Xenakis and Brownian motion: A compositional and analytical exploration

Evaggelia Vagopoulou
Musicologist, Athens, Greece
evgpl@yahoo.com

Tim Ward
Composer, Athens, Greece
timward100@yahoo.co.uk

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Background in composition. Composers today have easy access to a wide range of computer music tools that are able to facilitate probability-based procedures within musical composition. In addition to their primary compositional role, these tools should also allow us to revisit earlier works by a range of different composers, examining via simulation the probability-based procedures at work in each case and assisting in the process of musical analysis.

Background in music analysis. The music of Xenakis has been widely studied in terms of his use of probability-based procedures in the generation of musical material and the creation of structure. A particular focus of many studies has been the extent to which the details of these procedures can be traced in the pieces as they stand, and the implications of such knowledge for our understanding and appreciation of his music. Brownian motion is one of the better-known probability-based techniques that Xenakis employed.

Aims. (1) To examine the use of Brownian motion in the music of Xenakis and to consider his response to the possibilities of this natural phenomenon and its implications for musical material and structure. (2) To use current computer-based compositional tools to create musical models of Brownian motion, and placing these in the context of Xenakis's own practice, to use such models to assist in the analysis of his music.

Main Contribution. This article aims to contribute to the standard literature by supplying practical and immediately understandable examples of Brownian motion mapped to musical parameters, closely linking these examples to the work of Xenakis and using them to generate analytical insights into his music.

Implications for musical practice. The music of Xenakis presents unique interpretive challenges to performers and musicologists as well as a rich mine of compositional approaches and solutions for composers to study. Brownian motion is strongly linked to the generation and use of micro-glissandi in his music, and as such represents a key to understanding how best to perform and listen to such material as well as a model that could promote a better compositional understanding of the creative possibilities of such a technique.

Implications for musicological interdisciplinary. The use of natural physical phenomena for the generation of musical material and structure gives rise to interesting issues that are best examined from a wide range of different perspectives (including scientific, analytical and compositional approaches). In the case of Xenakis, the authors believe that there is considerable benefit to be obtained by drawing together the activities of music analysts and composers, bringing the computer-based tools of composers into an analytical examination of his music. The authors believe that a similar collaborative process would offer valuable advantages when examining other musical works in which technological systems played a compositionally significant role.

Di Scipio elegantly outlines one of the central issues when considering the music of Xenakis:

> I believe we need to be as deeply aware as possible of the mathematics and other conceptual tools Xenakis set up for himself, in order to also be able to catch on more intuitive aspects that are indeed crucial to his music. We should bring ourselves to the border beyond which compositional decisions and choices are found that evidently could not be dealt with in a systematic and wholly rationalized approach.[i]

In order to approach this border a significant amount of difficult theoretical ground has first to be covered. Of course there is a large body of published work in this area, based in the main on Xenakis's extensive theoretical writings. However, what is much less prevalent is an *audible* exploration of the manner in which mathematical theories can be translated into sound - in other words a guide that might help us to better understand the practical context of what we are hearing when we are listening to mathematical probability. This should give us a greater understanding of the parallel tracks of formalized and intuitive thinking in Xenakis's compositional thought, and better equip us to cross this difficult ground.

A compositional perspective

Xenakis's hugely influential role in the use of computers in musical composition is widely understood. Few current computer music composition tools do not support at least some aspect of his compositional strategies, to say nothing of entire fields such as granular synthesis that have grown directly from his work.[ii] He was of course equally pioneering as one of the first generation of composers to design and build their own computer music software tools - the UPIC and GENDY systems. This approach is widely prevalent among composers today and supported by a number of well-established higher-level programming languages for musical composition.[iii] In this way the compositional strategies of Xenakis are more accessible than ever before.[iv]

Listening to simple randomness

The simplest kind of randomness is in probability theory termed the *uniform distribution*. The physical corollary of this is the operation of a die. Each successive roll produces a numerical result that is randomly chosen from a fixed range of possible outcomes (equivalent to the number of faces on the die), with each numerical outcome having an equal chance (or probability) of occurring. In computer music software languages this would be implemented by a random number generator, a virtual die to which we supply a *range* value to set the range of possible outcomes allowed (in other words the number of faces on our virtual die).

In *sound example 1* we can hear the musical mapping of a stream of uniformly distributed random numbers, which has a range value of 20 to 100. A new random number is generated every 500 milliseconds, before being mapped directly to a musical note using MIDI pitch mapping, assigned a fixed note duration of 500 milliseconds and performed on a MIDI piano.[v]

Perhaps the most striking audible effect we hear in this example is the way in which we seem to divide up the sequence of pitches into multiple separate streams, picking out and connecting together different pitches according to pitch bands. In *sound example 2* we increase the tempo of the sequence of notes and this phenomenon becomes even more noticeable - here new notes are generated every 100 milliseconds and have durations of 100 milliseconds each.

Our perception here is of course explained by auditory scene analysis, and specifically stream segregation (Bregmann 1990). However we should also note that purely musical (or music technological) issues also need consideration - for example, the variation of attack duration according to pitch (with longer attacks at lower pitches) means that our uniform note duration accents notes in different ways according to their pitch.

Given greater space we could explore this simple uniform distribution in further detail, altering fine details of the mapping (note tempos, durations, instrumental forces etc.). Each change would alter - in some cases radically - our musical perception of the random number stream. From a musical (and certainly a compositional) perspective, this mapping seems to have an extremely significant role on our final acoustic perception, above and beyond the theoretical principle generating the initial stream of numbers.

Listening to Brownian motion

In computer music composition languages random walks (sometimes termed *drunken walks*) typically represent the next stage on from simple randomness. In this case the current value to be selected has some dependent link on the previous value selected - it moves away from this previous value according to a randomly selected *step-length* and *direction*. The overall impression is of a more planned movement with smaller scale localised randomness.

Brownian motion is a specific example of a random walk, and most computer music composition languages have specific Brownian motion generators. In *sound example 3* we can hear a very simple musical mapping of Brownian motion - once again successive random values are generated every 500 milliseconds and each is mapped according to the MIDI pitch system to a MIDI piano note of 500 milliseconds duration. In order to constrain the ambitus of our Brownian motion - and thus make it more easily recognisable -

the random number range has been limited between the values 49 and 89 (i.e. two octaves either side of A440 at 69). Changing this range makes the random walk-like character of Brownian motion even more evident. If the range becomes very small the pattern takes on an oscillating character. *Sound example 4* follows the same mapping as *sound example 3* but reduces the random number range, first to one octave (between 69 and 79) and then just three notes (69-A, 70-A# & 71-B).

Refining our musical mapping

In order to move one final stage forwards, and create a musical line that resembles in some way the work of Xenakis, we need to make more sophisticated adjustments to our mapping parameters. Consider *Mikka* (1971) where Xenakis mapped Brownian motion onto the violin's glissandi movements. In order to approach this kind of mapping we cannot continue to employ the discrete semitone mapping of MIDI. The easiest step is to replace it with sounds generated directly by simple sound synthesis - we will use a single wave table oscillator that produces pure sine waves.

In *sound example 5* each random number in a Brownian series is mapped directly to a specific pitch expressed as a frequency in hertz, with the sine wave oscillator instructed to use continuous smooth glissandi to move between these successive pitches. The random number range here is between 440 and 880 (i.e. one octave starting from A440). What we hear is a very rough simulation of the kind of pitch movement heard in *Mikka*.

Interim conclusions

The practical steps undertaken here outline what could be thought of as the very first steps in compiling a solfège for probability theories as found in musical composition. What we are engaged on is essentially a process of sonification - the use of sound in order to provide us with an audible image of a data set. Via adjustments of the mapping parameters we slowly come to a better understanding of the fundamental underlying data and the kinds of movements it contains.

We have limited ourselves to mapping Brownian motion as found in Xenakis's instrumental music - i.e. movement that is mapped to conventional musical notes. Xenakis did of course employ Brownian motion to directly generate sounds themselves, giving rise to his theory of Dynamic Stochastic Synthesis, where much work has already been undertaken in making computer music tools for simulation and composition.[vi]

An analytical perspective

Brownian motion was named after the British botanist Robert Brown (1773-1857), who was the first to observe with his microscope, in 1827 that pollen grains suspended in water experience a random motion. *Figure 1* shows the irregular pattern that the pollen grains may follow as they move randomly. Brownian motion is dependent on the temperature and the size of particles. When the temperature is high or the particles are small, for instance, the pollen grains move more rapidly. This theory was further advanced during the twentieth century by eminent scientists such as Albert Einstein.

The natural phenomenon of Brownian motion was used by Xenakis as a stochastic process with which to organize his musical material. In musical terms a hypothetical particle affects the velocity and the direction of glissandi. By using this natural phenomenon in his music, Xenakis a) confirms his interest in probability theory, b) proves his love of nature and c) finds a new way to think and work on his music on a macro and micro level, thus shaping its form.

As Xenakis states in his seminal work *Formalised Music*:

> **[**But] what about waves representing melodies, symphonies, natural sounds [...]? The brain can marvelously detect, with a fantastic precision, melodies, timbres, dynamics, polyphonies as well as their complex transformations in the form of a curve, unlike the eye which has difficulty perceiving a curve with such a fast mobility. An attempt at musical synthesis according to this orientation is to begin from a probabilistic wave form (random walk or Brownian movement) constructed from varied distributions in the two dimensions, amplitude and time (a, t), all while injecting periodicities in t and symmetries in a. If the symmetries and periodicities are weak or infrequent, we will obtain something close to white noise. On the other hand, the more numerous and complex (rich) the symmetries and periodicities are, the closer the resulting music will resemble a simple held note. Following these principles, the whole

> gamut of music past and to come can be approached. Furthermore, the relationship between the macroscopic or microscopic levels of these injections plays a fundamental role. [vii]

With this reference to periodicity and symmetry, Xenakis talks of the structural characteristic of sound which form the properties of waves which may be a direct outcome of the application of Brownian motion, as seen in his revolutionary development of Dynamic Stochastic Synthesis. He also refers to control at the macro level - that is the ongoing musical structure that shapes the form of a piece. Through this process, as indicated in the text from symmetry to periodicity, both the micro and macro structures are affected, from a single note to a whole section. At the same time the composer controls the final outcome (form) using raw material (sound).

Mikka - Cendrées - N'shima

In his instrumental music Brownian motion becomes a musical solution to the development of micro-glissandi observed in a mass orchestral section or even in the line of a single musical instrument. The idea of Brownian motion is perhaps best demonstrated in *Mikka* (1971), for solo violin, where it affects the direction of the piece. Looking at the initial bars of *Mikka* (shown in *figure 2* and available in *sound example 6*) we can easily detect the Brownian application which has as a result a limited musical contour and rather an unexciting sound. In the following bars Xenakis digress from this pattern and gives to the piece a more interesting sound, pointing to a structural shift.

In his large scale, vocal work *Cendrées* (1973), Brownian motion affects the overall form of the piece, creating mass glissandi gestures. Consider *figures 3a* and *3b* which accompany *sound example 7*, which show the opening two pages of the full score, where the ascending micro glissandi at the beginning determine a vivid, internal motion throughout the piece that indicate the influence of Brownian motion. On this occasion, alongside the change of direction, parameters such as velocity and pitch are also affected. As a result we get random, irregular glissandi and sudden changes of tempo. The dense galaxies of sound that exist in this piece are the outcome of an internal structure that form the microglissandi, an aspect of Brownian motion that in the end results in complex gestures of massive sound.

In *N'shima* (1974 - *sound example 8*), for two mezzo-sopranos or altos and five instrumentalists, Xenakis also makes use of Brownian motion. He states in the preface to the score:

> The melodic patterns of *N'shima* are drawn from a computer-plotted graph as a result of a Brownian movement (random walk) theory that I introduced into sound synthesis with the computer in the pressure versus time domain. I also applied this theory to creating linear paths in the pitch versus time domain (melodic patterns) for voices and for instruments as in *Cendrées* (1974).

Here Xenakis talks of the 'pressure versus time' curves of the waveforms, inspired again by the irregular motion of a particle. The 'pressure' is converted to pitch and melodic patterns based on stochastic calculations. In *N'shima* the Brownian wanderings result in a particularly interesting and expressive music, especially in the cello line which has an independent role for several bars that affects the structural process. In relation to *N'shima*'s music Harley writes 'it is remarkable that the peculiar force of his [Xenakis's] scientifically trained intellect could give rise to powerfully expressive music.'[viii]

Conclusion

Through extra-musical references concerning mathematics or natural phenomena, Xenakis achieved a structural development based on rules which leave space for the composer's own aesthetic criteria to take over and shape the final musical outcome. The structural result may not belong to a definite and recognisable form, but it is conditioned by an internal, partially deterministic, unity. The overall musical result is different in each of the works discussed above, depending in each case on the nature of the works and the parameters the composer wished to affect and alter. Xenakis used the concept of Brownian motion as a compositional element that helped him to organise his musical material in a different way each time, combining the laws of science with his own sense of musicality, as is always the case in his music.

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[i] See Di Scipio (2005).

[ii] Roads (2001) provides an extremely comprehensive view that explores the innovations of Xenakis and their pioneering role in the development of granular synthesis. Di Scipio (1998) explores many of the ideas in Xenakis's electroacoustic music and traces these to current practices.

[iii] At the time of writing leading examples are *MaxMSP* (www.cycling74.com), its open source relative *PureData* (crca.ucsd.edu/~msp) and *SuperCollider* (supercollider.sourceforge.net). All sites accessed February 2008.

[iv] The examples in this paper have been generated with the computer music language MaxMSP (see note above for availability), together with extensions to this language by Karlheinz Essl (his *Real Time Compositional Library* available from www.essl.at - accessed February 2008).

[v] MIDI pitch mapping is a discrete 12-pitch per octave equal temperament system where the number 69 is equivalent to A440 and 70 to a semitone above, 68 to a semitone below etc.

[vi] Dynamic Stochastic Synthesis has been well explored by contemporary software implementations. See Brown (2004), Bokesoy (2003) and Hoffman (2000).

[vii] See Xenakis (1992) pp. 289.

[viii] See Harley (2004) pp. 94.