COMPOSITION as an EVOLVING ENTITY
an EXPERIMENT in PROGRESS

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ABSTRACT

Composition as an Evolving Entity envisions a work in continuous transformation, never reaching an equilibrium, a complex structure whose components permanently fluctuate and adjust to global changes. The process never produces a definitive version, but does provide at any arbitrary point in time a plausible variant of the work - a transitory being. Directed Graphs are used to represent the structural levels of a composition (vertices) and the relationships between them (edges); parent-children and ancestor-descendant types of connections describe well potential hierarchies in a piece of music. By determining adjacencies and degrees of vertices and by introducing weights for edges, one can define affinities and dependencies in the complex and flexible structure that is a musical composition. Ways in which the all-incidence matrix of a graph with weighted edges can evolve are discussed including the use for that purpose of elements of Information Theory. Composition as an Evolving Entity model is closer the other paradigms to the way composers actually compose and refine their output; it also creates the equivalent of a live organism, growing, developing, and transforming itself over time.

BACKGROUND

The process of writing a new piece involves balancing elements that belong to different structural levels from the overall form of the composition to various sound characteristics. Composer Aurel Stroe and collaborators have discussed in the article "Morphogenetic Music" [1] the play between melody, rhythm, harmony, and phrase length in Mozart's *Piano Sonata in C Major K.W. 309* and showed how unexpected or more daring choices at one structural level are compensated by blander, more familiar occurrences at other levels. A related insight into the composition process is given by Beethoven's sketchbooks that show a constant adjustment, sometimes over years, of initial motives [2] and by the example of Charles Ives who continued to modify his music even after it was published.

Manifold Compositions

When a computer-generated piece contains elements of indeterminacy, multiple variants can be produced simply by changing the initial conditions (eg. the random number generator's seed). Randomness may be involved in selecting the order of macro and micro events, in the choice of attack times and durations of sounds, of their frequencies, amplitudes, spectra, etc. or of their environment's properties such as location in space and reverberation. Such multiple variants, members of a *manifold composition*, have exactly the same structure and are the result of precisely the same process but differ in the way individual events with their diverse characteristics are distributed in time; similar to faces in a crowd, they all have common basic features but exhibit particular attributes. A *manifold composition* is an equivalence class, a composition class produced by a computer under particular conditions [3]; it includes all its actual and virtual variants and requires that they all be equally acceptable.

DISSCO

The software used in the production of *manifolds*, a Digital Instrument for Sound Synthesis and Composition, DISSCO [4], provides a seamless approach to music composition and sound design. An integrated environment, it has three major parts: LASS, a Library for Additive Sound Synthesis, which builds sounds from first principles (sine waves), CMOD, or Composition MODule, a collection of methods for composition that drives the synthesis engine, and LASSIE, a graphic user interface (GUI).

DISSCO is comprehensive in the sense that it does not require the intervention of the user once it starts running. Such a "black box" set of instructions is necessary for preserving the integrity of *manifold* production: modifying the output or intervening during computations would amount to the alteration of the data or of the logic embedded in the software. Due to a LASS option unavailable on other systems, the precise control of the *perceived loudness*, a non-linear function of amplitude [5], post-production interventions become not only unnecessary but also incongruent with the purpose of the enterprise.

The structure of CMOD can be represented as a directed graph (DG), a *rooted tree,* where every structural level inherits from a generic Event class in a *matryoshka* type of arrangement: a unique Top event (the root) can include High events followed by Mid, Low, and Bottom events. In this model, events are represented as vertices each of them having siblings (except the root) and spawning any number of children, connected by edges that illustrate the relationships between them. By carefully determining adjacencies and degrees of all vertices and by

introducing weights for edges, one can start defining affinities and dependencies in the complex and flexible structure that is a musical composition. The scheme can accommodate both the stricter order found in traditional music (piece < sections < themes < motives < cells < sounds), and, at the other extreme, if only the root and its children are present, random distribution of undifferentiated events within the confines of the piece (sounds in Cage's chance music). Moreover, this model is well suited to create "floating hierarchies", unstable flows of information that favor change over established formulations [6].

It should be noted that Pierre Barbaud had explored the use of graphs in "automatizing" the production of tonal harmonic and contrapuntal sequences in his own compositions as early as the 1960s [7].

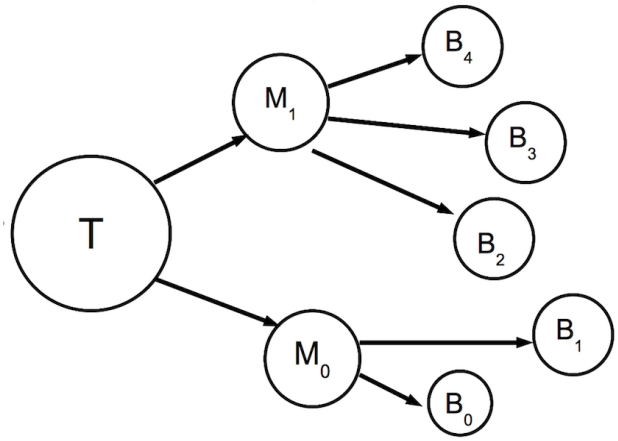

Figure 1. DISSCO structure as a rooted directed graph. For clarity only one intermediate level (M) is shown.

COMPLEX DYNAMIC SYSTEMS

Any composition can be thought of as a complex system. During the process of composing, the system is also dynamic in the sense that options are re-evaluated at various times leading to changes both in the structure and in the details of the work.

Composition as an Evolving Entity project models such a process by allowing the computations to continue for an arbitrary amount of time. It envisions a work in perpetual transformation, never reaching an equilibrium, a complex structure whose components permanently fluctuate and adjust to each other's modifications - a "brewing" piece. Such a composition can be regarded as a network of evolving interdependent elements whose alterations, refinements, and transformations create a series of unstable dynamic states. It could be likened to an electric grid where power is generated, routed, and distributed through different nodes: a network of diverse but interdependent components. Such a grid has to be responsive and to constantly adjust the flow of electric power, to compensate for surges in demand or for local failures. Its musical equivalent is a composition whose parts are interconnected at all levels in such a way that modifying one component could have global consequences and affect other parts of the system.

This view of the composition as a network of perpetually unfolding elements in search of an elusive balance, similar to a living creature, epitomizes an "organic" approach to creating music. The process never produces a definitive version but provides at any arbitrary point in time a plausible variant of the work - a transitory being.

The project is an extension and a corollary of the *manifold* idea as they both involve the presence of randomness at all structural levels and relay on the view of sounds as events in a multidimensional vector space whose degrees of freedom include parameters such as time/duration, frequency, amplitude, phase, etc. It adopts the view that a composition could be represented as a hierarchical structure and is predicated on discovering and creating new situations as opposed to attaining known, already established goals: an unstable equilibrium and NOT a search for a stable optimal solution.

THE DESIGN

Trivial Case

Upon finishing a new piece, a human composer might step back, take a fresh look at the work and, possibly, decide on making changes and adjustments. Composition as an Evolving Entity allows computations to continue after the first variant of the *manifold* is completed: a new edge is created between the last Bottom event $\mathbf{X}_{\text{last}}$, (a terminal vertex) and another vertex $\mathbf{X}_{\text{new}}$ which could be a sibling, a parent or an ancestor belonging to the same branch or to a different one. The operation takes place with the help of an all-incidence matrix $\mathcal{M}$ of the type:

	T	M_0	M_1	B_0	B_1	B_2	B_3	B_4
T	0.01	0.05	0.05	0.02	0.01	0.03	0.03	0.01
M_0	0.20	0.01	0.25	0.20	0.20	0.05	0.10	0.07
M_1	0.20	0.01	0.01	0.11	0.10	0.25	0.20	0.23
B_0	0.12	0.20	0.11	0.01	0.30	0.19	0.08	0.07
B_1	0.12	0.24	0.10	0.35	0.01	0.07	0.08	0.09
B_2	0.12	0.06	0.15	0.10	0.12	0.01	0.26	0.26
B_3	0.12	0.08	0.18	0.11	0.14	0.25	0.01	0.26
B_4	0.11	0.06	0.15	0.11	0.12	0.25	0.24	0.01

Figure 2. All-incidence weighted matrix

This transitional matrix is weighted (expressing probabilities of exploring different edges) and serves as a template for the Evolving Entity, a sort of genome of the composition.

The selection of $\mathbf{X}_{\text{new}}$ involves dividing the components of the vector $\mathbf{V}_{\text{last}}$ (corresponding to $\mathbf{X}_{\text{last}}$) by their sum, adding the results in order from the top to bottom, with 1 in the last row, and matching a random number to a probability interval. If the newly chosen vertex $\mathbf{X}_{\text{new}}$ is a parent, all its descendents are computed anew. Upon completion an audio file becomes available to be examined (or ignored) and a vector $\mathbf{V}_{\text{new}}$ corresponding to the chosen vertex $\mathbf{X}_{\text{new}}$ is used to continue. The procedure may be repeated an arbitrary number of times.

Continuity

If the process of re-evaluating vertices proceeds without interruption, a continuous sequence of pseudorandom numbers creates a history uniquely determined by the seed state and its integrity confers the equivalent of a perennial "personality", an identity to the Evolving Entity in question. There is a paradox here: the choices leading to a given variant of the manifold depend on chance but the random numbers themselves are part of a causal, deterministic chain. Combined with the fact that the directed graph and the matrix - the genome - are pre-determined, a balance is created between structure and indeterminacy and the piece starts to resemble a living organism whose cells are rejuvenated constantly while the creature endures.

Template Modification

Modifications of the template/genome may be introduced as the computations continue. If the column vector representing the last choice $\mathbf{V}_{last}$ is multiplied by the matrix $\mathcal{M}$, $\mathbf{V}_{last} * \mathcal{M}$, a Markov chain mechanism is initiated and the newly resulting vector $\mathbf{V}_{last+1}$ becomes part of an ordered sequence of causally connected vectors when the operation is repeated every time a new variant of the piece completes. In most cases the root of the tree, the piece itself, is not affected; however, that might change if the total duration of the entire piece is allowed to fluctuate between certain limits.

The user controls the likelihood of various connections/ edges between vertices through the static, all-incidence matrix $\mathcal{M}$. The Markov chain mechanism described above allows a vector to evolve in a predictable way but assumes that the content of the other vector/columns of the matrix remain the same. A more realistic alternative is to take into account global changes that might occur every time a new version is computed - something a human composer would probably do.

Such adjustments are construed as the result of the composer's intuition, taste, training, etc. but many times these subjective considerations can also be described using elements of Information Theory. The main concepts provided by Information Theory as applied to musical messages are those of Order expressed through the relationship between Originality and Redundancy - a dialectical opposition - in relation to the Complexity of the work [8]. Their relevance to this project is based on at least two facts: these are measurable quantities and, as Herbert Brün once put it: "the job of a composer is to delay the decay of information".

As an example, Originality may be equated with i*m*probability hence with the delivered Information, Redundancy with repetition and/or familiarity, and Complexity with the number of available choices, all quantifiable if not entirely objective. Since each variant of the piece exhibits new, different values for most vertices, an analysis of all values at all vertices followed by a comparison with a desired (dynamic) situation becomes necessary. In turn, such an extensive re-evaluation of data requires a significant increase in computing time and storage capacity since even a relatively short work may easily contain hundreds of vertices.

Moreover, the vertices representing the Bottom level contain significantly more information then those corresponding to higher level vertices and are more likely to trigger more often global changes. This is because sound design procedures are concentrated at the Bottom level: various ways of assigning the frequency and loudness of a sound, the rate and amplitude of vibrato (FM), of tremolo (AM) or of frequency and amplitude transients. Information about spatialization and reverberation should also be added to the list.

Developing Entity

The Complex Dynamic System that is the Evolving Entity/Composition includes the Directed Graph rooted tree that is DISSCO, the template/genome matrix $\mathcal{M}$, and the set of data used to create the initial variant of the piece. The preceding discussion has assumed the size of the rooted tree and, necessarily, that of the matrix, constant. However, the process could start with a tree and a matrix reduced to the smallest possible number of vertices/vectors, for instance only the Top vertex (the piece) and one or two Bottom or terminal vertices. The system is then allowed to grow, developing more edges and vertices at a rate controlled by the user until reaching its maximum potential. The opposite, a decaying slope can be engineered by cutting off branches of the tree and reducing gradually the size of the matrix. In the end, a restricted number of vertices and edges containing a smaller and smaller number of possible choices or a situation similar to reaching the ergodic (stationary) state of a Markov chain could signify the demise of the Entity/Composition.

IMPLEMENTATION

Composition as an Evolving Entity is an experiment in progress. It uses the structure and the features of DISSCO, a powerful, sophisticated, and complex application that has been proven reliable and robust during an almost a decade of use. Although the project is presently in an incipient stage, it benefits from the experience accumulated both by seasoned DISSCO users and by students in the classroom.

Present phase.

After considering a number of alternatives, the general framework described above was selected. The Trivial Case was implemented by seamlessly connecting the last Bottom, a terminal vertex to the Top event without interrupting the sequence of random numbers.

The Evolving Entity project runs in multithreading mode and has recently been ported on a multi-core system. Using 16 CPU cores when producing a complex eight channel piece, the ratio between computation time and the duration of the piece (real time) is a little less than 3/2 and increasing the number of cores does not res-

ult in a significant improvement. However, a meaningful functioning of the system requiring a ratio of 1/1 or less was achieved when computing a slightly less complex stereo work.

Future work

An urgent task is to profile, optimize, and parallelize the code in order to constantly achieve real time or better.

Next, meaningful ways of creating the $\mathcal{M}$ matrix need to be explored. A 12 minutes work produced recently can be represented by a rooted tree containing 132 discrete vertices (event types). A 132 X 132 matrix or even matrices an order of magnitude bigger in size are manageable but they will have to be constantly updated and various operations performed on them.

Finally, in the case elements of Information Theory are used, an analysis of each new variant of the piece is necessary which means information for 15,700 sounds (as in the example quoted in the preceding paragraph) or more will have to be not only stored but also analyzed.

CONCLUSIONS

Composition as an Evolving Entity embodies a new idea never explored before that it is seminal in the sense that it creates an original paradigm within the field of Computer-assisted (Algorithmic) Composition. It could be exploited and enhanced in the future by composers interested in innovating and in non-trivial ways to create music. Although the concept of Complex Dynamic Systems has been discussed in connection with Catastrophe Theory [1], in the context of (pseudo-)tonal music [9], or by regarding music as a language, there have been no proposals for building a concrete mechanism in order to generate a continuously evolving composition. Except for the efforts of Pierre Barbaud [7], to our knowledge, no other attempts have been made to use Graph Theory in Composition either.

This approach elevates the understanding of composition and composing to an abstract level by bridging the difference between music and other domains through the use of mathematical tools and by requiring a state of the art, high-performance computing. Similar to the *manifolds,* it is based on the solid foundation provided by the description of sounds as events in a multidimensional vector space and it creates a general framework that can be applied to different aesthetics not just to a particular style.

The Evolving Entity composition model is closer to how humans actually compose, by trial and error, and continuously refine the output: it better approximates the workings of the human mind. It also reflects the natural world by creating the equivalent of a live organism, growing, developing, transforming itself over time and thus fulfilling the goal expressed by John Cage: " to imitate nature in its mode of operation".

Composition as an Evolving Entity and m*anifold compositions* represent an idiomatic way of using computers in music by mass producing unique versions of the same archetype. Because of the provision already present in the production of *manifolds* that a version of the output can not be performed in public more than once, it becomes a reflection of a particular aesthetic and worldview. Presenting the piece as it exists only at one instance of a continuous process, an aspect of it which will be never repeated, stresses the ephemeral quality of any musical activity and prevents the piece to become a commodity.

This paradigm has the potential for further significant developments beyond the immediate scope of this proposal such as creating an "ecosystem" where the performance environment (hall acoustics) and live performers' decisions influence the composition.

Acknowledgments

We would like to acknowledge the support of Dr. Volodymyr Kindratenko and the Innovative Systems Laboratory at NCSA, for facilitating the computing infrastructure to perform our work.

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