2009

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ABSTRACT

This paper describes a simple technique for the sonification of branching structures in plants. The example is intended to illustrate a qualitative definition of best practices for sonification aimed at the production of musical material. Visually manifest results of tree growth are modelled and subsequently mapped to pitch, time, and amplitude. Sample results are provided in symbolic music notation.

1. INTRODUCTION

Sonification, according to David Cope, "produces sound by translating, in one way or another, traditionally non-audible data into sound." Cope suggests that "data typically used [for sonification] have no inherent musical logic, [therefore] the normalized output from data sonification is generally of little use musically . . . composers who utilize algorithms have used sonification for small sections of their works where random-sounding music seems logical or appropriate" [2].

Although many extant examples of sonification may appear random-sounding, it is my contention that sonification can result in coherent[1] musical objects, in part through the selection of suitable source phenomena, and in part through the careful manipulation of procedures by which non-audible data are mapped to the sonic domain. Music with a great degree of internal coherence can be produced by the sonification of processes or structures that naturally exhibit aesthetically provocative forms[2]. The extent to which this potential is realized depends on the extent to which translations are well conceived. Mappings must be carefully tailored to establish perceptible auditory analogues of elements observed in the "source states" of structures and processes.

There is no doubt that important data often get discarded in attempts to translate a phenomenon intended for one sensory apparatus into a phenomenon consumable by another. For example, the range of brightness information that the eye can receive is on the order of a thousand to one, while the skin only has a range of about 3 to 1 for magnitude of sensation [5]. There is no reason, however, to assume that the touch information can't be *interpreted* in the same way as the visual information. Paul Bach-y-Rita showed that the brain is plastic enough to allow one sensory apparatus to be used in place of another. His early experiments in this area proved that people could be trained to identify shapes through touch alone. His theories provide the basis for an experimental device that has been used to train a blind subject to "see" through his tongue. Cameras mounted on the subject's head send visual information to a computer that "converts the camera information into electrical pulses and delivers them to the tongue . . . [via] a 'brainport' [that] has 625 sensors to deliver fine-grained information to the tongue and then the brain" [1].

The type of cross-sensory activity associated with Bach-y-Rita's work in vision-to-sensation mapping is usually the product of special circumstances, such as the condition of synaesthesia. The experiment – a very literal instance of cross-sensory translation – is an analogy for the less definable capacity of humans with normally functioning brains to draw comparisons between different sensory experiences. Simple associations that drift into vernacular speech demonstrate this: higher frequency sounds are "up," while lower frequency sounds are "down;" bebop is "hot;" Miles Davis gave birth to the "cool." We draw analogies all the time between classes of data that come in through different senses. There may be some value to recognizing these relationships in the act of producing literature, visual art, music, etc. – especially if the medium employed is designed to be consumed through only one set of senses; the richness of the experience delivered through that medium may be enhanced by appropriating materials typically reserved for the other senses.

2. SONIFICATION OF L-SYSTEMS

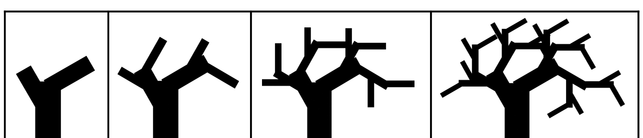
What follows is a description of a recursive algorithm designed to sonify two-dimensional branching structures,

[1] The use of the word "coherent" invites the question: what is musical coherence? For our purposes, coherent music is music in which a human being can identify patterns by listening. One presumes that by "random-sounding" Cope means music from which detectable patterns fail to emerge.

[2] "Aesthetically provocative forms" can be defined as objects presenting immediate and singular organizational coherence to any of the senses.

similar to the fractal structures that can be generated using Lindenmeyer systems. Lindenmeyer systems, or L-systems, are recursive re-writing systems originally intended to describe the structures of plants [3]. There are several existing musical representations of L-systems that exhibit the perceptible auditory analogues mentioned in the previous section; one of the most notable is a synthesis algorithm developed by Shahrokh Yadegari. In his sonification, an initial frequency, amplitude, and length of time are assigned fractional coefficients. These coefficients are multiplied by the initial values, then by the resulting values, and so on down to a minimum duration, at which point the collected values can be turned into sinusoids and summed [6].

The experiment I outline here functions on the "blockier" symbolic musical level. Though Manousakis claims that symbolic representations of music (e.g. through MIDI) are not sufficient to express the rich possibilities of L-system mappings [4], it can be demonstrated that even this limited space is capable of producing a wide variety of musically useful textures. In this simple case, the visual basis for the auditory mapping is an idealized tree. The generator for the tree – the nominal structural building block – is a straight-line "trunk" with a set of shorter straight-line branches attached to it. With each recursion, the branches of the generator are replicated on a progressively smaller scale around each of the branches drawn in the previous recursion. Figure 1 shows several recursions – including recursion 0, the generator – in the construction of a tree with 30º and 60º branches attached at heights 0.5 and 0.9, respectively, to a trunk of height 1.0. Angles are specified relative to the trunk: the top of the trunk points at 0º and the base points at 180º. With each recursion, identified by its index R, a scaling factor of $0.8R$ is applied to the lengths of the new branches, and branches diminish in thickness by amounts pre-determined for each recursion.



$R = 0$	$R = 1$	$R = 2$	$R = 3$

Figure 1. Recursive modification of a generator ($R = 0$).

2.1. Conditions for Visual-to-Auditory Mapping

A number of qualitative criteria were established in order to guide the formulation of relationships between visual and auditory domain representations of trees belonging to the class exemplified in Figure 1:

• *Every visual category admitted should be assigned a corresponding category in the auditory domain.* The sonification model described herein operates on line length, line thickness, location of line intersections, and measures of angles produced by line intersections. Categories omitted from this model include formations of negative space and cognitive segmentations of the image based on the recognition of similar structural components comprised of line groups.

• *Visual parameters should map directly to perceivable auditory phenomena*, and should not be converted into higher-level forms that may incidentally influence or indirectly control the production of basic auditory phenomena such as pitch, time, and amplitude. In other words, no mapping should seem trivial or extraneous, employed solely to satisfy the first criterion, and no mapping should incorporate a level of parametric abstraction that cannot be immediately related by a listener to the surface acoustic of the resultant sound object. Simplicity and directness should be maximized, and no mapping should be attempted without carefully considering the appropriateness of its implied visual-to-auditory analogy.

• *Complete mappings should be presented within a window of time not to exceed 30 seconds.* This ensures that all data can easily be held in short term memory, and precludes any notion of working with large-scale formal time structure, in violation of the second criterion.

2.2. Mapping Specifics

The most difficult parameter to deal with when translating from the visual to the auditory domain is time, since an image presents all of its data at once, while music presents its data over a span of time. Time in this case is oriented to the direction of growth: the trunk represents a pitch to be played at time = 0. The node, or root, at which each branch attaches to its parent represents a point in time corresponding to the distance between the base of the trunk and the intersection of the trunk with a perpendicular line drawn between the trunk and the node. The location of this point is actually determined by multiplying the cosine of the angle of the branch's parent relative to the trunk by the distance between the root of the parent branch and the root of the branch in question, and then adding the result to the point in time given by the root of the parent branch.

Figure 2 shows the values of all angles and nodes produced over three levels of recursion. Consider $n_{1,0}$ in Figure 2. The subscripts in $n_{1,0}$ indicate, respectively, the recursion index R to which n belongs, and the index of n within the set of nodes produced by recursion R. The value of $n_{1,0}$, 0.85, is given by a function $f(x, R, y, a, p)$, where x is the branch scaling factor, R is the recursion index, and y is the branch attachment point for the analogous branch in the generator. In this case, odd values in the second subscript slot of n correspond to $n_{0,1}$ and even values correspond to $n_{0,0}$; a is the angle of the parent branch relative to the trunk, and p is the n value for the parent branch:

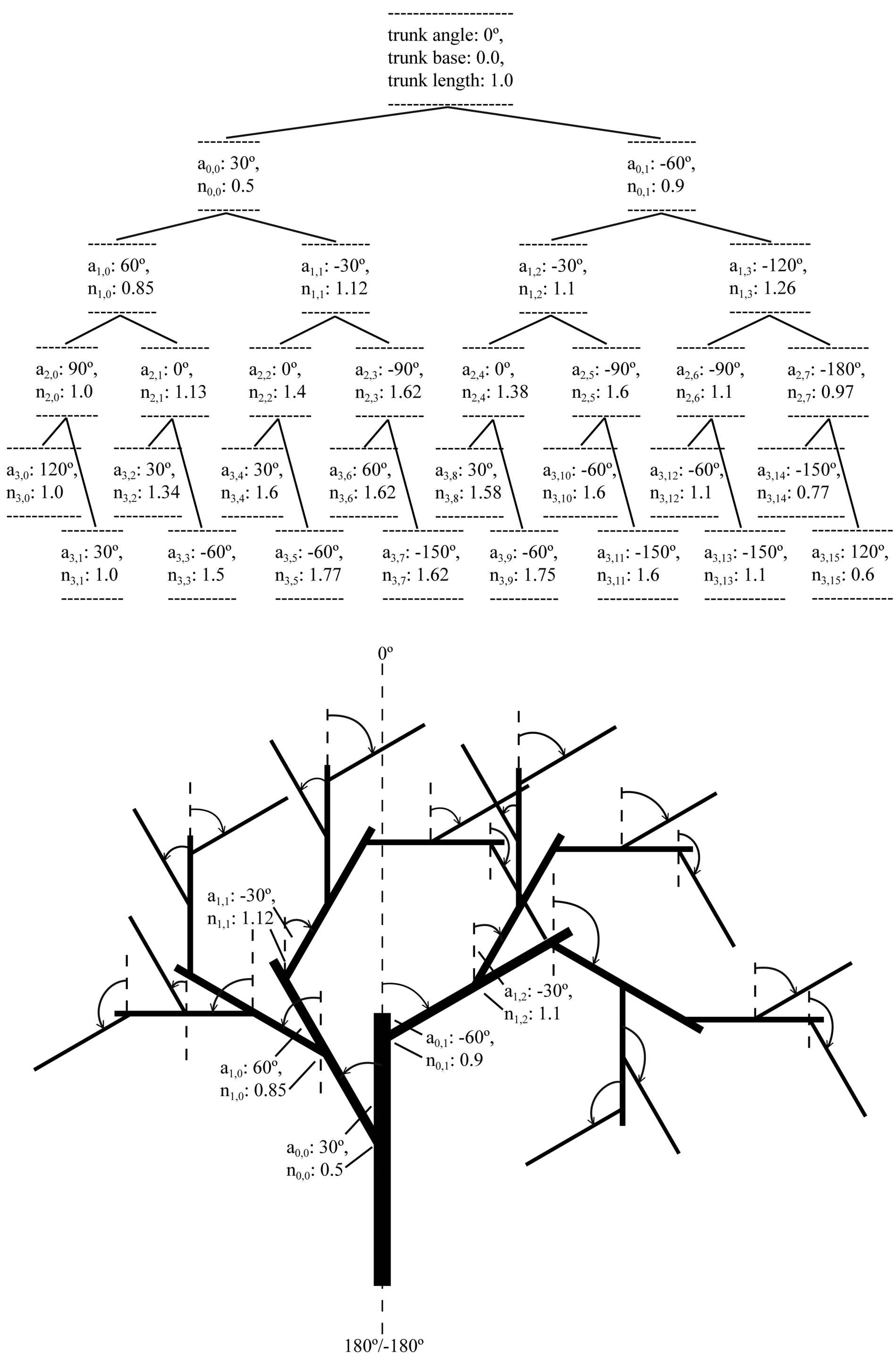


Figure 2. Angles and nodes produced over 3 levels of recursion; the trunk and its immediate branches provide the generator.

$$f(x, R, y, a, p) = x^R y \cos(a) + p \qquad (1)$$

Therefore, $n_{1,0} = 0.8^1 0.5\cos(30^\circ) + 0.5 = 0.85$. While branch nodes become time-points, their associated angles become pitches occurring at these time-points. All angles are expressed relative to the trunk. For example, a branch attached at 30º to a parent that is itself attached to the trunk at 30º is said to have an angle of 60º. Furthermore, since the upper pitch boundary of the tree is given by 180º and the lower pitch boundary of the tree is given by -180º, all angles above 180º and below -180º are converted to values between -180º and 180º, inclusive. Accordingly, each angle

θ produced by the addition of a new angle of intersection and its parent branch's associated angle is filtered through $f(\theta)$ below prior to translation into pitch.

$$f(\theta)=\begin{cases} 0, \text{ if } |\theta| \bmod 360 = 0; \\ \theta \bmod \frac{\theta}{|\theta|} 360 - 360 \frac{\theta}{|\theta|} \left| \lfloor 180 - \frac{\theta}{180} \rfloor \right|, \\ \qquad \text{if } 0 < |\theta| \bmod 360 < 360 \end{cases} \tag{2}$$

Pitch translation of $f(\theta)$ is achieved by applying $f(\lambda, \beta, \delta, \theta)$, where λ is the "center" frequency assigned to the trunk, β is the maximum coefficient of λ that can be applied to produce a new pitch (equivalent to the upper-bound, or 1/lower-bound), δ is the number of equal divisions of the pitch interval represented by β, and θ is the angle fed to $f(\theta)$.

$$f(\lambda, \beta, \delta, \theta) = \lambda \beta^{\left(\frac{\lfloor \delta \frac{f(\theta)}{180} + 0.5 \rfloor}{\delta} \right)} \tag{3}$$

Amplitudes are assigned to pitches based on a list associating each level of recursion with an amplitude that decreases by a perceptible amount with each successive recursion. At the end of the process, time-points are ordered from least to greatest. Pitch and amplitude values are sorted in parallel according to the sorted order of their associated time-points. The resultant data can be stretched or compressed in time to unclutter it or to increase its density. Events can also be quantized to a pulse, and intervals between notes can be normalized.

2.3. An Example

A sample call to the Common Lisp function that enables control of the algorithm is shown below, followed by a representation of the output in proportional music notation.

```
(make-tree-1
     ;; λ
     :trunk-frequency 440
     ;; Generator angles.
     :angles '(90 -30 77)
     ;; Relative locations of angles.
     :nodes '(.4 .75 .9)
     ;; x
     :node-scalar .4
     ;; Divisions of β, or δ.
     :equal-temperament 13
     ;; Maximum coefficient of β.
     :temperament-base 2.1
     ;; R
     :recursions 3
     ;; Scaled length (seconds) of output.
     :new-length? 10

)
```

Figure 3. Results of the above call to "make-tree-1." The numbers below notes indicate cents deviation from 12-tet pitches.

3. REFERENCES

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