
GENOMUS: REPRESENTING PROCEDURAL MUSICAL STRUCTURES WITH AN ENCODED FUNCTIONAL GRAMMAR OPTIMIZED FOR METAPROGRAMMING AND MACHINE LEARNING

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ABSTRACT

We present GenoMus, a new model for artificial musical creativity based on a procedural approach, able to represent and learn the compositional techniques behind a musical score. The aim of this model is to build a framework for automatic creativity, easily adaptable to other domains beyond music. The core of GenoMus is a functional grammar designed to cover a wide range of styles, integrating traditional and contemporary composing techniques. Musical *genotypes* are defined as functional trees, able to generate musical scores described as *phenotypes*. To enable the maximal diversity of outputs, each process uses the same generic functional structure, no matter what time scale, polyphonic structure or additional characteristics are being employed. The goal of this highly homogeneous and modular approach is to simplify metaprogramming of genotypes, as well as maximize search space. Genotypes and phenotypes are encoded as normalized numeric vectors. This abstract representation of musical knowledge as pure numeric arrays is convenient for the application of different machine learning paradigms. The user interface developed for GenoMus is oriented to the exploration of augmented creativity, regardless of user expertise. However, a composer can create and alter manually genotypes and algorithms to modify automatic results. The system allows the implementation of user-defined processes, which will expand the procedures library.

Keywords: automatic musical composition · metaprogramming · procedural representation of music · artificial creativity · GenoMus

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1 Introduction

But there’s a big difference between “impossible” and “hard to imagine”. The first is about *it*; the second is about *you*!
—Marvin Minsky [25]

[29] -> interesante para situar la discusion y encuadrar las motivaciones y posibles peligros. Motivations classes: 1. computer programs are written by the composer as an idiosyncratic extension to her own compositional processes; 2. computer programs are written as general tools to aid any composer in the composition of music; 3. theories of a musical style are implemented as computer programs; 4. cognitive theories of the processes

Failures: 1. a failure to specify the precise practical or theoretical aims of research; 2. a failure to adopt an appropriate methodology for achieving the stated aims; 3. a failure to adopt a means of evaluation appropriate for judging the degree to which the aims have been satisfied.

1.1 Composing composers

Metalevel -> [6]

[17] -> interesante la disgresion filosofica sobre la autoria. De Music composition to music recognition. Dice: Is the same? Yo digo: Can computer solutions get us to new styles, to nwe ways or feeling music?s

[21] -> ACTUAL! Algoritmic Music Composition Based on Artificial Intelligence: A Survey

El survey de Vico [31]

[12] -> survey actual de evolutionary music generation (para inicio)

Research in artificial musical intelligence demand for formalized grammars of musical structures. Besides, a model of creative mind is required to operate these abstractions. Aesthetic criteria are extremely subjective, furthermore the details of every model of automatic composition impose, consciously or not, a limited search space. Delimiting these boundaries and setting evaluation principles can be seen as metacomposition, namely composing composers.

Composers' interest in musical language pervaded the 20th century aesthetics. Transformation and overcoming of well-established methods inherited from Romanticism led to post-tonal music. Linguistic structuralism applied to musical syntax stimulated relativization and consciousness of compositional procedures. Reversing the logic of this analytic knowledge, the methods of serial dodecaphonic music was the first step for the foundations of an inverse creative strategy: synthesize new styles from the predefinition of new rules.

Computer assisted composition enabled far more complex procedures, tedious or unfeasible to explore by hand. Eventually, composers began to use computers not only for analysis and calculation of complex structures, but for the automation of the creative processes themselves. That fact opened the door to a new approach to composition: a metamusical level characterized by modeling the processes within the minds of composers.

[Reflexiones sobre metacomposicion, el concepto de autoria y consideraciones pedagogicas y humanas de fondo.]

[Interes de la musica en el modelado de creatividad artificial - multidimensionalidad de la percepcion y analisis]

[Sobre la necesidad de usar el metanivel de los procedimientos antes que la partitura]

Many approaches to artificial intelligence applied to the automatic composition of music are modeled using scores as its data source...

[Complejidad del diseno de lenguajes de representacion musical en la composicion asistida por ordenador. Cita de algunas aproximaciones analogas.]

1.2 New challenges for automatic composition

[Repaso rapido de los principales paradigmas de herramientas de CAC para hacer notar como es necesario un metanivel de trabajo]

Citar [26] -> -Pag. 4-5: Buen resumen de los paradigmas -> -5: justifica problema de neural nets con fragmentos largos coherentes

Muy interesante: Open Problems for Genetic Music: [23]

This proposal, beyond the technical details, is a model of augmented creativity from the point of view of the composer. The new paradigm of computation applied to creative tasks is tilting from ordering to the computer "what to do", to saying "what to get", as a starting point to detonate supervised or non-supervised creative processes. So, the goal of GenoMus is to combine a knowledge base of compositional procedures with the maximal freedom of recombination.

Hacer resumen del proyecto completo, referencias a los antecedentes y dejar claro que trata este texto

1.3 Overview of the framework and complementary materials

[Specifications. Code, Max Patches, Examples of specimens, Music excerpts]

2 A simple functional grammar to represent musical procedures

I believe that music today could surpass itself by research into the outside-time category, which has been atrophied and dominated by the temporal category. Moreover this method can unify the expression of fundamental structures of all Asian, African, and European music. It has a considerable advantage: its mechanization—hence tests and models of all sorts can be fed into computers, which will effect great progress in the musical sciences.

—Iannis Xenakis [37]

2.1 Foundations and requirements

Similaridad con [15] como el referente mas cercano. Mostrar diferencias. Tambien cercano a [2] como lenguaje creado por un compositor para autoexpansion.

[9] -> solo por citar una aproximacion hibrida muy actual, pero poco interesante

[10] > aproximacion similar en su planteamiento, pero muy limitada

[18] -> un ejemplo analogo a la generacion automatica de arboles de funciones

Referencia a compositor de referencia -> [37] Ya habla de la posibilidad de expresar la musica como expresiones logical and algebraic a partir de eventos sonicos basicos, a la par que habla de ir "towards a metamusic"

Over the last decades, a plethora of grammars to represent music have been proposed. This framework... After studying the potential and limitations of previous research, the *GenoMus* grammar has been design to satisfy these key features:

Grammar based on a symbolic and generative approach to music composition and analysis.

GenoMus is focused on the correspondences between compositional procedures as musical results. It employs the genotype/phenotype metaphor, as many other similar approaches, but in a specific way, discussed below.

Style-independent grammar, but able to incorporate complex processes from contemporary techniques.

In any approach to artificial creativity, a representation system is a precondition that restricts the search space and imposes aesthetic biases a priori, either consciously or unconsciously. The design of algorithms to generate music can be ultimately seen as an act of composition itself. With this in mind, our proposal seeks to be as open and generic as possible, to represent virtually any style and enclose any procedure. The purpose of the project is not to imitate styles, but to create results of certain originality, worthy of being qualified as *creative*.

A smooth integration of modern and traditional techniques is one of the purposes of our grammar. *GenoMus* allows to include any compositional procedure, even those from generative techniques that imply iterative subprocesses, such as recursive formulas, automata, chaos, constraint-based and heuristic searches, L-systems, etc.

Optimized for metaprogramming.

Each musical excerpt is generated by a function tree made with a palette of procedures attending all dimensions: events, motifs, rhythmic and harmonic structures, polyphony, global form, etc. All function categories share the same output scheme, which ease the implementation of metaprogramming routines encompassing all time scales and polyphonic layers of a composition.

Identical encoded representation of both compositional procedures and musical scores as single unidimensional and normalized vectors.

Compared to similar grammars, this is the distinctive feature of *GenoMus*. Functional expressions and the results of their evaluations are both encoded as sequences of floats within the interval $[0, 1]$. Thus, pairs of complex nested procedures and their corresponding complex polyphonic scores are mapped as flattened unidimensional arrays. This abstract representation of music is suitable to be handled with different machine learning techniques.

Alternative decoded format of compositional procedures, as function trees easily understandable and manually editable.

Functional expressions and their encoded format are alternative representations. So, the abstract vectorial format can be converted into a readable and editable text with convenient numeric scales for each parameter.

Representation of music able to capture expressive details and global structural features.

The aesthetic potential of computer generated artworks is often obscure. Human composers usually conceive sequences of notes, agogics, articulation gestures and dynamic expressiveness as a whole. There is no intrinsic value in a sequence of durations and pitches if it lacks of expressive attributes such as articulation and dynamics. Interrelations of different parameters, both in short and long term, are critical to get appealing results.

In our framework, macro and microformal features are created and transformed as a whole entity from the beginning of the transformational operations. Composers often construct a piece by planning interrelations between the details of motifs and the overall structure. This holistic conception of creativity have been perhaps obviated in many previous research, focused in some particular compositional tasks, but forgetting that a good piece of music is much more of than the sum of its parts.²

Support for internal autoreferences.

Consistency of the correspondences among procedures and musical outputs, regardless of the subsequent evolution of the grammar and the progressive addition of new procedures by other users.

Possibility of generating music using subsets of the complete library of compositional procedures.

Applicability to other creative disciplines beyond music.

Although this framework is presented for the automatic composition of music, the model can be easily adaptable to other areas where creative solutions are sought. Whenever it is possible to decompose a result into nested procedures, a library of such procedures can be created that takes advantage of their encoding as numerical vectors that serve as input data for machine learning algorithms.

[32] -> Conditions for creativity: Knowledge representation is organised in such a way that the number of possible associations is maximised. A flexible knowledge representation scheme. Similarly Boden (1996) says that representation should allow to explore and transform the conceptual space. Tolerate ambiguity in representations. Allow multiple representations in order to avoid the problem of ?functional fixity?. The usefulness of new combinations should be assessable. New combinations need to be elaboratable to find out their consequences. El articulo de Boden es: What is Creativity. In M. Boden, editor, Dimensions of Creativity, pages 75?118. MIT Press, 1996. (citado antes).

[14] -> Quiza recoger su apunte de las conclusiones: falta el long-term approach y el higher-level concept

Just con [13] -> para la generacion automatica de arboles y gramatica (f mas a fondo)

Una aproximacion tambien muy similar en el sentido de generar metaprogramas -> [33]

Similar pero muy simple -> [1]

too [4] -> para justificar el uso de arboles de funciones, ya que este articulo habla de parsear lenguaje (musical entre otros) para llegar al arbol original.

[16] -> Propone trabajar con ‘building blocks’ mas grandes, cercano a frases

[Conveniencia del paradigma de programacion funcional para la metaprogramacion. Antecedentes procedimientos compositivos como funciones (referencias a Haskell y LISP en la tradicion)]

[Necesidad de encontrar un medio de representacion adecuado a la automatizacion de analisis, a la flexibilidad de estilos, y a conjugar la programacion manual con la modularidad necesaria para las tareas automatizadas]

[Importancia de la codificacion como vector numerico como representacion abstracta de estructuras y resultados musicales para la aplicacion de tecnicas de IA.]

2.2 Musical genotypes and phenotypes

²Beethoven perfectly exemplifies how great sublime musical structures can emerge from trivial and seemingly uninteresting musical motifs.

para aclarar que no hay consenso entre el uso de la nomenclatura de genotipos y fenotipos [35]

[30] -> usa el paradigma genotipo fenotipo, aunque de un modo diferente Muy importante: Indirect encoding: IAMUS -> importancia de la evo-devo incremental. El proceso importa, no solo la codificación del ADN
 ?Using an effective indirect encoding, a small genotype can potentially specify a large and complex phenotype, accounting for the scalability problem previously mentioned. Additionally, a small change in the genotype can potentially provoke a variety of coordinated changes in the phenotype?

?They are currently being used to a certain extent for automating tasks that demand creativity, proposing different variations to existing solutions, which evolve toward desired design targets, resembling an automated form of brainstorming.?

[34] -> In order to meet this challenge, many researchers are proposing indirect encodings, that is, evolutionary mechanisms where the same genes are used multiple times in the process of building a phenotype.

[Marco conceptual básico del paradigma genotipo-fenotipo (referencias de otros proyectos)]

[Definiciones estrictas de genotipo y fenotipo]

[Similitud con la programación funcional: la pieza musical como función de funciones.]

2.3 Species and specimens

Ejemplo preliminar de aplicación a la síntesis de sonido -> [20]

2.4 Anatomy of a genotype function

2.5 Function types

[Tabla con los tipos de funciones. Figura ilustrando la estructura score/voice/chord]

2.6 Leaves, parameter mapping and readability

2.7 Function libraries

2.8 Specimen data structure

[Tabla con la estructura de datos de cada par genotipo-fenotipo]

3 Encoded genotypes and phenotypes

Lerner appears to believe that transformations that could be carried out by a computer program [...] could not possibly generate anything sensible—and that no program could tell sense from nonsense anyway. The implication [...] is that no computational theory could describe the generation of valuable new ideas, and that only an unanalyzable faculty of “intuition” or “insight” could recognize their value. None of these beliefs is justified.

—Margaret Boden [5]

- Propósito de la codificación en el marco del machine learning
- Codificación como vectores unidimensionales normalizados
- Universal valid format
- Modularidad y posibilidad de manipulación manual
- Encoding as safety filter

3.1 Encoding genotypes with Gödelian resonances

[11] -> para las resonancias gödelianas

Any random sequence of numbers generates a valid program.

$$P = \{x_n \in \mathbb{R} \mid 0 \leq x_n \leq 1\}$$

Figure 1: Structures of S. Reich’s *Clapping Music*.

Multidimensional search space of all possible vectors with normalized parameters:

$$P^n$$

Each vector in P is mapped to a valid encoded genotype (that is a valid functional expression which generates an excerpt of music). Let G be the set of all possible valid encoded genotypes. To create genotypes, the map f works as a decision tree such as every vector $\mathbf{p} = (p_1, p_2, \dots, p_n) \in P^n$ will be mapped to G :

$$f : P^n \rightarrow G$$

Most of times n doesn’t match the number of required items to complete a valid encoded genotype. If \mathbf{p} has more items than needed, they are ignored. If f needs more items than those supplied by \mathbf{p} , f reads \mathbf{p} repeatedly from the beginning as a loop, until closing the valid encoded genotype. That implies that even vectors with a single value can be mapped to large functional expressions.

3.2 Scores represented as normalized vectors

3.3 A unique format for procedures and results

3.4 Safety through encoding

4 A minimal example: *Clapping music*

[...] in general the rules don’t make the music, it is the music that makes the rules. Then, instead of relying only on a set of imperfect rules, why not making use of the source of the rules, that is the compositions themselves?

—Ramoón López de Mántaras [19]

Presentacion de la pieza

Figure 1 is here.

4.1 Code and interface for the experiments

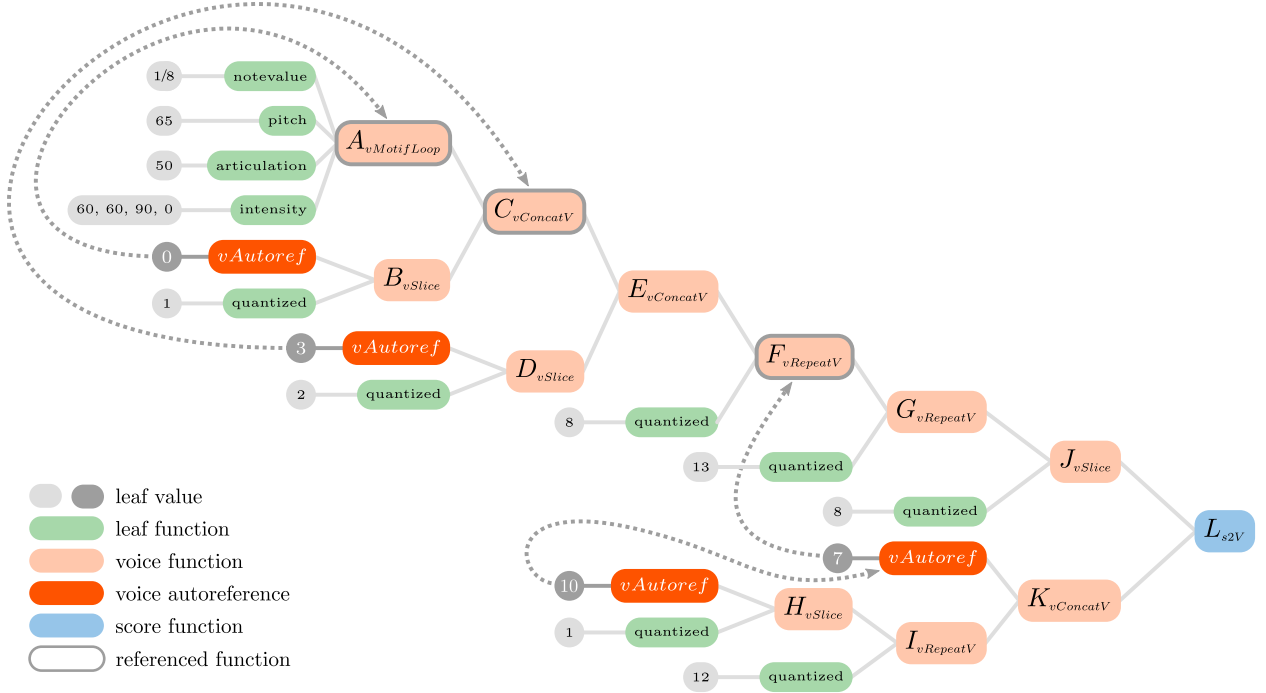
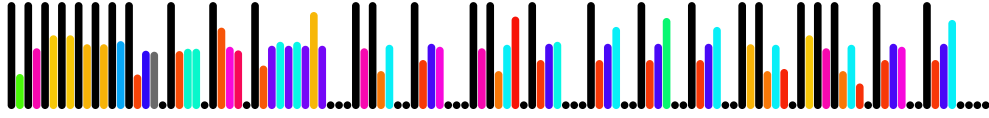
[manual coding to extract procedural and extendable knowledge][15]

4.2 Decoded genotype: a procedural function tree of the piece

```

1 s2V(                                     // score L: joins the 2 voices vertically
2   vSlice(                               // voice J: slices last cycle because of phase lag
3     vRepeatV(                           // phase G: F 13 times
4       vRepeatV(                         // cycle F: E 8 times
5         vConcatV(                      // pattern E: C + D

```

Figure 2: Structures of S. Reich's *Clapping Music*.Figure 3: Structures of S. Reich's *Clapping Music*.

```

6      vConcatV(           // motif C: A + B
7          vMotifLoop(     // core motif A: 3 8th-notes and a silence
8              ln(1/8),     // note values
9              lm(65),      // pitch (irrelevant for this piece)
10             la(50),      // articulation
11             li(60,60,90,0)), // intensities (last note louder for clarity)
12         vSlice(         // motif B: A with 1st note sliced
13             vAutoref(0),
14             q(1))),
15         vSlice(         // motif D: C with 1st note sliced
16             vAutoref(3),
17             q(2))),
18         q(8)),
19         q(13)),
20         q(8)),
21     vConcatV(           // voice K: F + H
22         vAutoref(7),
23         vRepeatV(       // phase I: H 12 times
24             vSlice(     // cycle H: cycle F with 1st note sliced
25                 vAutoref(10),
26                 q(1)),
27                 q(12))))

```

Listing 1: A possible decoded genotype for S. Reich's *Clapping Music*

Extrapolacion de estructuras y variantes:

ClappingMusic ([.04,.04,.08],[65],[.5],[50,50,120],1,3,2,8,13,8,1,12) =

4.3 Encoded genotype: an abstract representation of compositional processes

```

1 [1, 0.275535, 1, 0.534808, 1, 0.665631, 1, 0.665631, 1, 0.575462, 1, 0.575462, 1,
  0.606798, 1, 0.27051, 0.51, 0.5, 0, 1, 0.506578, 0.53, 0.53, 0, 1, 0.742646,
  0.55, 0.51346, 0, 1, 0.36068, 0.56, 0.6, 0.56, 0.6, 0.56, 0.9, 0.56, 0, 0, 0,
  1, 0.534808, 1, 0.304952, 0.57, 0, 0, 1, 0.416408, 0.58, 0.55, 0, 0, 0, 1,
  0.534808, 1, 0.304952, 0.57, 0.854102, 0, 1, 0.416408, 0.58, 0.6, 0, 0, 0, 1,
  0.416408, 0.58, 0.75, 0, 0, 1, 0.416408, 0.58, 0.84, 0, 0, 1, 0.416408, 0.58,
  0.75, 0, 0, 1, 0.575462, 1, 0.304952, 0.57, 0.326238, 0, 1, 0.665631, 1,
  0.534808, 1, 0.304952, 0.57, 0.18034, 0, 1, 0.416408, 0.58, 0.55, 0, 0, 1,
  0.416408, 0.58, 0.82, 0, 0, 0, 0]

```

Listing 2: Encoded genotype for S. Reich’s *Clapping Music*

4.4 Encoded phenotype and possible outputs

- Un ejemplo clasico con varias voces y conteniendo armonia, dinamica y articulacion
- Modularidad y posibilidad de manipulacion manual
- Ejemplos basicos de tecnicas habituales en CAC (movimiento browniano,
- Handling of recursive techniques (fibonacci, y extension del modelo a expresiones matematicas complejas)
- Puentes entra la notacion tradicional, la sintesis de sonido y la espacializacion
- Multimedia

5 Evaluation and evolution

Edward Fredkin suggested to me the theory that listening to music might exercise some innate map-making mechanism in the brain. When I mentioned the puzzle of music’s repetitiousness, he compared it to the way rodents explore new places: first they go one way a little, then back to home. They do it again a few times, then go a little farther. They try small digressions, but frequently return to base. Both people and mice explore new territories that way, making mental maps lest they get lost. Music might portray this building process, or even exercise those very parts of the mind.

—Marvin Minsky [24]

[3] para el problema del ?fitness bottleneck? con la eval. humana

[8] -> IMPORTANTE distincion entre Genetic Programming and Gen. Algorithms: ‘An overview of earlier studies in EC for musical composition is offered in [12], determining that Genetic Programming (GP) methods perform better than those that use Genetic Algorithms (GA). This may be unsurprising as GP methods use a tree-based structure whereas GAs are limited to a linear string in their representation. Hence, GP can represent more complex representations and operations | something that would be very useful in representing music.’

[22] -> The evolution of a population offers so much scope and possibility that it is reminiscent of the music creation process a solution is not linearly determined but instead emerges from a uid, incremental process.

[25] - > interesantes perspectivas de la evaluacion, relacionadas con los prejuicios apuntados por Minsky

Citar [7] para -> Ejemplo de sistema basado en programacion textual, para introduccion manual de expresiones complejas -> A menudo son sistemas creados por los propios compositores como medio de extender su estilo

Buscar donde meter el asunto de la hibridacion Otro ejemplo de hibrido -> [9]

El texto de [27] segun Mantaras, usan fitness basado en contorno, intervalica, y otras cuestiones cuantificables

When modeling artistic creativity with algorithms, probably the most evasive issue to address is programming fitness functions. By definition, the assessment of a piece of art can only be made from a subjective point of view, since the goal of art is to provoke inner and personal reactions. These individual responses are very dependent on cultural and social context. However, provided enough data some predictions can be made about the expected rating for a new piece.

In GenoMus, we divide evaluation of each specimen in two categories:

- Autoanalytic profile: objective analysis of a set of musical features, such as variability, rhythmic complexity, tonal stability, global dissonance index, level of inner autoreference, etc.
- Human evaluations: subjective ratings made by human users, attending to aesthetic value, originality, mood and emotional intensity. This informations are stored individually and together as global statistics.

The self-analysis contained in every specimen allows to measure distance and similarity to other specimens, as well as to classify results and to drive evolution processes.

Defining how to evaluate and select results is now the most creative effort, and can be identified with the act of composition itself, since composing music is ultimately making choices.

- Esta propuesta de gramatica posibilita la implementacion y competencia de diferentes sistemas de evaluacion
- Design of evaluation methods as the crucial act of composition
- Objective vs. subjective evaluation
- What to learn?
- Evolutionary paradigm as the most promising

5.1 Evolutionary paradigm

Determining how to evolve and mutate an specimen towards a best version is crucial question too. Starting from a simple motif, endless evolution paths can lead to satisfying results based on heuristic approaches, using accumulated knowledge from examples, human ratings and automatic self-analysis.

The GenoMus grammar is designed to favor the broadest diversity of combinations and transformations. Genetic algorithms are suitable for the automation of an incremental exploration and selection of multiple ways. A GenoMus decoded genotype tree expression can be transformed using these methods:

- createGen
- mutateLeaves
- growTrunk
- growBranch
- insertBranch
- flattenBranch
- pruneBranch
- splitGen

Approaches based on neural networks need a very controlled format of data and big training datasets. The encoded genotype format of GenoMus can represent any piece of music as a simple unidimensional sequence of normalized floats, which can be profitable for techniques as recurrent neural networks (ref. to LMSTD), able to learn patterns from sequential streams of data.

5.2 Scalability

- Como conjugar universalidad de las expresiones con optimizacion para tener los vectores codificados con mayores diferencias entre si.
- Estrategias de caracterizacion de perfiles estilisticos
- El problema del mapeo de funciones y su extensibilidad
- Como establecer una base de datos de conocimiento
- Metricas automatizadas de ciertos resultados

5.3 Integrating traditional and contemporary techniques

5.4 Expanding our musical perception

[36] -> para afirmar que GenoMus reúne diferentes paradigmas en sus árboles multicapa. Estos paradigmas según el artículo son: Analytic, Transformational and Generative

[A genotype como un árbol multiagente, que puede incorporar nodos con funciones de todo tipo: analíticos, recursivos, de constraints, etc. Una vez se tiene un marco de función, todo puede caber en el árbol de procesos.]

Justificar con [19]: -> 2: En los 50 era lógico excluir la parte expresiva. Los modelos Markovianos son de resultados muy pobres. Ahora debe estar incluida? IMPORTANTE: -> referencia a Minsky, que plantea la posibilidad de los multiagentes, que puedan actuar sobre bloques mayores de música, y que sean a veces solo analíticos -> ?the rules don't make the music, it is the music that makes the rules? -> Truly creative! para el final

6 Conclusions and ongoing work

A generation later, we should be experimenting on programs that write better programs to replace themselves. Then at last it will be clear how foolish was our first idea—that never, by their nature, could machines create new things.

—Marvin Minsky [25]

[28] -> concluye que los avances prometedores vendrán de la integración de sistemas diferentes

De la referencia citada al principio [21]: ?Symbolic AI methods still have not enough rules therefore, they hardcoded in limited database knowledge. This could be extended with machine learning techniques but the lack of an automatic evaluation method makes it difficult to solve.?

The artistic results of every algorithm designed for automated composition are strongly constrained by their own representation system of musical data. This paper presents GenoMus, a framework for the exploration of artificial musical creativity based on a generative grammar focused on the abstraction of creative processes as a metalevel of compositional tasks. We define musical genotypes as functional nested expressions, and phenotypes as the pieces created by evaluating these computable expressions. GenoMus' grammar is designed to ease the combination of fundamental procedures behind very different styles, ranging from basic to complex contemporary techniques, particularly those able to produce rich output from very simple recursive algorithms. At the same time, maximal modularity is provided to simplify metaprogramming routines to generate, assess, transform and categorize the selected musical excerpts. The system is conceived to maintain a long term interrelation with different users achieving individual musical styles. This proposed grammar can also be an analytic tool, from the point of view of composition as computation, considering that the best analysis of a piece is the shortest precise description.

Cuestiones interesantes:

- ?Cuántas funciones primitivas son necesarias para generar música en un determinado estilo? Hay innumerables expresiones funcionales diferentes que pueden generar la misma música. Se puede deducir que la expresión funcional más breve es el mejor análisis. Se pueden ver diferentes paradigmas de enseñanza/aprendizaje de la música con estos modelos.
- ?Cómo puede hacerse ingeniería inversa automatizada para extraer estructuras desde la música?

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