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Original article

Designing a multi-agent system for composition

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The main purpose of this paper is to design a collaborative multi-agent system for providing an XML output which is used in composition. Explaining the performance of rhythm and melody agents is the main part of the paper structure. In this research, systems analysis and design has been adopted as the methodology; and computational calculations have been used. An XML output that is a printable music note can be used by famous music software packages like Sibelius and Final. The novel method introduced in this paper is new and can help musicians make new music with better quality and more diverse content anywhere anytime.

1. Introduction

As Human Computer Interaction (HCI) studies show, we can investigate the information behavior of musicians on the Web. They not only search the W3 for entertainment, but also look for information to develop professional skills. Composition is one of the main skills that any music specialist should know a lot about.

Nowadays, there are huge amounts of music information on the World Wide Web including notes and tablatures that could be used in formal and informal performances. In addition to the existed notes, there should be an opportunity for musicians to produce notes with more variations. Mathematics facilitates this process; and calculations introduced in this paper could also be used in mathematical composition of the next music era.

Generally a piece of music consists of notes that are arranged beside each other, and the intervals between notes performed. To make the music more attractive, we often use several instruments and even more than one melody in a piece. But finally notes and intervals are essential components of any musical piece. Intervals are tensions of each note that could be a whole, half, quarter, eight or sixteenth note. In the field of computer applications in music, there are two areas of activity, including:

1. Analyzing and extracting information from wav and mp3 music files through signal processing and pattern recognition. The input of these systems is mostly a music audio file (De Mantaras & Arcos, 2002) which is out of the scope of this article.
2. Creating and making music using computers and the rules of music theory. This is the focal point of the present article.

The proposed multi-agent system as a collaborative environment uses an XML standard protocol and lets agents communicate to each other. The main advantage of such a system is that the result of collaboration could be provided to musicians as a printout in Final and Sibelius. Unlike previous experiments reported in (Delgado, Fajardo, & Molina-Solana, 2009), there is no competition among agents to build music. It could be said that there were multiple composition agents in earlier systems competing with each other to manipulate user's input. Those agents had similar rules, but were different in composition style; and hence, could independently generate melody and rhythm (Delgado, Fajardo, & Molina-Solana, 2009). But agents introduced in this paper have tasks for melody making and composing them with each other to create a given note (Center, 2001). Each one of these agents has been experted in a specific field of music, and according to the input received from the environment, produces an appropriate output. Agents can also receive feedback from the environment and develop their working style. The music theory was adopted in the proposed model; and random algorithms were used in melody making. These algorithms are very popular and could be used as agents' default in composition. At the rest of article, we do a review on the literature; propose a model for the first agent that creates rhythm for melody; and then describe tasks of the second agent.

2. Related works

There are few related works in which composition has been discussed from an engineering viewpoint. In this section, each project is introduced; and then, necessity of the current research is justified.

van Kranenburg (2006) described an experiment in which statistical pattern recognition algorithms were used to characterize a particular musical style with respect to other styles. He took a theory of musical style and proposed a description as an aid to authorship activity in music; i.e. composition. van Kranenburg looks at the style as the replication of patterning, whether in human behavior or in the artifacts produced by human behavior that results from a series of choices made within some set of constraints; and concludes that without repeating patterns, there would be no style at all. To do the research, he designed a data set, identified twenty features, and shaped a 20-dimensional space. The data set was a three-class one incorporating compositions of Johann Sebastian Bach; his eldest son, Wilhelm Friedemann Bach; and his most important student, Johann Ludwig Krebs. Each composition from the data set was segmented, and the clustering was made. Findings showed a degree of similarity between composition style of J. S. Bach and his followers.

Pikrakis and Theodoridis (2007) applied Empirical Mode Decomposition (EMD) for inducting notated tempo from music recordings. There was a data set comprised of 400 recordings from various genres, including western pop/rock and Greek traditional music. They segmented recordings and through clustering exhibited similar rhythmic characteristics in the framework of a matrix. Works manipulated in this research, had fractional music meters of $\frac{2}{4}$, $\frac{3}{4}$, and $\frac{4}{4}$.

Previous studies considered composition style as a sign of similarity. In both research projects, recordings were segmented and some clusters were created to classify songs based on the similarity of their audio signals. This means that attentions were focused on analyzing the result of intellectual activities of composers; and no attempt has yet been done to help them compose easier and faster. Considering this fact and through computational calculations, the present research tries to fill this gap.

3. Rhythm agent tasks

In order to explain tasks of the rhythm maker and to save the beats of notes in an XML file, we should firstly explain the mathematical model of beats. According to the Fig. 1, there are six types of beats in music theory that are different in stretch duration and performance.

	Code	Time Duration	Note
Whole	1	1	𝅝
Half	2	1/2	𝅗𝅥
Quarter	4	1/4	𝅘𝅥
Eighth	8	1/8	𝅘𝅥𝅮
Sixteenth	16	1/16	𝅘𝅥𝅯
32th	32	1/32	𝅘𝅥𝅰

Fig. 1. Six types of beats in music theory.

The duration of each note is twice of the upper note (Fig. 2).

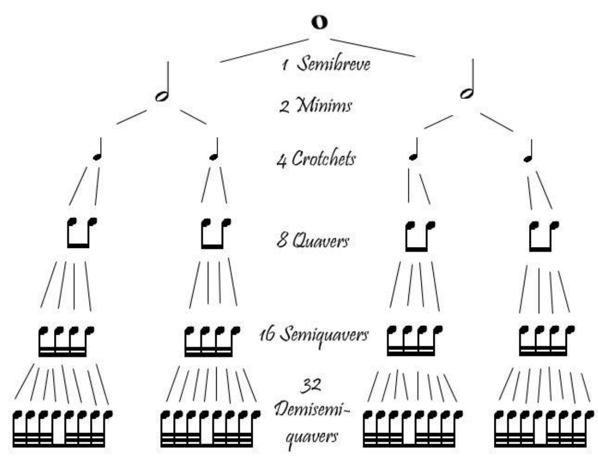

Fig. 2. Duration of each music note.

To create rhythm in music, there are different rules; and in contrast, rhythms have many variations. For determining and displaying the rhythm of a music piece, a semi-fraction is used. Of course, it is not a real fraction. The numerator represents the beat code; and the denominator represents the number of beats in each bar. For example, $\frac{2}{4}$ rhythm indicates that there are 2 beats by code 4 or two quarter notes. We suppose such a number as a fraction, to explain tasks of the rhythm agent. Coding $\frac{2}{4}$ in XML for Final and Sibelius (Center, 2001) will be as follows:

```
<attributes>
<divisions>2</divisions>
<key>
<fifths>0</fifths>
```

```
<mode>major</mode>
</key>
<time>
<beats> 2 </beats>
<beat-type> 4 </beat-type>
</time>
<clef>
<sign>G</sign>
<line>2</line>
</clef>
</attributes>
```

As the above XML document shows, the rhythm agent should consider type and number of a given beat in any bar. This means that 2 beats with code 4 should be available. When the rhythm agent receives these two numbers from user, its task is to create different combinations of the fraction. We can break the first quarter note and replace it with two eight notes. It sounds like the following two formulae:

$$\frac{2}{4} = \frac{1}{4} + \frac{1}{4}$$
$$\frac{2}{4} = 2\left(\frac{1}{8}\right) + \frac{1}{4}$$

According to the Formula (1), the sentence that is created by the rhythm agent is as same as Fig. 3.

Figure 3. The rhythm $\frac{2}{4}$

By the Formula (2), the rhythm agent can prefer two eight notes to one quarter note; and hence, the sentence will be as same as Fig. 4.

Figure 4. The rhythm $\frac{2}{4}$

In general, the rhythm agent can manage different mixes of the $\frac{2}{4}$ fraction. The relationship between each bar and the notes created by the rhythm agent is as follows:

$$\frac{2}{4} = \mathrm{a}\left(\frac{1}{1}\right) + \mathrm{b}\left(\frac{1}{2}\right) + \mathrm{c}\left(\frac{1}{4}\right) + \mathrm{d}\left(\frac{1}{8}\right) + \mathrm{e}\left(\frac{1}{16}\right) + \mathrm{f}\left(\frac{1}{32}\right)$$

As the formula (3) shows, the rhythm agent's task is to make different combinations of the earlier rhythm, as much as the user determined in the system input. On the one hand, the rhythm agent can do this by using different algorithms among which the randomized algorithm is the easiest. On the other hand, implementing any sentence requires adding XML tree to the note file. For example XML code of the Fig. 3 is as follows:

```
<note default-x=84>
<pitch>
<step>G</step>
<octave>4</octave>
```

```
</pitch>
<type>quarter</type>
<stem default-y=5.5>up</stem>
</note>
<note default-x=178>
<pitch>
<step>G</step>
<octave>4</octave>
</pitch>
<type>quarter</type>
<stem default-y=5.5>up</stem>
</note>
```

And the same for the Formula (3) is as follows:

```
<note default-x=84>
<pitch>
<step>G</step>
<octave>4</octave>
</pitch>
<type>eighth</type>
<stem default-y=5>up</stem>
<beam number=1>begin</beam>
</note>
<note default-x=140>
<pitch>
<step>G</step>
<octave>4</octave>
</pitch>
<type>eighth</type>
<stem default-y=5>up</stem>
<beam number=1>end</beam>
</note>
<note default-x=196>
<pitch>
<step>G</step>
<octave>4</octave>
</pitch>
<type>quarter</type>
<stem default-y=5.5>up</stem>
<beam number=1>end</beam>
</note>
```

As can be seen, we used the quarter and the eighth written in type tag for quarter and eight notes respectively. Through such a step by step process an output in the XML format can be easily shown.

4. Melody agent tasks

As stated, by using both the rhythm and the melody, we can create a simple piece of music. The rhythm provides an appropriate context for the melody; and conversely, it prepares the melody on the rhythm output (Fig. 5).

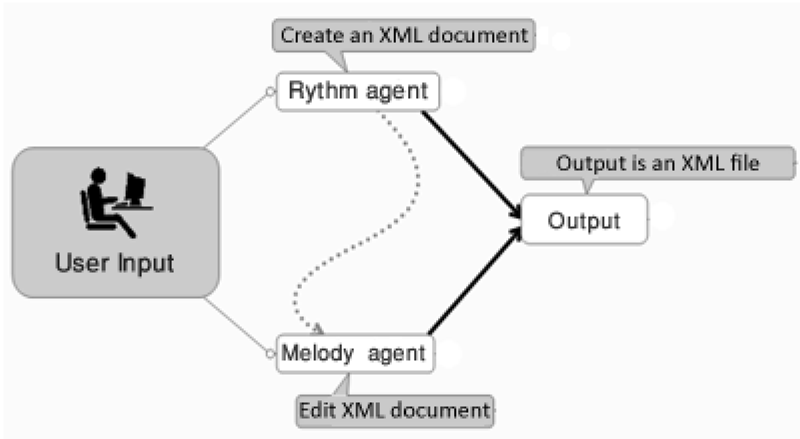

Fig. 5. Tasks of rhythm and melody agents.

Some of the user's inputs are dedicated to the melody agent. An important input is the mode which is in fact the musical scale. The musical scale specifies notes that the melody agent can produce in its output. (This parameter has been defined as pitch in the XML tree.) Another task of the melody agent is to set arrangement signs of a melody. The melody created by this agent can be performed by different algorithms. Two algorithms are enumerated in this article:

1. Randomized Algorithms; and
2. Fractal algorithms.

Randomized algorithms: Such algorithms are among the simplest composition algorithms. Notes randomly selected in the framework at the user specified scale. Of course, this algorithm can choose the notes from outside of the popular music scales (Bulmer, 2000).

Fractal algorithms: We can produce music and sound by fractals in different ways, or even get new ideas for an art work. The secret mystery in fractal music is named mapping (map) in mathematics. We can also expect more various songs from a single formula, because a couple of parameters in fractal music are more than a fractal image. For example, the melody agent can use Morse-Thue algorithm to produce a melody. To work the algorithm, numbers in an arithmetic sequence (0, 1, 2, ...) are considered. These numbers have a very simple structure in mathematics, but they have many interesting properties such as self-similarity. In this range of non-negative numbers, they are started from zero, and then, one is added to each number; a type of usual counting. To find the self-similarity relation, we put binary equivalent of each number:

0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, …

0000, 0001, 0010, 0011, 0100, 0101, 0110, 0111, 1000, 1001, 1010, 1011, …

Then, we calculate the sum of that binary unit for each number:

0+0+0+0, 0+0+0+1, 0+0+1+0, 0+0+1+1, 0+1+0+0, 0+1+0+1, 0+1+1+0, 0+1+1+1, 1+0+0+0, 1+0+0+1, 1+0+1+0, 1+0+1+1, …

Thus

0, 1, 1, 2, 1, 2, 2, 3, 1, 2, 2, 3, …

To convert these numbers into music, mapping is done. We can map numbers into a musical scale; for example "do" or C scale. The note C will be mapped into zero and the note D to 1, E to 2, F to 3, G to 4, and so on. As a result we will have:

C, D, D, E, D, E, E, F, D, E, E, F, …

Because in do major scale, notes are: do - re - mi - fa - Sol - La - Si. The Morse-Thue algorithm creates a sequence of notes by this scale; and the sequence makes up finally the fractal melody. For example, if the melody agent uses the algorithm Morse-Thue and gets the rhythm of Fig. 4 from the rhythm agent, it will provide the note in Fig. 6 as the output:

Fig. 6. The rhythm $\frac{2}{4}$.

The XML output of the rhythm agent will be changed by the melody agent as follows:

```
<note default-x=84>
<pitch>
<step>C</step>
<octave>4</octave>
</pitch>
<type>eighth</type>
<stem default-y=5>up</stem>
<beam number=1>begin</beam>
</note>
<note default-x=140>
<pitch>
<step>D</step>
<octave>4</octave>
</pitch>
<type>eighth</type>
<stem default-y=5>up</stem>
<beam number=1>end</beam>
</note>
<note default-x=196>
<pitch>
<step>D</step>
<octave>4</octave>
</pitch>
<type>quarter</type>
<stem default-y=5.5>up</stem>
</note>
```

The melody agent has different algorithms for composition; and users would be able to determine it in the system input (Fig. 5).

5. Conclusion and future work

Analyses of musical data are divided into two parts:

1. Analysis of the composed works: We discussed analysis of the composed works and extracting music information in (Borna & Tejareh, 2013). To follow the research agenda, we can use agents introduced in this paper, to extract fuzzy information of a given agent. For example, the rhythm agent produces notes, extracts rhythm, and defines the time interval between notes, instead of focusing on rhythm production and pattern of notes arrangement. The supposed rhythm agent does the process through an audio file. Accordingly, the melody agent has a similar behavior.
2. Analysis resulted in composition: Whether it is a music file conveying an audio performance or a music note capable of performing in given software, analysis can be resulted in composition.

In summary, we can use computers to create various music tracks and get their notes as an XML document from the system output. Diversity in composition is one of the applications of this system; which in turn, helps composers keep away from repetition and reinforce by new patterns. What considered in this article is just an example of the applications of mathematical rules in music. There are still more opportunities for musicians in mathematics. Set theory, mathematical logic, number systems, combinatorics, and the probability theory are among the susceptible areas of mathematics that could be injected in music and get more complicated and more delighted tracks. Processing of preexisted data is another application of the current system. This means that written notes could be manipulated by variation and different outputs could be prepared. Finally, a web-based version of the proposed application would help musicians compose online. This version should also be computable with cell phone operating systems like Android and IOS. Developing a mobile gadget of this system will be a sign at its maturity, if we consider inter-personal communications anywhere, anytime.

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