Improved Believability in Agent-Based Computer Musical Systems Designed to Study Music Evolution

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Abstract. This paper introduces the main design elements implemented in the agent-based interactive music system CoMA (Autonomous Musical Communities), aimed at the study of music evolution in virtual environments. Among these, a 2D representation of the virtual agents' geographical position, the decision-making and life cycle models provide a better user experience and result is in an enhanced sense of system's believability in respect to the interaction between the real and artificial worlds.

Keywords: music evolution, interactivity, computer simulation, believability

1. Introduction: a shift of paradigms

Among the many transformations occurred in the twentieth century, the emergence of computing, artificial intelligence, techniques for imaging the brain and, at the same time, the declining popularity of Behavioural Psychology, among other factors, led to the so-called "cognitive revolution" [1]. Increasingly, a growing interest in the study of memory, attention, pattern recognition, concept formation, categorization, reasoning and language occupied the space that previously belonged to Behavioural Psychology [1]. In this context, the Cognitive Sciences emerged as an interdisciplinary area of research gathering Philosophy, Experimental Psychology, Neuroscience and Computing in order to study the nature and structure of cognitive processes.

Accompanying these changes, Musicology, especially in recent decades, adopted a perspective in which music is not only seen as a work of art but, in particular, as a process that results from the (inter)actions of various agents - musicians, listeners, etc. - [2]. As the "academic study of any and all musical phenomena", Musicology "incorporates a blend of sciences and humanities, and is grounded in musical practice (performance, composition, improvisation, analysis, criticism, consumption, etc.)" [3]

Consequently, it is not surprising that Cognitive Musicology assembled in recent decades a growing number of enthusiasts interested in studying the musical thought, or in other words, the musical "habits of the mind" [1]. Being a branch of the Cognitive Sciences, Cognitive Musicology has its same interdisciplinary character, bringing together theories and methods developed by Philosophy (e.g., theories of knowledge), Psychology (e.g., experimentation), Neuroscience (e.g., brain imaging) and Computer Science (e.g., simulation).

Computer modelling plays a particularly important role in this area by providing a formal representation of musical knowledge and experimental verification of different theories of human cognitive processes. Obviously, the closer the model is to these processes, the closer it will be to accomplishing that purpose. It is known, however, that these models have yet not fully achieved the objective of evaluating and falsifying the theories they represent [2].

Inspired by these initial considerations, in this paper we introduce our research and, in special, the improvements recently implemented in the interactive computer musical system CoMA, designed to study music evolution in virtual environments. These improvements refer not only to the user interface (a 2D representation of the geographical space in the virtual world where the agents can move) but also a more detailed model of the agents' cognitive abilities (decision making and life cycle models). The result is in an enhanced sense of system's believability in respect to the interaction between the real and artificial worlds.

2. The research

Cognitive Musicology's multitude of subjects and interests is particularly influential in our research, which mainly addresses how musical styles would emerge and evolve in artificial worlds. Strictly speaking, the questions we face are much broader, and consist of understanding the processes that, after centuries of evolution led music to its current state of development. Computational modelling and simulation are especially useful because they allow the isolation of specific issues and to establish parallels between what happens in the real and synthetic worlds. Of particular interest, simulations allow the study of complex phenomena such as adaptive dynamic systems and the occurrence of emergence, generating data that can be inductively analysed afterwards.

2.1. Social simulations

At the centre stage of our research is the idea of artificial agents. The agent paradigm is particularly interesting because it allows the implementation of "units of operation" around which a myriad of questions can be raised. Agents, for instance, have perceptive and cognitive abilities, are able to communicate, to evaluate their inner states and the environment, to make decisions and to take actions in order to achieve specific goals. Most notably, agent-based systems can simulate social interactions.

The ideas behind virtual agents are not recent, though. Back in 1967, for instance, Simon [4] compared the central nervous system to a serial information processor "that must serve an organism endowed with multiple needs, and living in an environment that presents unpredictable treats and opportunities". According to him, these requirements would be achieved through mechanisms of goal management that would be serially processed and allow the re-prioritization of urgent needs in real time. In 1994, The Birmingham Cognition and Affect Project, was introduced by a group of researchers [5], based on these (among other) ideas, and focusing on the requirements for the design of agent-based systems that deal with goals, desires, preferences, intentions, and other types of drivers, including emotions.

Virtual agents are particularly useful to model social simulations. Multiple agents-based systems are considered complex systems, as their overall behaviour cannot be predicted in advance by the description of the properties and/or relations between its parts. It is said that the behaviour of the system results (emerge) from the local behaviour of the agents. These systems are characterized by reproducing extremely dynamic scenarios.

The simulation of human societies involves extremely complex interdisciplinary issues (e.g., motor control, perception of the world and high-level behaviour, such as decision making, motivation and social behaviour). Designing these simulations require the definition of the conditions in which virtual agents can interact, cooperate, and perceive the world [6]. In society, people act (e.g., cooperate, make friends, negotiate) according to their preferences, moods, goals, emotions, fears, etc. and, in order to be convincing or believable, computer systems that deal with social simulations must replicate these characteristics.

In simulations applied to the Social Sciences, the research paradigm predominantly used is based on the principle of the rational choice [7]. Normally used in game theory, this principle allows conclusions based on mechanisms of deduction. It happens that simulations, besides the rational choice principle, can also reproduce adaptive behaviour in the individual level (learning), as well as in the level of a population (differential survival and reproduction of fittest individuals) [7].

As the emergence and evolution of music styles can be considered a social phenomenon, the adoption of the agent paradigm is a natural corollary. A number of important musical interactive systems use the paradigm of artificial agents [8]. Only a few, however, are designed to explore social interactions [9-11] and the evolution of music styles.

2.2. The evolution of music styles

According to Miranda [12], evolution "occurs when a transformation process creates variants of some type of information. Normally there is a mechanism which favours the best transformations and discards those that are considered inferior, according to certain criteria". To illustrate this process, Miranda [12] describes a musical game where a group of virtual agents engage in a drumming session where it is initially agreed that agents would play in any way they wish. At first, a highly disorganised mass of rhythms is produced but, after a number of interactions and the occurrence of spontaneous imitation, some patterns start to become conventional.

In Biology, evolution can be defined as the changes that occur in living organisms after a number of generations and result from the mechanisms of genetic transmission, variation and natural selection (fitness for survival). In regard to cultural evolution, by analogy, Dawkins [13] introduced the idea of memetic transmission: memes would be units of cultural information in the same way that genes are units of biological information. Jan [14] defines musical memes as small (indivisible), discrete and self-contained structures that would survive a large number of generations so as to represent units of culture transmission. According to the memetic theory, memes would propagate by leaping from brain to brain and be subject to the mechanisms of variation and natural selection.

Although our research doesn't fully embrace the memetic theory, we adopt the idea of a musical meme, as it is concise and connected with the definition of music style. According to a well known definition proposed by Meyer, musical style is "a replication of patterning, whether in human behaviour or in the artefacts produced by human behaviour, that results from a series of choices made within some set of constraints" [15]. As musical patterns (memes) become part of one's vocabulary, they define a particular musical style.

Miranda [12] claims that "variations in musical styles, for example, result from the emergence of new rules and/or from the shifting of existing conventions for music making (...). Musical styles maintain their organisation within a cultural framework and yet they are highly dynamic; they are constantly evolving and adapting to new cultural situations."

People generally identify specific styles as a manifestation of one's personality or identity. American pianist Bill Evans once declared that he never strived for identity: "That's something that just has happened automatically as a result, I think, of just putting things together, tearing things apart and putting it together my own way, and somehow I guess the individual comes through eventually" [16]. The effect of "putting things together" and "tearing things apart" is that music styles evolve as a consequence of the events involved in the development of the musicality of individuals. In science ontogenesis refers to the development of (anatomical or behavioural characteristics of) an organism since the early stages until maturity. We call the series of events that influence the development of the agents' musical behaviour musical ontogenesis.

In our research, the musical style of a particular agent is defined as a complex object (memory) that stores the set of musical memes (defined by parameters such as information related to pitch, rhythm, etc., and the relationships between them) and corresponds to the musical knowledge that an agent accumulated during its lifetime, according to its musical ontogenesis.

3. Previous and current experiments

The ideas mentioned in the preceding sections have already been tested in two agent-based interactive computer musical systems we implemented in our previous research. The first one, the Rhythmic Meme Generator (RGeme) sought to demonstrate the possibility of transmission of rhythmic structures (memes) in a virtual environment where agents practiced musical tasks (e.g., listening to, performing, and composing music) [17]. The second system (iMe - Interactive Musical Environments), also based on multiple agents, dealt with polyphonic music and a broader set of characteristics of the music flow (e. g., pitch, loudness, rhythm, etc.). In both systems, agents evolved their musical styles from the pieces with which they interacted. After each interaction the new adapted memory was compared with the previous one in order to evaluate how the agents' music styles evolved. A thorough description of the models implemented in this system can be found in [18].

The model implemented in the above-mentioned systems presupposes that the user plans in advance the entire sequence of activities that agents will perform during the simulations in a kind of "ontogenetic map". This allows the design of simulations with specific musicological interests. The effect of this approach, however, is that agents have no freedom to choose the tasks they will perform or at what time these tasks will be performed.

In order to improve the believability of the model, in our current research we implemented a third system (CoMA - Comunidades Musicais Autônomas or Autonomous Musical Communities) which, in addition to improving specific algorithms, implements two additional principles: independence of execution and autonomy of the agents. Independence of execution means that the system can be run without the need of any user intervention. Once a new document (simulation) is created and a minimal musical material is given to the agents, a simulation can be started simply by clicking on the start button. **Fig. 1** shows CoMA's main window:

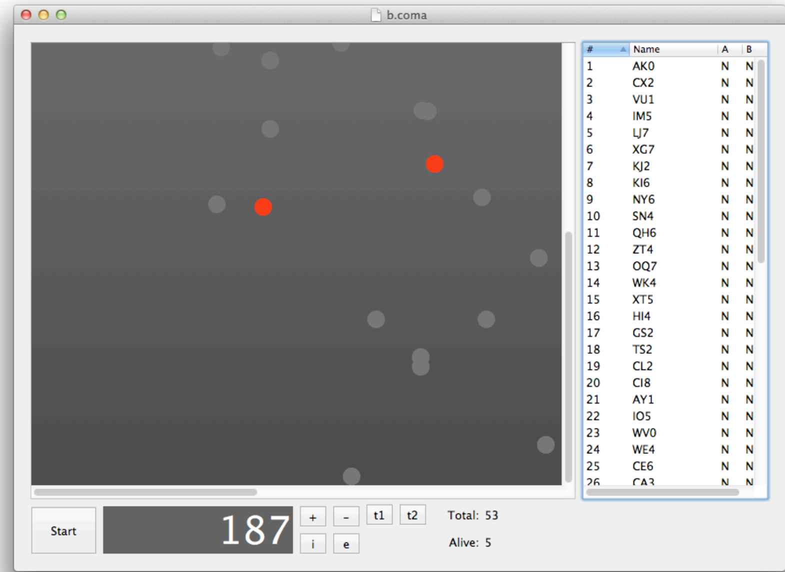

Fig. 1: CoMA's user interface

If desired, the user can interfere in real time by changing some of the parameters of the simulation. This can be sometimes interesting but not necessary. Autonomy, on the other hand, refers to the fact that the agents have the ability to make motivated decisions. A noticeable improvement shown in **Fig. 1** is the 2D space, which represents the geographical position of each one of the agents. This information is used in specific tasks, such as reproduction and choosing music for interaction, as described below.

3.1. Decision-making model

Motivations are values, needs, aspirations, etc., that are constantly changing, guide human behaviour, affect the execution of our goals and directly influence learning. Motivational control states (e. g. psychological states) would be in the system's jargon, the variables that allow the agents to make motivated decisions, guiding their actions. In the system CoMA, these control states as well as the algorithms that govern their operation are globally called the "decision making model" (DMM). This is one of CoMA's five global models, in addition to the perceptive, cognitive, generative and life-cycle models (see **Fig. 2**). In order to explore the emergence and evolution of musical styles in (believable) virtual autonomous communities, the DMM obviously must have characteristics that favour the occurrence of these phenomena.

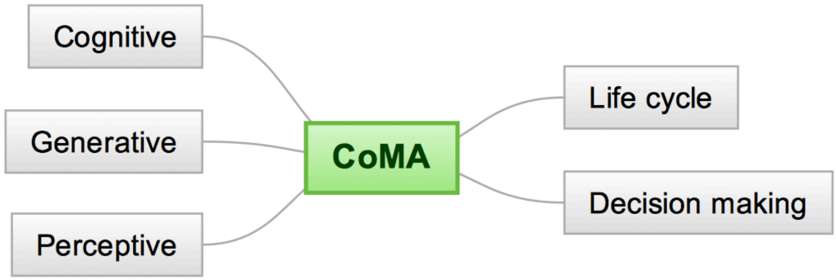

Fig. 2: Models in CoMA

Fig. 3 graphically represents the idea of the scale of values of control states. The concept of "trust", for example, would have (hypothetically) two extremes (fear / trust) where the number 0 represents the maximum amount of fear (or minimum confidence) and the value 1 represents the maximum of trust (or minimum of fear).

Fig. 3: Spectrum of confidence

The main control variables in the system CoMA are energy (sets the overall energy level of the agent to perform tasks), self-esteem (sets the trust agent has in its skills and values), libido (sexual energy level of the agent for reproduction) and popularity (condition of an agent to be admired by other agents in the community)

Inspired by human behaviour, different architectures of agent-based systems model decision-making motivations in different ways [19-22]. One of them, the BDI (Belief, Desire, Intention), for example, was initially proposed by Bratman [21] in order to explain action planning. In this context, agent's actions depend on the relations established between a system of individual beliefs, desires and intentions (actions for which we have a plan) to achieve a goal.

Another model, proposed by Balkenius [20], consists of a central system responsible for activating and inhibiting agents' behaviours. A centralized decision determines the motivational state, which, in turn, determines the behaviour. This model adopts three categories of factors to determine motivations: internal (perception of a desired object) and external (perceptive or cognitive processes triggered by external events) incentives and internal drives (agent's homeostatic state). The selection of a motivation is made by a competition mechanism in which motivational states inhibit each other in proportion to their current level of activation.

Allen [19] proposes some motivational characteristics that an agent with human characteristics must possess: basic mechanisms, as processes that manage the "pre-attention" (automatic response to activation conditions of the environment) and attention (manages resources for general purpose, e. g., primary concerns), attention filters (protect the attention processes that have limited resources from excessive interruptions by reactive motivators) and goal management processes (agent's adaption through monitoring and control of management mechanisms of reaction/attention").

In another system called GOMASE (Goal Orientated Multi-Agent Simulation Environment), Baillie and Lukose [22] investigate how to organize the goals of an agent to simulate the behaviour of a human worker in a system that model initiatives. In this system agents receive a hierarchy of goals (related to general life goals, i.e., self-preservation and preservation of the species), a digraph of activities and a motivational mechanism. In view of multiple possibilities of action, it is necessary to establish priorities between goals. What makes us prioritize goals are impulses or desires (e.g., emergency biological, cognitive and social). Each goal is located in a hierarchy by a fairly complex mechanism, which combine these motivational desires [22]. This mechanism also includes motivational states such as emotions.

Emotions could also be considered a category of motivational control states. Emotions are a complex set of patterns of chemical neural responses that occur in certain situations whereby the body is prepared to react. They are "mental states accompanied by intense feelings and involving bodily changes of a widespread character" [Koestler, 1967 apud 23]. Emotions play an important role in human cognition (including learning, perception, decision making, etc.).

There are scientific demonstrations that emotions may underlie cognitive functions. Damasio, for example, observes that there would be important neurological evidences that demonstrate that "the processes of Emotion and Feeling are part of the neural machinery for biological regulation, whose core is formed by homeostatic controls, drives and instincts" [Damasio, 1994, 2000 and 2003 apud 24]. The amygdala, a specific region in the brain, contributes to the mechanisms of emotion to the extent that its performance is critical for fear conditioning, a form of implicit memory [25].

Studies of emotions involve evaluation reports, imaging studies of the brain and other physiological measures (e.g., heart rate, skin conductance, respiration rate, blood pressure, blood volume and muscular tension). In some of these studies were established relations between specific musical features and emotional responses. Trying to relate emotions to musical structures, Sloboda, for example, analysed the responses of 83 music listeners on the occurrence of a number of physical reactions when listening to music. These studies demonstrated, for example, that spine chills, laughter, tears and "lump in throat" were reported by most respondents. The musical passages associated with these emotions indicated that “tears were most reliably evoked by passages containing sequences and appoggiaturas, while shivers were most reliably evoked by passages containing new or unexpected harmonies" [26].

Huron [28] has extensively studied the effects of music on emotions and proposed a psychological theory of musical expectation. According to it, emotions evoked by expectation involve five functionally distinct response systems: reaction responses (which cause defensive reflexes); tension responses (where uncertainty leads to stress); prediction responses (which reward correct predictions); imagination responses (which facilitate deferred gratification) and evaluation responses (which occur after the processing of conscious thought.)

In CoMA, among other aspects, the DMM controls the agents emotions and personality and the fact that they are subject to social pressure. The evolution of the agents musical style and, ultimately, of the environments’ musical style, could be influenced by these pressures through a system of rewards (and punishments) in view of the choices agents make during their careers. In this regard, for instance, agents are rated according to their popularity (number of times they are chosen for interaction). An agent who chooses more popular songs has more "social acceptance" than others who choose less popular songs. These choices influence the degree of satisfaction that an agent has about his career.

Under the DMM, the main goals of the agents are "self-preservation", "preservation of the species" (called generic goals), and having a "successful music career" (specific goal). The search for self-preservation takes place through actions with which agents seek to optimize their "welfare". The preservation of the species, controlled by the life cycle model, occurs to the extent that agents seek to reproduce. At last, a successful career in music is pursued from the perspective of an agent’s "career plan".

During a simulation, in a given cycle, agents have the ability to (i) perform a reproductive action (generating a new agent), (ii) perform a musical task (remembering, reading, listening to, performing, composing, solo/collective improvising with agent/human), or (iii) to perform no action. Moreover, as discussed below, each of these actions have related actions (sub-tasks or sub-actions), among which are (i) which partner to choose for reproduction, (ii) which musical task (remembering, reading, listening, performing, composing, solo improvising, agent improvise, and improvise with human) to choose in a given cycle and (iii) what music piece to choose for interaction in reading, listening and performing tasks.

Where there is more than just one possible action (or sub-actions or sub-tasks), agents must decide what to do. Some general rules were established to determine this choice. First, an agent can only perform one action at each cycle. Second, reproductive actions take precedence over musical tasks. Finally, while not fulfilling the requirements for performing a reproductive or musical tasks, the agent performs no action in the cycle.

3.2. Life-cycle model

Another important improvement designed to improve the general believability of the system, the "life-cycle model" controls the agents' life span as well as reproduction. Starting from an initial (configurable) value, an agent's life span increases or decreases depending on the behaviour of its psychological states during the simulation. The system implements sexual reproduction by isogamy in order to maintain the number of individuals at a constant level and guarantee genetic inheritance.

Reproduction is performed in three steps: (i) decision and population check, (ii) courtship, and (iii) reproduction. In “decision and population check”, for instance, if agent ‘A’ is “sexually active” (i.e., libido > threshold) it could “decide” to reproduce. If population allows (agents in the environment < threshold), A proceeds to courtship. If not, A skips cycle and libido decreases. In "courtship", A looks (within radius range in the 2D space) for other “sexually active” agents and could, by hypothesis, find agent ‘B’. A invites B for reproduction (B’s libido and self-esteem increase). If B refuses the invitation, A’s libido and self-esteem decrease. Finally, in "reproduction", If B accepts, A’s libido and self-esteem increase. Agents generate offspring (agent ‘C’) with shared genetic information (e.g., size of LTM, size of STM, character) from both parents. After reproduction A’s and B’s libido decreases. C’s libido is set to 0.

Roughly speaking, simulations are performed in discrete cycles in which each agent perceives the environment, updating its vision of the world and their internal states. They then check the rules applicable in each case and make decisions about the actions to be taken. These actions are then executed by changing their internal states and the environment.

To start a simulation, the user must provide some files with music data (MIDI) with which the agents will initially interact. Clicking on the start button (see **Fig. 1**), the system generates an initial number of agents who then start to perform their actions. Once the initial learning phase is finished, the agents begin to perform the tasks in accordance with the career plan defined at this time. When performing each one of the musical tasks agents have their memories adapted to the knowledge contained in the musical pieces with which they interacted. After each interaction, the system keeps a copy of the agents’ memory that, as seen above, represents their musical worldview, i.e., their music style. At the end of the simulation it is possible to run CoMA's analysis tools and compare the successive memories, hence assessing the evolution of the agent's musical styles.

4. Conclusion

From the application of the principles described above, we conduct a series of experiments in which we observed the emergence of different behaviours, in view of the decisions taken by the agents, suggesting the occurrence of different dynamics of social interaction.

Some of CoMA's control variables (e. g., self-esteem and popularity) functioned as a system of checks and balances that (apparently) guided these dynamics. We believe that the dynamics of social interaction caused by the decision making model have the potential to directly influence the development of the agent's musical styles. Such a condition, however, requires the completion of further analysis that is being scheduled at this time. We can say, however, that the life cycle model implemented in the system, which involves the reproduction and death of agents was able to conveniently keep the number of agents at a stable level throughout simulations.

In brief, we believe that the models implemented in the system CoMA described above (autonomy, independence, etc.) had a positive impact on the system's believability specially in respect to the interaction between the real and artificial worlds.

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