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INTERNATIONAL CONFERENCE ON TECHNOLOGIES FOR MUSIC NOTATION AND REPRESENTATION (TENOR) TENOR'20/21 PROCEEDINGS

Document version: Accepted Manuscript
Acceptance date: 2020-10-19
Published date: 2020-03-06
Deposit date of initial version: 2024-03-01 15:03:55
Deposit date of this version: 2024-03-21

NEXUS: LIVE NOTATION AS A HYBRID COMPOSITION AND PERFORMANCE TOOL

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ABSTRACT

The NEXUS live notation system, the latest product of the Hayden-Kanno collaboration, contrasts with their previous projects which utilised live DSP and synthesis. NEXUS is first discussed in the contexts of a comparison of Kanno's experience of performing solo violin works involving the live generation of music in both the audio and symbolic domains, and the affordances of Common Practice Notation for generative music. As with previous Hayden-Kanno projects, the main goal is the creation of a musical work which is fluid and spontaneous, both in its global form and specifics of detail, yet maintains a sonic consistency and coherence, but now in the symbolic domain. The implications of performer reading and interpretation for system design are explored. The second half of the paper outlines the main functions of the Max patch, how GMN code is generated for rendering as CPN in INScore during the performance, and, of the performer GUI which constrains the stochastic processes underlying the generation of specific musical parameters, general textual characteristics, and global formal shaping. The challenge was to formalize Hayden's compositional procedures so the generated notations retain a musical identity and interest, whilst leaving space for Kanno's interpretative decisions and being technically simple enough to be sight-readable. The uses of the system for hybrid performance and compositional applications are discussed, and some directions for future development.

1. INTRODUCTION

1.1 The *NEXUS* project: antecedents

As part of an ongoing collaboration involving the artistic potentials and *affordances* (after Gibson) [1] of new music technologies, composer Sam Hayden and violinist Mieko Kanno extend their practice-based research into the area of 'live notation', used as both a real-time composition and performance tool. Their previous Arts and Humanities Research Council (AHRC, United Kingdom) funded research collaborations resulted in two works for electric violin (*Violectra*[1]) and interactive computer: *schismatics II* (2010) and *Adaptations* (2011) [2]. *schismatics II* involved seven movements of fixed notation (in a fixed order) with real-time DSP. *Adaptations* involved various short modules of fixed notation performed in an indeterminate order, also with real-time DSP, to which the computer *adapted* to the performance using Nick Collins' machine listening and learning system (ll~ object) [3]. The patches were designed to run autonomously but can be used as a digital 'instrument' with input from a (human) performer. Given Hayden and Kanno work primarily with Common Practice Notation (CPN), a domain which, according to Legard and Morgan '…remains a necessary symbolic language for composers to communicate their intentions to performers'[4], the *NEXUS* project takes Hayden and Kanno's collaboration in a new direction, the emphasis being on the live generation of CPN, where previously it was live audio processing. As a result of having worked in a composer-performer collaboration for more than 10 years, this project allows detailed consideration of where the boundaries between composer and performer lie in an artistic practice that uses technology-mediated CPN.

2. AESTHETIC COMPARISONS: DIFFERENT APPROACHES TO LIVE GENERATION OF SONIC/SYMBOLIC MATERIAL

2.1 New perspectives on live notation?

One might legitimately ask what 'new' perspectives are on offer from the *NEXUS* project to the field of live notation. The technology is well-established (Max + INScore), as are the use of generative algorithms such as Markov Chains and other stochastic methods. The aesthetic goal of having the notation be different in every performance yet maintain a coherent identity, and the common issues and solutions around live notation (e.g. making the music easy to sight-read by imposing constraints and combining pre-generated and live material) are also familiar territory.

[1] Violectra is a range of custom made, skeletal-frame, electric violins, violas, cellos, and vio-basses, designed and made by David Bruce Johnson (Birmingham, UK, since 1992); http://violectra.co.uk/violin/

Nevertheless, we consider that there are three key questions at the heart of the project that require exploration:

- Why we find the combination of CPN and generative music an attractive creative option.
- Which are the effects of *reading* and *performing,* i.e. symbolic interpretation, on the part of the performer, on the system's aesthetic function(s).
- What are the risks to which this system exposes Hayden and Kanno, in terms of their established professional practice.

Our answers to these questions shed light on the nature and significance of this project, both in terms of the development of the Max programming and the actualisation of the work as performance; an examination of the relationship between system and performance offers a unique perspective to the live notation research communities.

2.2 Common Practice Notation (CPN)

In order to examine the creative potentials of Common Practice Notation (CPN) and generative music, it is useful to first discuss the musical affordances of CPN per se. While 'sight-reading' frequently refers to the reading 'on-the-fly' of CPN, the use of notation in music improvisation (technology-mediated or otherwise) involves a much wider range, including images, graphics, text and other metaphorical stimuli. It is often assumed by practitioners that in a live performance setting involving the *reading* of material, the use of non-standard notation is more creative and 'open' than CPN, engendering more freedom and promoting more creativity and structural coherence by the provision of 'cues'. Conversely, the reading of CPN is often assumed to involve less creativity and be more prescriptive, promoting (more) exact reproduction of the written properties by its commonly understood specific rules for reading, with its requirement for expert skill in sight-reading. Yet, CPN has been used to promote more varied readings, precisely because of its widespread use for many centuries in Western art music. Harris emphasises the importance of the quasi-linguistic understanding of CPN's representational aspects (emphasis by the authors):

'Music reading depends on <u>understanding the language</u>, instantly recognizing the symbols and knowing exactly what they mean. You need to know the different keys, spot recurring melodic patterns, really understand how rhythms go and develop an instinct for fingering.' [5]

The musical 'language' in traditional Western art music consists of varied parameters, including pitch, rhythm, key, speed, phrasing, character, mood, timbre, historical style, genre-specific style, instrument-specific idioms, expressive rhetoric, technical ease, and others. Sight-reading triggers a whole set of *learned skills* automatically, combining all of the information pertaining these parameters that come with this rich language. The sight-reading skill has much in common with a style recognition skill traditionally required as part of a tonmeister training where learners identify a compositional style at sight, from an open page of an unknown score.

The sight-reading skill of professional performing musicians allows them to read off more information than that which is given on the page (or screen). They infer, anticipate, and guess. The gathering of an excess amount of information from the visual information, and making it available in performance, is at the heart of excellent sight-reading skill. Music notation, in this sense, is designed as stimuli to inspire spontaneity. You may ask: what about the level of specificity that is a feature of CPN? The question points to what this specificity is *for*, otherwise, in music performance. While one-to-one correspondence is important, one of the purposes of CPN is to communicate the music to the performer, as oppose to communicating the written properties that make up the music. Much like other notation types, it functions to inspire the reader/performer's imagination. Paradoxically, the specificity of the information in CPN has the capacity to trigger a vast range of references beyond written information itself, precisely because of its specificity.

An approach towards music notation as a triggering interface for the performer's imagination may seem overly utilitarian. Yet, an excellent capacity to read off the page a varied range of information both visible and invisible and set it in motion, is a hallmark of good musicianship. In discussing scores in CPN, pianist Ian Pace comments that he prefers "to see scores as the means for channelling performers' creative imagination in otherwise unavailable directions, rather than as an obstacle [to limit the imagination]" [6]. Kanno and Hayden also view using CPN with generative algorithms as the means for channelling performers' and composers' creative imaginations. We wish to take advantage of the wealth of references that CPN is capable of communicating, as well as of our expertise in handling it as composer and performer in the context of the new creative affordances of live notation.

2.3 The effects of *reading* and *performing*

The practice of reading CPN makes it clear that there is a temporal as well as conceptual hiatus between *reading* and *performing*, a situation that remains in the digital domain. Much like poetry reading, reading aloud is a performance unlike silent reading which is devoid of communication potential. Live notation involving human performers is never precisely 'live' in a sense of temporal simultaneity between the display and performing. There is always a time-lag, however small that may be. There are instructive comparisons to be made with generative musical works involving solo violin, performed by Kanno, where computer-mediation enters the symbolic domain (including CPN). We see performer interpretation taking a more significant role in terms of the *structural* actualisation of the work. The works described below deploy this hiatus between reading and performing using original approaches.

Georg Hajdu's *Ivresse '84* for violin, laptop quartet and electronic conductor (2007), a piece which involves computer mediation in *both* the sonic and symbolic domains, is a case in point, a piece that Kanno has performed in collaboration with the composer. From the point of view of the violinist, various notational fragments (Hajdu calls them 'measures') taken from the first of Cage's *Freeman Etudes* (1977-80) [7] are recombined algorithmically during the performance, in combination with audio samples from other performances and spoken text from a recorded interview the composer undertook with violinist János Négyesy in 2007. Hajdu describes the notation:

'For each of the 20 sections, a stochastic process chooses among a range of measures and recombines them into a new structure, which is sight-read by the performer. (This approach, of course, assumes familiarity with the material.)' [8]

In a significant sense, the notation *is* 'live', in as much as the stochastic ordering of the notational fragments generated during each performance is necessarily unique. However, the material is not sight-read in a literal sense, given Kanno (in this case) pre-prepares the Cage extracts in advance of the performance, even if the specific ordering that will occur is not known. She half-recognizes the material as it appears during performance, knowing the language, but not necessarily exactly where the particular fragment comes from within the *Etude*. She retains a level of familiarity with the material, yet has a necessarily context-specific interpretative flexibility (e.g. how fast/slow, what pauses in between, whether to 'phrase' over some fragments, etc). It gives a different *meaning* to how time passes within this music: Hajdu's live notation system influences how she listens to the ongoing sonic landscape and how she may contribute to it structurally. Compositionally, what the violinist plays is designed to influence the laptop quartet and the other sonic materials, and to have a significant impact on the formal actualisation. In both Hayden's *NEXUS* and Hajdu's *Ivresse '84*, the act of reading and performing the score (i.e. the symbolic aspects of the piece) by a live performer reduces the hierarchical primacy of the system as a structural determinant of the performance; placing much more responsibility with the live violinist who performs the 'language' of the given CPN by connecting disparate notated musical objects into a coherent formal shape.

Hajdu's example is a case of live generation of familiar material. A further comparison can be made between works involving real-time generation of the notation *during* the (live) performance and live performances of scores that are completely algorithmically generated but the scores' material exists *before* the performance (so the material is pre-prepared). The latter type of notation engages the performer in much the same way as most fixed notation scores do, except in the sense that the score can be generated anew for every performance occasion. In this sense, the generated scores are 'performances' of the system which is the work: such conceptual framework introduces a new perspective for interpretation by the performer.

Michael Edwards' *hyperboles 2* for violin and live electronics (2015) exists in an interesting position *between* live notation and fixed score [9]. The score is generated *prior* to each performance, leaving time for the soloist to pre-prepare the work as if it were a fixed score, but for that specific performance only. Here, Edwards stretches the temporal displacement between algorithmic generation and live actualisation. *Hyperboles 2* presents the option of notational re-generation by Kanno herself, through a user interface, by setting criteria (in domains such as the 'terrain', duration, and some pitch characteristics), but again, this is something that is done *prior* to the performance. In practice, Kanno regenerates scores for *hyperboles 2* as many times as she needs, until she finds a score that she likes to play, for each performance occasion. The duration is a critical parameter in decision-making; for example, as she considers a one-hour performance requiring different material to a 15-minutes performance, she changes the parameters in the user interface, until she finds a satisfactory result. Her decision-making is informed by the expressive potential in performance that she observes in the generated notation. In other words, her reading of the language expressed in the notation informs her performing potential.

Repeated generations of scores provides another insight for the performer. Kanno starts to see a correspondence between the chosen parameters and scores in terms of expressive potential. Here, we mean general 'musical' aspects such as the character, atmosphere, and overall mood of the music rather than specific material properties. She recognises a musical *style,* in addition to a compositional style, resulting from the structural choice. This foresight knowledge is crucial in dealing with works with multiple generations. Andrew R. Brown also observes, while discussing his work *Appearances*, how programming constraints on the generative systems enable familiarity with the material for the performer, even if specific details are unique (an idea that Hayden embedded in the design of *NEXUS* and was observed by Kanno as the user):

'...because the nature of the generated music is tightly constrained, the more familiar the performer is with the processes of the algorithm, either as a result of analysis, explanation or experience performing it, the more comfortable they become with the stochastic nature of the work.' [10]

2.4 Comparing formal paradigms: the performer + live audio / live notation + the performer

In Hayden's own *schismatics II* for e-violin and computer (2010), the computer-processed live audio, resulting from the performance of a fixed (common practice) notated score, is based on stochastic algorithms and machine listening to control live sampling, envelope-based sample playback, convolution, delays and other live DSP modules, combined to produce a computer-generated *doppelgänger* which shadows the sound of the live violin. *schismatics II* uses a model long-established by many works developed at IRCAM, such as Boulez's *Anthèmes 2* for violin and live electronics (1997), which involves a fixed score with prepared electronics which are live-triggered, and also live-processed electronics, using real-time score-following techniques [11]. Another example in this category is James Wood's *Autumn Voices* for violin and electronics (2001), a BBC commission written for Kanno, whose sonic landscape is based on the spectral analysis of violin recordings of Kanno [12]. In this case, pre-prepared electronics are live-triggered and spatialized by the composer in combination with the live violin sound.[2]

This category of the live violin + live audio has a number of common characteristics. First, the outcome varies from one occasion to another while retaining the majority of the details consistent across all possible performances. Second, the uniqueness of the outcome at each performance occasion lies for the most part in the electronics and *not* on the part of the performer. This second point is significant when considered the role of the violin sound in these compositions: the interactivity on the part of the violinist is limited, even though the violin sound itself is central to the conception and production of the electronic part. For example, the performer's role in *schismatics II* is limited to making subtle adjustments of balance and timing in their reading of a fixed notated object in relation to the live computer part: interactivity is more a feature of the computer's relationship to the soloist than vice versa. In this sense, the interactivity is an additional feature in the established practice of electroacoustic music, which gives nuance to the outline though not challenging the role of the composer as the provider of the sonic design, and that of the performer as the interpreter of this design.

When the 'reading' is centred on computer-generated notation, interpretation becomes inexorably tied to the generative aspects of the work and system design. The nature of what such systems do is transformed and reconfigured as the computer becomes an *active* site for performer interpretation, as opposed to the more *reactive* role it plays in *schismatics II*, requiring the performer to realise entirely the sound of a generative work. The computer is no longer assigned the role of generating an actualised sonification of data, instead offering a symbolic 'proposal' to the performer to 'complete' a sonic object whose outline is suggested by the *NEXUS* system. The notation is necessarily incomplete, Kanno not only having many choices of musical details (e.g. tempo, articulation and dynamics) of any particular generated notation, but also choices which affect the overall formal contouring of the piece during the performance, where her anticipation of the larger-scale parametric changes in phrase-length, phrase direction, register, density of events and so on feedback into her 'on-the-fly' interpretative decisions. This aesthetic 'incompleteness' in the symbolic domain has fundamental implications for the conception of the programming: the goal is no longer to create a coherent sonified digital musical 'agent', as if equivalent to a human musician; rather the goal becomes the creation of a symbolic musical space with enough information to *enable* the performer to actualise both the details and the formal trajectory of the work as a performance. The system is designed to present a suggestion of a musical structure, but one where there is space left (what Hayden terms a 'symbolic deficit', see section 4.4) for real-time performative decisions. Otherwise, there would be no need for a human performer and a MIDI, or other synthesised output would suffice.

This category of live notation + the performer brings some risks to both the composer and performer of Western art music. The composer hands over control of a significant portion of actual material outcomes to the generative system and performer. The performer, on the other hand, may have limited access to their 'toolkit' that makes up their usual professional practice. For example, the generated notations may call for very little actions. In other words, the notations may trigger very little learned (instrumental) skills. It then challenges the performer's musicianship to find a musical solution on the spot, which is also a skill of an experienced performer. The risks describe the conceptual challenges on the norms of composition and performance in Western art music. This is because the experimental practice we conduct involves learning, but more significantly, some 'unlearning' of the norms and standards that have been fundamental in our respective careers as professional composer and performer. The shift from the category of the performer + live audio to that of live notation + the performer seems ultimately to correspond to the shift from 'additive learning' experience to that of 'unlearning in order to learn'. It has involved revision of what Hayden and Kanno take for granted, respectively as composition and performance.

2.5 Live notation: implications for the system

The combination of live-generated *and* pre-prepared materials is an option open to the performer using the *NEXUS* system in order to practically enable more complex (pre-prepared) material and simpler (sight-readable) materials, the aesthetic benefit being more variety in the material, and more variety of strategy within a performance. The fact that live generation occurs at a higher level of symbolic abstraction beyond the direct sonification of live DSP (actually *two* levels of abstraction higher, given the patch first generates GMN code, which is then rendered as CPN in INScore) has implications for system design and aesthetic functions. The system is primarily concerned with the splicing of strings of text (the building-blocks of GMN code). As such, this process represents a step 'out of time',

[2] Kanno's other collaborations include John Hails' *La Pastora* for violin and live electronics (2007), the computer functioning as a complex delay system, where linear 'found' material originating in folk song is stretched and presented canonically using combinations of precise numerical ratios [13]; Dimitris Papageorgiu's *deti* (2017), composed as part of Kanno's AHRC-funded project 'Modelling a virtual violin' [14], which uses live-generated DSP and triggered samples (according to the 'scrolling score' principle, where samples are triggered at certain points in the notated score on a sequencer timeline) [15], the notational system focussing on parametric specifications of physical actions (often involving the 'decoupling' of left-hand and right-hand violin techniques); and Stylianos Dimou's *For Violectra* (2018) which combines fixed notation with live electronics, featuring sophisticated real-time granulation of the violin timbres [16].

however brief, between data generation and sonification by the live performer, a temporal displacement that is exaggerated in Michael Edwards' works. In the *NEXUS* system, Hayden perceives a clearer mediated 'trace' of his compositional intentions in the performance results than is the case in *schismatics II*: the constraints of the symbolic domain were shaped entirely by Hayden's programming decisions which were all, in effect, aesthetic compositional decisions, as opposed to being the sonic result of stochastic combinations of pre-existing live synthesis methods.

Whether notated material is generated live, pre-prepared, or somewhere in between, the implications to the system are that many more parametric decisions in the symbolic domain, usually taken by the composer, are handed to the performer. As the *NEXUS* system is designed to create notational objects that are necessarily incomplete, Kanno is required to view the performance potentials of such decisions, mediated through her own instrumental technique, embedded experience and sedimented performance histories. The specific sonic realisation of a generated notation, the anticipation of its place in a larger-scale form (see section 3.6), its formal (dis)connection with previous/subsequent notations and so on, are examples of compositional decisions and local/global criteria that Kanno is constantly aware of during performance, aspects that the system is designed to enable rather than determines.

3. *NEXUS*: THE PROTOTYPE

3.1 The *NEXUS* project: context

Begun in 2016, the *NEXUS* project uses Max with INScore to generate score fragments algorithmically in real-time, to be sight-read by Kanno during the performance. An earlier Max6 prototype was presented to the SOUND WORK seminar (Orpheus Instituut, Ghent, 2016) [17]. The current Max7 version involves no DSP, existing only in the symbolic domain. There has been extensive research into the many applications of real-time synthesis and DSP in artistic practices, to which Hayden and Kanno have already contributed. Dominique Fober observes that real-time algorithmic composition using *notation,* or other symbolic musical representations (as opposed to interactive/generative systems which use MIDI, real-time synthesis and machine learning e.g. Karlheinz Essl's algorithmic music generator *Lexikon-Sonate* [18], George Lewis' interactive improvisation system *Voyager* [19], Thor Magnusson's IXI software [20] and IRCAM's OMAX system [21]), remains comparatively under-explored in interactive music:

'Today, new technologies allow for real-time interaction and processing of musical, sound and gestural information. But the symbolic dimension of the music is generally excluded from the interaction scheme.' [22]

Indicative examples of compositions utilising live notation range from the SuperCollider-generated CPN of Richard Hoadley's *triggered* [23] to the generative graphic scores of Andrea Valle's *Dispacci dal fronte interno* [24]. Various interactive notation-based composition systems exist, including the Bach project [25] and Maxscore [26], both Max-based applications, and computer-assisted composition environments such as Opusmodus [27], OpenMusic [28], Escore [29] and the Active Notation System [30]. The goal of the *NEXUS* project is to create a system that 'works' as a *performance* outcome and is not only a demonstration of digital music techniques or a music programming investigation. The *aesthetic* aim is the creation of a live *notated* musical work which is fluid and spontaneous, both in its specifics of detail and global form, yet maintains a sonic consistency and identity. This was also the aim of *schismatics II* where the computer-processed live *audio* was always different within defined constraints; a coherent sound world with different specifics of detail and a consistent global form [31].

Hayden's motivation for the *NEXUS* project originated in his speculations about the extent to which his compositional ideas in the 'fixed' symbolic domain of CPN could be mediated by generative music technologies, to be 'completed' by Kanno's interpretation, and still result in a coherent (co-)authored work. *NEXUS* represents a formalisation, in simplified form, of Hayden's recent compositional methods, such as interpolations between atonality and diatonicism, inharmonicity and harmonicity, rapid gestures and stasis; the use of stochastic rhythms and pitch sequences, and large-scale formal contouring involving progressions of density and register. *NEXUS* is both a *compositional* output from Hayden and a performative output from Kanno, but one where the 'territories' of composition and performance are conceived in a different way, redefining what Hayden and Kanno do.

3.2 *NEXUS* and GUIDO Music Notation (GMN)

The prototype *NEXUS* patch live-generates and combines event-lists of pitch, duration and register information with randomly selected GMN 'tags' [32] representing standard CPN aspects (e.g. meter, clefs, beams, dynamics, and some articulation classes). It involved more string formatting (via the *sprintf* object) than was undertaken in previous Hayden-Kanno projects, in order to generate complete lines of GMN code, rendered as CPN in INScore. Figure 1 is an example of GMN code with its associated CPN.

```
/ITL/scene/myscore set gmn "[\\meter<\"4/8\"> \\clef<\"g\">
\\beam ( \\slur ( g1/8 c1/16 e1/16 a&0/16 c&1/8 c1/16 ))]"
```

Figure 1. GMN to CPN example

Given the *NEXUS* system does not use the more metaphorical notations often utilised in pieces involving generative scores, such as images, graphics or text, there is a more direct (less arbitrary) representational relationship between the generative aspects - what is rendered from

GMN - in terms of properties: what the performer sees as CPN, what is played by the performer, and what the listener hears in performance.

3.3 The performer Graphical User Interface

The *NEXUS* system functions somewhere between an instrument/performance system and a composing tool. It has a modular construction which generates live notational fragments of varying lengths and complexity, a process triggered by the performer, using the GUI (see Figure 2).

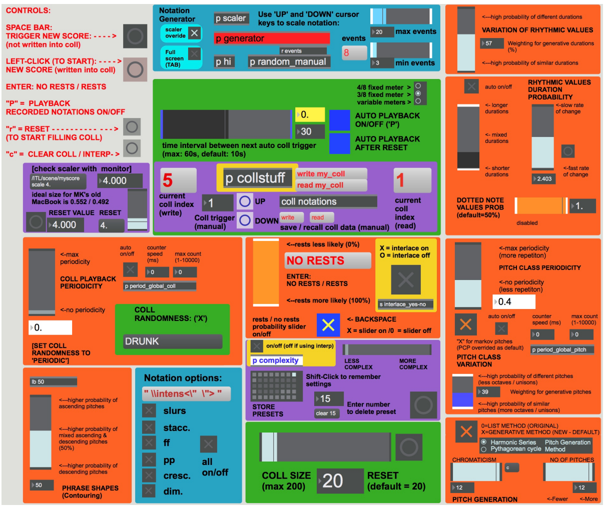

Figure 2. Prototype performer GUI (detail)

The performer can alter the GUI settings to influence various musical parameters:

- *Pitch generation method*
- *Rhythm generation method*
- *Variation of registers*
- *Variation and periodicity of pitch classes*
- *Variations of rhythmic values (length, similarity)*
- *Probability of rests and dotted rhythms*
- *Phrase shape, contour and phrase direction*
- *Max/min number of 'events' ('event' = rest or note)*
- *Interpolation between 'initial' and 'target' settings.*

3.4 Generative musical parameters: pitch-classes

Underlying pre-compositional decisions were involved in the patch design: e.g. a selection of pre-composed pitch-class sets (messages containing pre-defined numerical lists) were built into the initial programming to facilitate the controlled random generation of 12-TET pitch materials. A later development was the addition of the option to generate pitch-sets algorithmically using Markov Chains via some abstractions from Essl's Real Time Composition Library (RTC-lib 7.1) [33], making selections from the harmonic series or the Pythagorean cycle, facilitating pitch-fields on a continuum between chromatic atonality and quasi-diatonicism (see Figure 3). Markov Chains can also be applied to the domains of rhythm and register, according to user choice via the performer GUI.

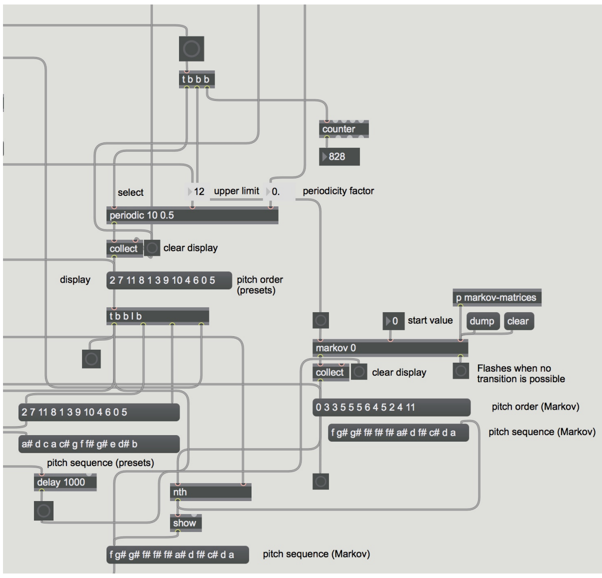

Figure 3. Pitch-class set generation sub-patch (detail)

3.5 Generative musical parameters: duration

To make the live-generated music sight-readable, Hayden limited the possible set of subdivisions of the beat to simple duplet ratios (no tuplets), although dotted rhythms are possible, and the semiquaver (16th note) is the shortest possible rhythmical unit. A duration series is generated with the pitch-sets in a sub-patch called 'generator' (see Figure 4). Using stochastic processes, the patch then splices these pitch-sets and rhythmical series together into an event list, distributing events across registers according to the GUI controls. This sequence can be interleaved with another randomized series of rests or pitches. The event list forms the basis of a line of GMN code, excepting the 'tags' added at the end of the generative process.

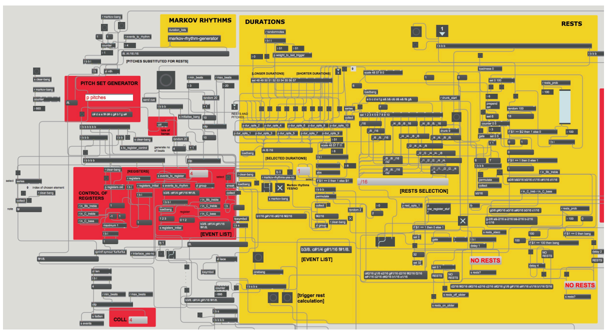

Figure 4. 'Generator' sub-patch (detail)

3.6 Saving generated notations: the coll

A useful feature of the system, with both performative *and* compositional applications, is that it can save and recall generated materials, using the *coll* object. Figure 5 shows an example of a coll ('notations') within which each complete line of GNM code is stored and recalled. The automated control of timings triggering the recall of saved materials can be adjusted, or, saved notations can be recalled manually in combination with newly generated materials.

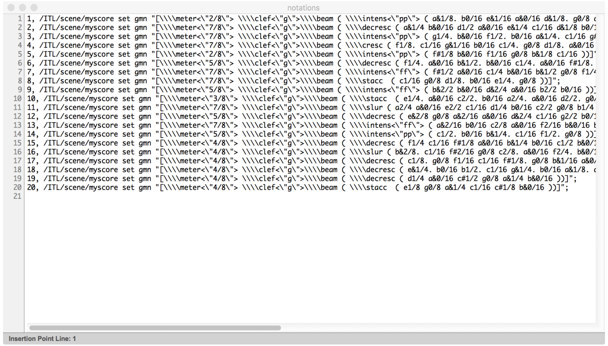

Figure 5. Coll of GMN code (detail)

These functions arose from Kanno's desire to have a mixture of familiar and new notations when interpret-ing the material on-the-fly. Hayden and Kanno became aware of the interpretive distinction between live-gen-eration (of not-so-new material) and live-notation (of newly generated material). They use this variety in or-der to produce multiple levels of attention on the part of the performer. To provide performance flexibility, an option was added to splice 'simple' (i.e. live-generated) and 'complex' (i.e. pre-saved) colls into a single coll, in order to combine simpler (live) materials and more com-plex (pre-prepared) materials (see section 2.5). The splic-ing of coll indices can either be randomised, or, the order of generation preserved if the interpolation system is used (see section 3.7). This was deemed necessary to utilise fully the expressive skills of the performer and realise more fully the compositional potentials of the system (see section 4).

3.7 Global formal shaping: interpolation functions

Most musical parameters defined in the patch can either be given fixed (numerical) values or can transform gradually *within* each successively generated notation (single coll index). However, creating effective larger-scale formal transformations *between* successive coll indices has been an important development of this project. To achieve this end, a *pattr* system was implemented to interpolate values between user-defined 'initial' and 'target' global settings (see Figure 6). Almost every musical parameter (in numerical form), as defined on the GUI, is connected to the *pattr* system so a linear, exponential or user-drawn table interpolation can be selected, across a user-defined coll size, to give a large-scale transformation of multiple parameters simultaneously. Michael Edward's *hyperboles 2* (see section 2.3), has parallels with Hayden's *NEXUS* system, although Kanno's potential compositional interventions in *hyperboles 2* affect more global criteria. When performing *NEXUS,* Kanno can also influence the local detail of the music more directly (as well as global formal shaping), through the various parametric controls available on the GUI connected to the interpolation system. This aspect of the system crucially enables Kanno to *anticipate* the likely global direction and formal contouring according to the chosen parameters and interpolation type and adjust her performance of each notation accordingly.

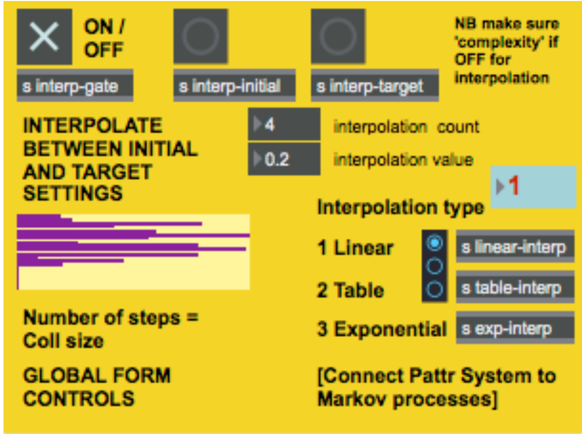

Figure 6. Interpolation controls in main GUI

4. *NEXUS*: CHALLENGES AND SOLUTIONS

4.1 The function(s) of 'live' generation in making the piece: why 'live' notation?

The following section outlines some of the practical challenges and solutions in response to questions raised so far in the development and uses of the *NEXUS* system. An innovation afforded by live notation systems is that the performer has the means to change the generative parameters of a notated composition *during* its performance, while remaining in the symbolic domain. Nevertheless, 'live-ness' in computer music is an oft-debated point by John Croft amongst others [34]. The extent to which the 'real-time' generative approach is 'live' is a moot point, discussed at length by Simon Emmerson [35]. It is not 'in-time' in the sense that the production of the musical data and its sonification by the human performer are *not* simultaneous when material is generated in the symbolic, not audio, domain. What can be said for certain is this approach can guarantee the uniqueness of each performance (although colls can be saved and recalled: see section 3.6), and the uniqueness of performer responses, which is nevertheless based on defined musical objects resulting from concrete constraints. The question of the identity of the *NEXUS*-generated piece and/or performance inevitably arises, and whether the computer should be regarded as an instrument or a compositional tool (or both): computer-mediated 'live' notation somewhat deconstructs this traditional binary division in Western art music. The answer to this question lies in the artistic *uses* of the system. Part of the aesthetic of the piece (in fact, an infinite set of pieces), is that each performance is unique, created by defined algorithms which have infinite variations yet are highly constrained. Many of the generative processes are automated versions of Hayden's 'out of time' formalised compositional methods when writing fixed scores but are simplified to enable sight-reading. Likewise, through experience, it has become something akin to an instrumental extension for Kanno as she learns to anticipate the general effects of changing certain parameters as a means of directing the live performance. The idea of a *hybrid* compositional and performance tool is therefore apt.

4.2 How is notation generated so that the system creates the symbolic material Hayden-Kanno want to use to make music?

Notation is one of the most influential communication tools in classical music, and the knowledge and skills embedded in its use amongst composers and performers remain significant. Hayden and Kanno are interested in how the computer could complement creatively their existing expertise in their handling of notation, to the extent that the relationship between live computer-generated CPN and human performer interpretation intrinsic to the project expands their understanding of the potential of 'text' in music. The *NEXUS* system has been developed iteratively, after feedback from Kanno's experimentation, gradually constraining the parameters until notated material emerges that is both musically convincing and sight-readable (constraint of register was an important factor). Programming decisions are also aesthetic decisions, affecting directly the notational outcomes of the system. Yet the material is necessarily incomplete (Hayden's 'symbolic deficit'), in particular regarding timbre and articulation, and 'needs' the interpretation of a human performer to 'complete' its transformation into sonic musical material.

The affordances of Max-enabled live notation for the performer's interpretative spontaneity are the main points of investigation, as is finding a useful definition of what Hayden and Kanno mean by 'musical' in this digitally-mediated context. The point at which the outcomes can be regarded as 'music' is an aesthetic judgement: e.g. Hayden's use of Markov Chains, for more weighted probabilities in relation to pitch, rhythm and register, has significantly helped to achieve this 'musicality' from the points of view of composer and performer alike. Hayden and Kanno observed that the use of Markov Chains reinforces the linear melodic character of the generated material by suggesting a sequential direction, thus helping Kanno to create phrasing (what Essl calls 'controlled randomness', where the sonification of weighted probabilities means less general scattering of pitches) [36]. The use of Markov Chains to control registers made the generated notations more 'musical', given the importance for the violin of register for melodic shape, phrasing and tone quality, in the sense of having more differentiation and perceived cumulative flow, whilst being less predictable in overall character. There is a need for a certain balance between predictability and surprise in the generated material, in order for it to bear some sense of 'musicality'. With too much predictability, the composition-performance becomes a pastiche exercise; if there is too little predictability, it becomes too random and reduces Kanno's role to merely being a translator. The generated notation has to 'give' something, i.e. 'speak' to the performer, enabling and inviting them to make sense of it, which in turn requires the performer to have a certain familiarity with the visual 'language': it cannot be *completely* different each time.

4.3 How do computer-generated notation and performer interpretation contribute to 'expressivity'?

In the process of computer-generated CPN fragments becoming musically 'expressive' through performance interpretation, determining the contributions of the patch and of the performer is not a straightforward question. To begin to answer this, Kanno makes an important distinction between 'properties' and 'behaviours' of musical material; 'properties' are the combined statistical/numerical processes that generate the material (the various parameter sliders and settings on the GUI and associated internal algorithms), whereas 'behaviours' are the perception of the nature of the musical object or entity itself, in totality or *gestalt*. As a performer, Kanno is less worried about *how* the musical object has been generated, but more focusing on *what* is generated. From a composition point of view, this is relatable to a distinction between generative *processes* (multi-variable algorithms internal to the patch) and generative *results* (the notation *as a musical entity*).

Kanno and Hayden consider the potential multiple action possibilities arising from notation material (one definition of 'expressiveness') as an important aspect of this project. They are concerned mostly with the material's 'behaviour', more than its 'property'. The statistical properties of the material determine possible 'behaviours', but 'behaviours' themselves have so much more 'expressiveness' than the material (or its said 'property'). During the early stages of the project, Kanno thought she was going to select (or find a rule for selecting) action possibilities from notation (in a Cage-like procedure). However, what Kanno does now is to recognise and amplify material 'behaviours' observable within notations, an aspect that the interpolation system has significantly enhanced. Kanno selects or gives perspective to simultaneously appearing 'behaviours' according to how the performance is going.

Excepting 'minimal' music, the *results* of compositional processes are usually heard, as opposed to direct perception of the processes themselves. When performing, musicians don't usually think about *how* the material has been made, but more *what* the material is and how to interpret it expressively/musically. The *NEXUS* project makes Kanno consider *compositional* parameters more than she usually would when interpreting fixed notations, given she can manipulate what are more usually called *compositional* parameters at any point. Many decisions are deliberately left to her, including choices of tempi, details of dynamics and articulation classes, as well as the (dis)continuity between successive generated notations. It is not Hayden and Kanno's aspiration for the system to become an autonomous virtual composer nor performer, so the notational outputs from the system are necessarily incomplete.

4.4 The symbolic deficit: what is the relationship between generated notation and live interpretation?

Given the generative CPN material is deliberately lacking in detail, the 'symbolic deficit' means that much of the sonification decisions are in the hands of Kanno's musicianship. Her focus is to shape the material, make it into a performance that 'works' and is in some way 'musical', relying heavily on performance intuition and experience. Much of the performer's decision-making will be around parameters not defined by the programming: phrasing, timbre, articulation, tempo, intermediate dynamics (beyond ff and pp) and so on. There is a controlled quasi-improvised process taking place where Kanno reacts to the notations in the moment: the system is an invitation for performance. On the one hand, the CPN was necessarily simplified from Hayden's usual practice (his fixed scores are *much* more complex) whilst still embedding something of his compositional ideas in the programming. On the other, it gives Kanno the ability to influence the outcome of a performance that is nevertheless very constrained, given the composer-defined limits on what can happen.

4.5 Symbolic generation and interpretation: 'in-time' or 'out-of-time' actualisation?

To use Xenakis' famous distinction, there are both 'in-time' and 'out-of-time' applications of the *NEXUS* system [37]. Although we have focused on a performance use which is as close to being as 'in-time', 'live' or 'real-time' as possible (minimum time-lag between generation and interpretation), one can use the system to generate material *any* time before the performance, an 'out-of-time' compositional application. One could, as Michael Edwards does with his 'slippery chicken' software, generate notation algorithmically, to create a fixed score to be rehearsed in preparation for a later performance [38]. Each generation of the piece would still be unique so it would be a valid approach as long as that version was not repeated. Hayden and Kanno *decided* to use the *NEXUS* prototype to combine pre-prepared and live-generated materials for variety of output and performance strategy, but this is not a given. These are aesthetic decisions, adopting a more 'experimentalist' approach which requires performance uniqueness and unpredictable (but not unknown) outcomes: it is the *controlled* randomness that interests Hayden and Kanno, in between the aesthetics of Cage and Xenakis.

5. FUTURE DEVELOPMENTS

5.1 Initial phase of the project

The first phase of the project has been a technical consolidation of the current Max7 prototype, which focused on improving the efficiency and effectiveness of the generation of the GMN data rendered as notation in INScore, the underlying stochastic mechanisms which generate the GMN data, the GUI design, organization of sub-patching, functioning of parametric controls, and fixing fundamental notation issues (e.g. beaming, groupings of rests and beats, dotted rhythms, clefs and transposition, visual formatting, completion of incomplete bars with rests and so on).

5.2 Current phase of the project

The current phase of the project is optimizing the *musical* affordances of the GUI and generated CPN *for the performer*, finding solutions to the issues of maintaining *musical* interest and variety, while retaining playability, through combinations of sight-readable (live) and more complex (pre-prepared) materials. This has included implementing more variability within the idea of 'complexity' from a perceptual point of view, more variety in the possible lengths and characters of generative notations, more efficient handling of larger-scale global formal control of musical parameters (via the interpolation system), and a more flexible generative approach to pitch-class set and duration series creation, selection and succession (via Markov Chains). The next part of this phase will be the notational implementation of violin-specific techniques (e.g. double-stops, harmonics, microtones, and articulations).

5.3 Final phase of the project

The final phase of the project will be to make the *NEXUS* system interactive by implementing the real-time analysis of sonic descriptors, e.g. timbral and temporal features of the live violin signal, by using Max externals such as Nick Collins' ll~ object (see section 1), Tristan Jehan's library (pitch~, loudness~, brightness~, noisiness~, bark~, analyzer~, shifter~, segment~, beat~) [39], the iana~ object (Todor Todoroff) [40], the yin~ object (Norbert Schnell, implementing the Cheveigné and Kawara model) [41], the *FTM/Gabor* object library (IRCAM) [42] [43], fiddle~ and bonk~ objects (Miller Puckette) [44], or the *Zsa.Descriptors* libraries (Mikhail Malt and Emmanuel Jourdan) [45], in order for the computer to influence decisions about the generation of future notations in a feedback situation. We are also considering adding some live DSP, so the patch generates sound which is related in pitch, rhythm and timbre to; (a) the generated notation; and/or (b) the played sound from the live violin, as counterpoint to the live violin sound itself. A further development could be to implement a network connection to enable the coordination of multiple generative notations between different computers, allowing an ensemble of live musicians to use the system, whether synchronized or in free time.

6. CONCLUSION

The project has raised fundamental questions about the past, present, and future significance of CPN in technologically-mediated composition and performance. The exploration inherent in the development of the *NEXUS* system has involved: (a) an interrogation of the relationship between the underlying technical aspects of the system design and (pre)compositional programming decisions that determine the processes of how material is generated in the symbolic musical domain; (b) the evaluation of resultant generated CPN fragments as a symbolic language appropriate for making music; and (c) how such generated symbolic material becomes musically *expressive* through performer reading and the implications of interpretation for system design. The current phase of the project has focused on two technical developments: (1) implementing higher-level interpolation controls to enable larger-scale formal transformations; and (2) implementing a more musical control of linear contouring via Markov Chains. Such ‘higher-level controls’ shape the global transformation of the notated materials through the gradual interpolation between user-defined ‘initial’ and ‘target’ states (or presets), where previously, successive colls were separate, discrete and non-connected entities. This necessitated the finer tuning and calibration of multiple control parameters. The more musical control of linear contouring, phrase direction and phrase shaping was achieved by mapping Markov Chains to successions of pitch-classes, rhythmic units and registers. This proved to be a more flexible and musically intuitive approach to the (performer-defined) constraints enacted upon the algorithmic generation of materials. We continue to investigate controlling the larger-scale transformation of such constraints over time in relation to perceived ‘musical’ performance *outcomes*. Within these processes, it has been fundamental to calibrate the system to identify enough space in the generated CPN to enable Kanno to do something *interpretative* so that the final work engages her skills and musicianship, rendering a live performance as more than the sum of its parts.

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