer data invariably submits first to the chromatic scale. In *Heartstone* a number of strategies are developed to map symbolic data across collections of novel and algorithmically-generated tonality objects. Although the questionable purity of a one-symbol-to-adjacent-semitone consequence is lost, the deep structure of the L-System data is felt to remain in place. This approach makes it possible for the stream of L-System data to flow across a background of changing tonalities, enabling harmonic rhythm to become a compositional constituent. With a small range of L-System generated symbols this has proved most effective and avoids the feeling of being all at sea in the lower depths of a chromatic soup.

In *Chert* two of its three sections are mapped onto a tonality continuum that progresses in a regular harmonic rhythm from a chromatic scale through modal, diminished, whole-tone and pentatonic forms. As the symbolic data re-maps on each scale and the interval difference changes the aural perception of this data intensifies, rather like rescaling a 2D visual object.

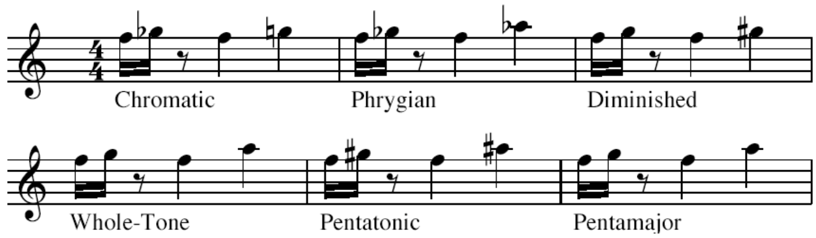

Fig. 3. The simple symbolic phrase (a b = a c) mapped over the tonality continuum of *Chert*.

In the third section the onset and duration of this progression of tonality objects is made peculiar to each instrumental part resulting novel complexes of poly-tonality. All in all the musical implications of these strategies give the sound a livelier and more 'open' aspect.

In later movements algorithmically-generated tonalities provide a means of defining and structuring content through the cognitive impact of the degree and incidence of change in harmonic rhythm. Indeed the flow-control of streams of symbolic data is managed by decisions made on how and when a tonality description is applied to contain phrases within the symbol stream. Such management results in the defining of tonality-zones, a kind of barring structure to contain tonality objects.

7 Picking Tonalities and Generating Rhythms

In *Sard, Tuff* and *Marl* (movements 3, 4 and 5 played without a break) rhythm and harmony replace heterophonic melody as the predominant musical parameter discerned by the listener. In *Sard* the collection of tonalities devised for *Prase* is assembled into a library. Four concurrent sequences of tonality descriptions are extracted and then arranged on templates produced from the original definition formulae for L-System generation. This process uses the same template-based picking mechanism previously described for picking the 4-bit binary rhythmic sets in movement 1. The instruments are then arranged in pairs (much as in Bartok's *Giuoco Delle Coppie* from the *Concerto for Orchestra*) and their parts generated from the Hopalong algorithm. This algorithm, as its name suggests, uses each new value generated as the seed for producing the next value. It creates two outputs like mirror-images of each other. Rhythmic mapping sets a default note-length value to the symbol output, but this is distorted by replacing the incidence of adjacent note repetition with rests. For example, (a a b c d d e f) might be rendered as (a = b c d = e f) producing lively syncopations. The incidence of instrumental activity or silence is represented as a graphic object with a resolution of 2/1 as seen in Fig. 4. This illustration also shows how the onset and duration of the harmonic sequences interact with the activity of pairs of instruments.

```
;                     |---|---|---|---|---|---|---|---|
changes1 tonal1      "    .   .   .   .           . "
changes2 tonal2      "      .   .   .   .      .    "
changes3 tonal3      "  .   .   .   .          .    "
changes4 tonal4      "  .      .   .       .      .  "

pt1  changes1        "------        ---  -  --      --" ; picc.
pt2  changes1        "------     --------- -----------" ; flute
pt3  changes2        "  --  -----      ----   --    ---" ; oboe
pt4  changes2        "  --  -------------  ----    --" ; bsn.
pt5  changes3        "     ---- ---  -------     -----" ; cl.
pt6  changes3        "     -- ----  ------ ------  ---" ; sax.
pt7  changes4        "------ ---  ---      ---- -------" ; trp.
pt8  changes4        "--- ---  ---  -    - - - - --  ---" ; tbn.
pt9  changes3        "-------------        - - -  -----" ; horn3
pt10  changes3       "-------------        - - -  -----" ; horn4
pt11  changes4       "    ------      ---- - - --  ---" ; horn1
pt12  changes4       "    ------      ---- - - --  ---" ; horn2
```

Fig. 4. Tonal change and instrumental activity in *Sard* represented graphically.

Tuff is scored for a trio of vibraphone, marimba and a kit of un-pitched percussion, a 'background' quartet of winds adding emphasis and punctuation to the musical texture It was suggested previously that one-to-one mapping of the symbol stream to rhythmic values was not the recipe for satisfactory results. With un-pitched percussion instruments this is certainly not the case. Hence these definition formulae can exist side by side as in Fig. 5 and generate symbols and note-lengths concurrently.

```
(defsym a '(b c))
(defsym b '(b b a d))
(defsym c '(c c d a = ))
(defsym d '(a = = b c))

(defsym 1/8 '(1/16 2/32))
(defsym 1/16 '(1/16 1/16 1/8 1/4))
(defsym 2/32 '(2/32 2/32 1/4 1/8 -1/8))
(defsym 1/4 '(1/8 -1/8 -1/8 1/16 2/32))
```

Fig. 5. Definition of one-to-one mappings used for percussion in the movement *Tuff.*

8 Self-Similar Tonality Structures

In the final two movements, *Paramoudra* and *Heartstone,* tonality asserts itself as the dominant musical parameter. In *Paramoudra,* the most extended and complex movement of the composition, the music is devised in four sections. These sections are built upon tonality schemes derived from each of the original symbolic formulae a, b, c and d. Here shown in Fig. 6 is a summary of the tonality material for the first section derived from generation with transposition of the definition at two levels of recursion, thus (a b b b a d c c c d a =) becomes (a c d d e f d e e f c).

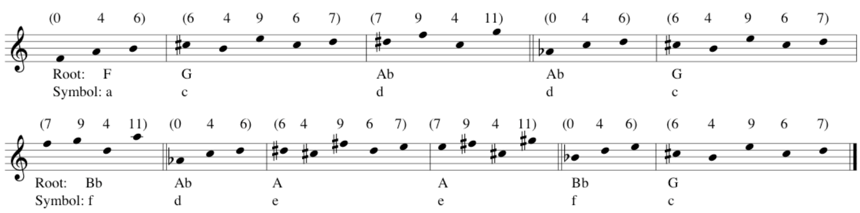

Fig. 6. The tonal structure of *Paramoudra*. Each grouping represents a single tonality.

The final movement called *Heartstone* is scored for solo piano and is a self-similar rendering of the previous movement for full ensemble. The entire 4-section tonality structure of *Paramoudra* is telescoped and condensed from 27 pages of full-score to a single page of 20 bars.

9 Aesthetic Fitness of Data

Testing for fitness assumes a likelihood that some material will not appear appropriate to serve the musical argument no matter how it might be transformed or mapped onto musical parameters. From a close re-examination of the code of *Heartstone* it would seem that symbolic material as it appears after its initial generation has to evoke the possibility of a musical response. In the area of pitch, even prior to any mapping strategy, alphabetic patterning can quickly demonstrate essential aspects of content distribution. This is not so with output lists of rhythmic elements, which in visual representations that express rationals rather than CMN symbols have to be displayed in simple, compound or irrational groupings to enable their aesthetic fitness to be assessed. What is clear from a re-assessment of *Heartstone's* symbolic material is that the L-System generation, albeit observing the composer's intricate definitions, seems well able to secure lively responses from the trained composing mind because the output clearly suggests discrete phrases and repetitive structures. That said, in movements 4 and 5, the parts generated from the Hopalong algorithm would with hindsight have benefited from some element of distortion able to bring more edge and fuzziness to what is a steady pattering continually stepping through a chain of tonality descriptions.

10 Data Transformation and Mapping into CMN

As to the fitness of approach taken in the transformation and mapping of data into musical score, it seems clear to the Author that musical intention and vision is inseparably linked to the search and choice of modes of transformation and mapping. Alternative strategies and oblique solutions abound in *Heartstone* but these have not always been further refined and progressed in later compositions. Association structures to enable selected musical parameters to have concurrency have been proved aesthetically less effective as with strategies possible through the neural network systems the Author has favoured since 1996.

There is something of a happy intuition at the core of this composition's *poesis* revealing that organic modeling does provide the wherewithal for establishing structural coherence, and more significantly can be integrated within the composer's existing musical practices as well as appearing to converge with objects long embedded in the musical memory. The context that surrounds the piece makes associations with a deep vein present in English Music and culture, that of the pastoral (Vaughan Williams, *The Lark Ascending*), the rhythm of natural cycles (Tippett, *Ritual Dances*), and a response to the lie of the land (Oldfield, *Hergest Ridge*), its geological structure and history (Birtwistle, *Earth Dances*) along with its effect on the evolution of human occupation (Maxwell-Davies, *Stone Litany*).

11 Conclusion

In the early days of composing with Chaotic and A-Life systems there was a tendency to regard such work as a search for musical revelation, an entry into a new and different world of sound and structure. Some composers have reacted against this by working with dynamic non-linear systems that bring together the beauty and simplicity of fractal generation with extreme highs and lows of disorder [13]. *Heartstone* makes a serious attempt to seek integration of modes and possibilities in organic modeling within the Author's *modus operandi*. This paper's attention to aspects of fitness confirms that for this to happen the composer has to draw upon a wide repertoire of strategies for transformation and mapping.

Finally, the ethnomusicologist John Blacking offers a valuable observation to composers who use computers to explore structures outside the musical domain: 'It is remarkable how the coherence and consistency of musical compositions that are conceived without direct reference to their sound structures, can be deeply affecting, as if human beings are touched by the immanence of a beautiful structure, although they hear only the resultant sounds . . . and so the message to computer composers might be: 'Don't worry too much about the sounds you want to make; think about the (numerical) symbols with which a computer can produce sounds and invent humanly significant order with them' [14].

For the Author his introduction to the beautiful tree-like structures visualised in 2D with L-Systems (in [15]) speak of the Gestalt of *tree*, a *treeness* more intense and exact than the living object, and able, because of this exactness, to be embedded as a structural mechanism to play in the musical imagination – with or without sounds.

References

1. Jones, K.: Exploring Music. Pitman (1984)
2. Steintiz, R.: Gyorgy Ligeti: Music of the Imagination. Faber, London (2006)
3. Xenakis, I.: Arts-Sciences Alloys: The Thesis Defence of Iannis Xenakis. Pendragon Press, New York (1983)
4. Moravec, P. (ed.): New Tonality. Harwood (1992)
5. Morgan, N.: Touched by Machine? Tonality Systems Press, Wakefield (1988-91)
6. Jones, K.: Self-Similar Syncopations: Fibonacci, L-Systems, Limericks and Ragtime. Times Educational Supplement. 17/09/90 (1990)
7. Owen-Thomas, J,: Unpublished MA thesis, University of York (1991)
8. Lindenmayer, A.: Mathematical models for cellular interaction in development, Journal of Theoretical Biology, 18 (1968) 280-315
9. Worral, D.: Web Resources for Exploring L-Systems in Sound and Image. Online: http://www.avatar.com.au/courses/Lsystems/Intro.html (Visited: 16/03/07) (1992)
10. Wishart, T.: Touching a Public - ICMC Keynote Address. ICMA Array Vol. 15, NL (1994)
11. Harvey, J.: Music and Inspiration. Faber, London (2002)
12. Cook, J.: MetaMuse: A Teaching Agent for Supporting Musical Reflection and Self-Explanation. Association for Learning Technology Journal, 6/1 (1999) 102-8
13. Wallin, R.: Fractal Music – Red Herring or Promised Land? Lecture given to the Nordic Symposium for Computer-Assisted Composition, Stockholm. Online: http://www.rolfwallin.org/Fractalarticle.html (Visited: 16/03/07) (1989)
14. Blacking, J.: A Commonsense View of All Music. Cambridge University Press, Cambridge (1987)

15. Frakas, B. Romanyshyn, N., Cary, P.: L-Systems Construction Kit. Online: http://l3d.cs.colorado.edu/~ctg/classes/ttt2005/projectreports/Lsystemreport2.pdf (Visited: 16/03/07) (1990)

Heartstone is published by Tonality Systems Press, Wakefield, UK. A study score and annotations of the original LISP code are available on-line at www.nigel-morgan.co.uk.