Polyphonic Accompaniment Using Genetic Algorithm with Music Theory

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***Abstract*—Computational creativity using artificial intelligence and computational intelligence has received increasing attention. Automatic music composition is a blooming field in computational creativity; especially, automatic accompaniment has gained some promising results. However, most of the automatic accompaniment systems based on evolutionary computation require human feedback as evaluation criterion, which is vulnerable to the fatigue and decreased sensitivity after long-time listening. This study adopts music theory as the basis of evaluation criterion for accompaniment to address this issue. Specifically, we develop a genetic algorithm (GA) to generate polyphonic accompaniment, in which the fitness function consists of several evaluation rules based on music theory. Three accompaniments, i.e., main, bass, and chord accompaniments are considered in the study. Experimental results show that, given a dominant melody, the proposed method can effectively generate multiple scores to form polyphonic accompaniment.**

I. Introduction

With the advance of computer technology, the idea of using artificial intelligence and computational intelligence in creativity emerges. Computational creativity in music, visual art, literature, architecture, and industrial design has received encouraging results and becomes a blooming research area. Automatic music composition attracts particular attention in that music plays an important role in human life and entertainment. Evolutionary computation is widely used in computational composition in view of its recognized capability in global search and optimization. McIntyre [1] first used genetic algorithm (GA) to generate four-part Baroque harmony. Laine and Kuuskankare [2] introduced functions in music generation and adopted GA to find the music functions and estimate their parameters. The music functions help to express music in a logical way and make it easy to generalize. Pazos et al. [3] established a model for creating rhythmic patterns based on GA interacting with musicians. To export some rules of composition, Marques et al. [4] weighted the rules as a basis for distinguishing good and bad music. Further, Towsey et al. [5] analyzed the features of good songs, divided them into five categories, and utilized these features to evolve music using GA. Schoenberger [6] utilized Western tonal theory to analyze works of many famous composers such as Bach. In addition, Khalifa et al. [7] proposed composing a song with four motifs and evaluated them according to some grammar rules. Chen et al. [8], [9] presented the CFE framework given that feedback is a key element in music composition.

In addition to the dominant melody, accompaniment plays an important role in music. Good accompaniment can strengthen harmony, tighten the structure of tunes, and reinforce the expression of music. Some studies have been presented for automatic accompaniment. Luo et al. [10] presented a real-time accompaniment system for the sung voice. By detecting the pitches of the sung voice, the system can create a proper score from the mixture of sung voice and accompaniment. The result shows the system is robust against noise and makes a good accompaniment for the sung voice. Chen et al. [11] proposed a music accompaniment system that can catch the tempo of the music. They designed a tempo-based accompaniment through analyzing the tempo and an interactive system. Jo et al. [12] developed a chord-based music composition system, incorporated with an auto-accompaniment program to compose music for non-musicians. In addition, Simon et al. [13] established the system MySong, which trains a Hidden Markov Model using a music database and then adopts the model to automatically choose chords for a vocal melody. Using this system, a user who has no experience in music can create a song by singing into a microphone, and can experiment with different styles and chord patterns without music knowledge.

As above stated, GA is widely used in the music composition and accompaniment systems. However, evaluation of the composed music is a key issue at GA-based systems. Although human feedback is of great use for evaluation, the required interaction between human and composition system (machine) is very exhaustive and impractical. In addition, good accompaniment should consider several factors, such as bass line, harmony, and moderate contrast to the tunes. These factors substantially increase the difficulty of computer accompaniment.

This study proposes a polyphonic accompaniment using GA with music theory. Specifically, we utilize music theory in the fitness function to evaluate the candidate accompaniments, rather than depending upon subjective personal experience. The proposed system conducts GA three times with different fitness functions for polyphonic accompaniments. First, the system analyzes the rhythm and pitch of the dominant melody. Based on this information, it generates a fitness function for the evolution of main accompaniment. This customized fitness function not only harmonizes but also reinforces the rhythm of the dominant melody. Next, we repeat the above procedure and use the chord information to establish the second fitness function for bass, which provides a steady bass line for melody connection. For advanced harmony and rhythm, the chord accompaniment utilizes the information of the dominant melody and the generated main accompaniment as the basis of the third fitness function. Finally, we add simple percussion to enhance the structure of the generated music.

The remainder of this paper is organized as follow. Section II elucidates the proposed GA for the three types of accompaniment. The experimental results are presented in Section III. Finally, Section IV gives the conclusions of this study.

II. Genetic Algorithm for Accompaniment

Genetic algorithms (GAs) have shown their effectiveness on a variety of problems. The general principle of GAs is to simulate the mechanisms of natural evolution, such as selection, crossover, and mutation [14], [15]. Based on Darwin's theory "Survival of the Fittest", GAs are believed to be capable of evolving candidate solutions into better ones. To this end, GAs encode candidate solutions as chromosomes. The way of encoding chromosomes is referred to as representation, which is essentially related to the problem to be solved. Instead of a single chromosome, GAs evolve with a set, called the population, of chromosomes. The fitness function is devised to evaluate the quality (fitness) of candidate solutions (chromosomes). Intuitively, for a maximization problem, the better the solution, the higher the fitness.

The evolution begins with initialization of the population. Afterward, GAs embark on the process of reproduction. First, the selection operator picks two chromosomes from the population to serve as parents. Next, GAs perform crossover on these two parents to reproduce their offspring. A predetermined probability, crossover rate, defines the probability to perform crossover. Analogously, mutation is performed with a probability, mutation rate, on the offspring reproduced by crossover to slightly alter some genes. This process of reproduction repeats until the set of offspring is filled. Acting on "Survival of the Fittest", the survivor operator draws the fittest chromosomes out of the offspring population with (or without) the primitive population; the chosen chromosomes will constitute the population for the next generation.

This study proposes using GA to generate main accompaniment, bass accompaniment and chord accompaniment. Restated, the GA is conducted three times for the three accompaniments, respectively. First, the proposed method generates a fitness function based on the rhythm and pitch of the given dominant melody. The GA with this fitness function evolves out the main accompaniment. Second, it uses the chord information to establish the second fitness function and runs the GA to generate the bass accompaniment. Third, we repeat the above procedure to generate the third fitness function, created by using the information of the dominant melody and main accompaniment. The chord accompaniment can then be produced through GA with the third fitness function. Finally,

Table I: Encoding of notes

Note	Number	Note	Number
rest	-1	F	5
tenuto	-2	#F	6
		G	7
C	0	#G	8
#C	1	A	9
D	2	#A	10
#D	3	B	11
E	4	C (high)	12
		⋮	⋮

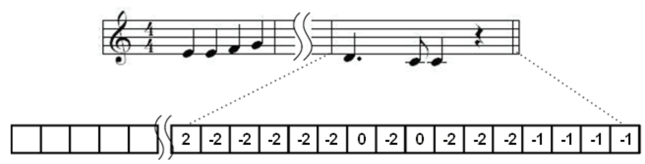


Figure 1: Chromosome representation

we add simple percussion to enhance the structure of the generated music. More details about the proposed method are given below.

A. Representation

In this study, music sections are represented by a series of numbers for a chromosome in GA. According to Bach's 12 equal temperament, each octave is divided into 12 equal notes denoted by C, #C, D, #D, E, F, #F, G, #G, A, #A, and B. Table I lists the corresponding numbers of notes for chromosome representation: Note C is represented by number 0, #C by 1, D by 2, and so on. In addition, we fix music beat at four-fourths and limit the range of note length from one sixteenth to a quarter, where tempo is variable. In the example of Fig. 1, bar 1 consists of four quarter notes, i.e., E, E, F, and G; bar 4 consists of dotted quarter note E, eighth note D, dotted quarter note D, and eighth rest.

B. Fitness Function

Design of fitness function is critical for evolutionary composition systems. To address the fatigue issue of human feedback, this study proposes using music theory as the basis of fitness function. More specifically, the fitness function consists of several weighted rules based on music theory to evaluate the generated accompaniment. The fitness function evaluates an accompaniment by summing up the scores from the rules. Such evaluation holds two major advantages. First, the evaluation criterion is consistent. Since the compositions are scored according to the music theory rules, the evaluation is not affected by the personal experience or preference in the traditional human-machine-interaction manner. Second, the evaluation is stable. The human-assisted evaluation suffers from fatigue and the decrease of musical sensitivity after a long time of listening. The evaluation based on the proposed rules, although not including all theories for different genres,

Table II: Weighted rules for main accompaniment

Harmonious interval	
Perfect unison	+8
Perfect octave	+8
Perfect fourth	+15
Perfect fifth	+15
Imperfect consonance interval	
Minor third	+8
Major third	+8
Minor sixth	+8
Major sixth	+8
Inharmonious interval	
Minor second	-20
Major second	-20
Minor seventh	-20
Major seventh	-20
Augmented interval	-30
Diminished interval	-30
Complementary of rhythm	
The note of melody is -1 (rest) and the main accompaniment has a tone;	+1
(continued) the accompaniment tone is a chord note	+10
The note of melody is -2 (tenuto) and the main accompaniment has a tone;	+5
(continued) the accompaniment tone is a chord note	+10

Table III: Weighted rules for bass accompaniment

The first beat	
Chord root notes	+20
Chord other notes	+5
No chord notes	-20
The second beat	
Chord root notes	+8
Chord other notes	+5
No chord notes	+1
The third beat	
Chord root notes	+12
Chord other notes	+5
No chord notes	-10
The fourth beat	
Chord root notes	+10
Chord other notes	+5
No chord notes	+1
Connection note for the major second	+3
Connection note for the minor second	+3
Connection note for the chord note	+5

can serve as an effective guideline for the GA to evolve into and result in satisfactory accompaniments.

The proposed accompaniment system generates three types of accompaniment, viz., main, bass, and chord accompaniments, for a given dominant melody. Three fitness functions are designed with respect to different music theories for the three accompaniments.

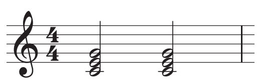
1) Main Accompaniment: In the proposed method, the main accompaniment focuses on tone harmony and rhythm complementary for the dominant melody. The music theory provides an objective measure for the harmony between the dominant melody and the main accompaniment. Although many rules exist in the music theory, we selected only the most important ones and weighted them empirically for fitness evaluation. Table II summarizes the weighted rules for main accompaniment. Note that the rules are triggered according to the interval between candidate accompaniment and the dominant melody.

2) Bass Accompaniment: Table III lists the weighted rules for bass accompaniment. The bass accompaniment utilizes the chord information from the dominant melody. This accompaniment is expected to provide a stable bass line for melody connection.

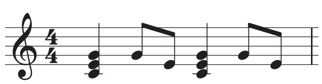
3) Chord Accompaniment: The aim of chord accompaniment is to harmonize and make up the rhythm of dominant melody and main accompaniment. Table IV lists the weighted rules for chord accompaniment. The rules adopt the note density of the dominant melody and main accompaniment. Figure 2 presents the four chord types used in the accompaniment: Type 1 is used for intensive notes in dominant melody and main accompaniment; Type 2 is used for regular density; Types 3 and 4 are used for low density of notes (rest or tenuto).

Table IV: Weighted rules for chord accompaniment

Type 1	
Sum of notes of melody and main accompaniment is more then five	+5
Sum of notes of melody and main accompaniment is less then five but more then two	+2
Sum of notes of melody and main accompaniment is less then two	-2
Type 2	
Sum of notes of melody and main accompaniment is more then five	-2
Sum of notes of melody and main accompaniment is less then five but more then two	+5
Sum of notes of melody and main accompaniment is less then two	+2
Type 3	
Sum of notes of melody and main accompaniment is more then five	-5
Sum of notes of melody and main accompaniment is less then five but more then two	-1
Sum of notes of melody and main accompaniment is less then two	+3
Coincide with the progress of melody(Progress up)	+2
Coincide with the progress of main accompaniment(Progress up)	+1
Type 4	
Sum of notes of melody and main accompaniment is more then five	-5
Sum of notes of melody and main accompaniment is less then five but more then two	-1
Sum of notes of melody and main accompaniment is less then two	+3
Coincide with the progress of melody(Progress down)	+2
Coincide with the progress of main accompaniment(Progress down)	+1



(a) Type 1



(b) Type 2

(c) Type 3

(d) Type 4

Figure 2: Chord accompaniment types

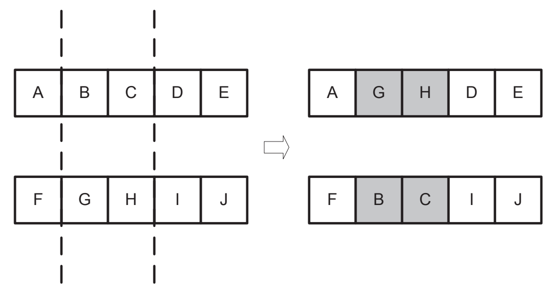


Figure 3: Crossover for compositions

C. Genetic Operators

The genetic operators in GA include parent selection, crossover, mutation, and survivor selection. For the parent selection, the proposed GA adopts the 2-tournament selection, which selects as a parent the fitter of two randomly picked chromosomes from the population. The selected parents are further performed with crossover and mutation to produce their offspring.

The crossover needs to be specially designed in that arbitrarily exchanging two parts of parents can hardly result in acceptable compositions. To address this issue, we introduce the notion of *crossover unit* into the 2-point crossover [14]. Restated, the cutting points can only be situated between bars. As Fig. 3 shows, the crossover randomly cuts two selected parents, and then exchange the bars in the way of order crossover.

Mutation slightly changes the genetic information of a chromosome and helps to explore the problem space. This study uses the random resetting mutation. This mutation operator probabilistically changes one randomly-picked note with a random value. In this study, we set the probability (mutation rate) as $1/\text{chromesome\_length}$.

For the survivor selection, the proposed GA simply replaces the parental population with the offspring population for the next generation.

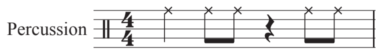
D. Percussion Accompaniment

The accompaniment system finally adds the percussion accompaniment to enhance the rhythm. This study devises three types of percussion accompaniments (cf. Figure 4). The systems will randomly choose one of them and add it to the music generated from GA.

III. Experimental Results

This study conducts several experiments to generate music and evaluate the performance of the proposed GA-based accompaniment system. Table V lists the parameter setting of GA used in the experiments. The compositions are set

(a) Type 1



(b) Type 2

(c) Type 3

Figure 4: Percussion accompaniment types

Table V: Parameter setting of GA

Parameter	Value
GA type	Generational
Representation	Integer
Chromosome length	400 (20bars)
Population size	32
Selection	2-tournament
Crossover	2-point
Crossover rate	0.9
Mutation	Random resetting
Mutation rate	1/400
Survivor	Replacement
Termination	500 generations

to be of 20 bars. The obtained compositions are processed with the orchestral instrument virtual studio technology (VST). Some sample results (WAV files) can be downloaded via http://cilab.cs.ccu.edu.tw/cec2012.zip.

Figure 5 depicts the progress of mean best fitness over 15 runs of the proposed GA for accompaniment. The figure shows that GA can effectively increase the fitness values of the three types of accompaniment. The example music files further demonstrate the improvement of the accompaniments evolved by GA in euphony.

Figure 6 shows one of the resultant compositions, where the five parts are the given dominant melody, main accompaniment, bass accompaniment, chord accompaniment, and percussion, respectively. According to the score, the main accompaniment follows the move of melody and replenishes the rhythm. For example, considering the last beat of the second bar, the melody is in resting; thus, the main accompaniment completes this beat with some proper notes. In addition, the bass accompaniment provides stable bass and great connection between bars. The last beat of the third bar, for instance, is a major second connection to the fourth bar, which makes the music smooth. The chord accompaniment further makes up the harmony and rhythm of the composition. For example, the first half of the eighth bar in the dominant melody and main accompaniment is inane, for which the chord accompaniment makes up the rhythm with abundant chord notes.

IV. Conclusions

This study presents an automatic accompaniment method using GA with music theory. Specifically, we develop a GA

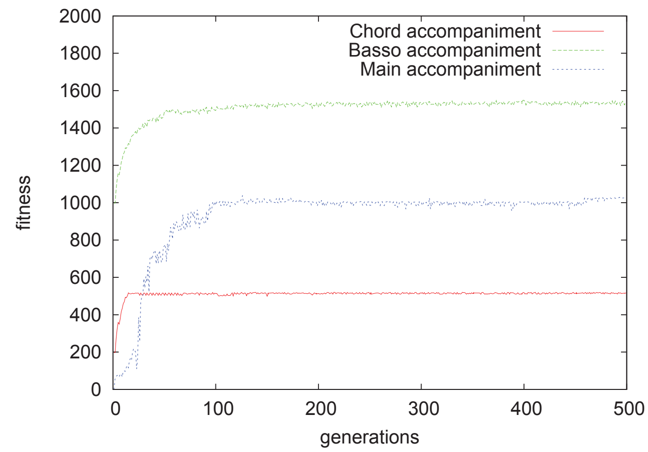


Figure 5: Progress of mean best fitness

for three accompaniments: main, bass, and chord accompaniments. To evolve the three accompaniments, three fitness functions are respectively designed on the basis of music theory. Restated, the fitness function consists of several weighted rules to evaluate the generated accompaniments.

In composing the accompaniments, the GA is conducted three times with the respective fitness function. First, GA produces the main accompaniment using the fitness function based on the rhythm and pitch of the dominant melody. Second, the proposed method uses the chord information to establish the second fitness function; then it runs the GA to generate the bass accompaniment. Third, the chord accompaniment is generated through GA with the third fitness function, which adopts the information of dominant melody and main accompaniment.

Experiments were conducted to evaluate the performance of the proposed method. Experimental results show that the GA effectively increases the fitness values and achieves satisfactory accompaniments. The adopted music theories, moreover, provide an objective measure for the evolutionary accompaniment system.

Some work remains for future study. First, more accompaniments to coordinate the music can be considered. Second, the adopted music rules and their weights are cornerstones of the fitness function. Enhancement on these parts is promising to improve the resultant accompaniments. A system for automatically determining the weights is also an important direction for future work.

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Figure 6: Composition with accompaniments generated by GA

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