

Music Evolution in a Complex System of Interacting Agents

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Abstract- The evolution of music, from random note strings to certain “pleasant” note sequences, is traced in a multi-agent computational model. A community of agents, with some musical guidelines and expertise from different aspects, compose their own and criticize other’s music to improve individual music performance. Based on common musical interest, some social structure with Small World characteristics is formed up. Through adopting general rule-based system and some evolutionary mechanisms, this model introduces a realistic communication scenario and shows an optimization process following local information. It provides an instructive computational framework to study music as well as other cultural phenomena, such as language.

1 Introduction

Throughout human history, on every part of the globe, in every extinct or extant culture, individual has played and enjoyed the music (Hasuer and McDermott 2003). Music influences us no matter whether we like it or not (Peretz et al. 1998). It yields emotional responses from us, such as tears or shivers down the spine (Sloboda 1991; Krumhansl 1998). Moreover, psychological responses are shown in experiments on other animals like chickens (Panksepp and Bernatzky 2002). The “magic” of music lies on its physical features and cultural backgrounds.

Music is temporally organized note combinations (Biles 2005), the key principle of which is its physical relationship among notes. For example, *note pitch*, the vibrating frequency of one note, e.g., A(440.00Hz), C[#](554.37Hz) as in American Standard Pitch; *notes interval*, the pitch distance between two consecutive notes on a major or minor scale, e.g., an *octave* is the distance between C and C', and *perfect fifth*, between C and G; *rhythm*, the temporal sound quality at regular time periods; and *tempo*, the speed at which music is played, measured in *Beats Per Minute*. Various psychological responses, from the simple “likes or dislikes” response to the complex emotional ones, are reflected from these physical relationships. Cross-culturally, certain acoustic stimuli are universally accepted as “pleasant” music, and are recognized quite early in human’s life span (Temperley and Sleator 1999; Hasuer and McDermott 2003). For example, note combinations with simple frequency ratios

are pleasant, e.g. octave (frequency ratio 2:1), perfect fifth (3:2), etc. However, other intervals with complex integer ratios are unmusical or dissonant, e.g. minor second (243:128). The melody of music, as a horizontal arrangement of notes, is expressed by the flow of consecutive notes. People like the music which strikes a balance between continuity, continuous flow of the melodic line, and novelty, occasional jump or pause somewhere in the melodic line. *Sequence*, defined as the note combination inside a bar, is used to indicate this feature. For example, in a 4-note bar, such sequence as (+3, +3, +4) (see Fig. 1) is pleasant, while, others are not.



Fig. 1. Example of Sequence (+3, +3, +4)

Besides physical features, music is a cultural phenomenon, created, developed and influenced by individuals from different cultural backgrounds. Cultural and individual heterogeneities result in the variety of music styles around the world (Sloboda 1991). In the community level, certain music form in one culture or one generation might be intolerable in another. In the individual level, as listeners, different individuals may have different responses to the same music; as composers, different individuals may create different pieces to express the same feeling.

Music is analogous to language, both having some universality in their general features, yet some heterogeneity caused by different individuals or cultures that create music and language. However, compared with language, the global fitness of music and its evaluation criteria are difficult to define, and music is more flexible in structure than language. Therefore, the origin of music is always an intriguing question puzzling cognitive scientists. Many evolutionary theoretical or practical frameworks from comparative or computational perspectives were presented (e.g., Burton and Vladimirova 1999; Hasuer and McDermott 2003). The focus of our paper is the computational framework on music evolution.

Many computational experiments, studying diverse aspects of music in light of evolution and optimization, are available (e.g., Horner and Ayers 1995; Mandelis and Husbands 2003; Miranda et al. 2003). Many computation techniques are adopted in these experiments, such as Genetic Algorithms (Holland 1975), neural network,

swarm, etc. Most of these experiments either zero in on individual's music performance, using some optimization methods to adapt some specific music forms (e.g., Biles 1994), or let human to evaluate the performance of the music generated by some mechanisms. These experiments neglect the variety and cultural basis of music. There are few models studying music as a cultural phenomenon in a community level (e.g., Miranda et al. 2003), and even fewer ones implementing a system with automatic music generation and automatic music evaluation. Besides, although human's subjective evaluation can help to improve the quality of certain modern forms of music, there is still devoid of some objective criteria, and it is difficult to use the similar questioning method to study the acquisition of musical abilities in children. In this paper, a multi-agent model is adopted to simulate the phylogenetic emergence of music from random note strings to primitive, pleasant note combinations. In this model, following certain musical guidelines summarized from many musical forms, each agent can not only compose but also evaluate music automatically. It can trace the emergence of primary music in the community level, and study the evolvement of social connections in consideration of musical interest.

The rest of the paper describes the model (Sec. 2), summarizes the results (Sec. 3), gives the conclusion and discusses the framework (Sec. 4), and finally, points out some future work (Sec. 5).

2 Description of the Model

In this model, a group of agents, possessing some musical competence, iteratively interact in pairs by composing and criticizing musical notes to improve individual's music composition. The music adopted in this model is very primitive: it contains only one melodic line (32 notes in 8 bars) and no chords; the tone is limited to C-major or A-minor scales and each note is chosen from 22 possible notes from C-major to A-minor; all notes have equal durations (quarter) and there is no pause; the time signature is 4/4 and the timbre does not change.

The agent in this model is shown in Fig. 2. His musical abilities include the music composition (randomly create notes in the beginning and play his music to other agents during communications) and the music criticizing (change other agents' music following his own musical knowledge and expertise). Considering universal musical features concerning the melodic harmony and flow, each agent bears some general music knowledge in mind, and this knowledge is in the form of musical rules. In the current model, only 4 aspects of music, beat, sequence, interval and jump, are considered and summarized as musical rules. The model can be easily modified by introducing more complex musical rules concerning more aspects of music. Among these 4 aspects, each agent shows different expertise when applying his music knowledge to criticize other agents' music. For example, an agent expertizing in

beat aspect will prefer music with consistent beat patterns. All these musical knowledge and musical abilities equip agents with the competence to automatically generate and evaluate music in the system. And the multi-agent environment provides an arena to study the relationship between individual musical activities and global social connections.

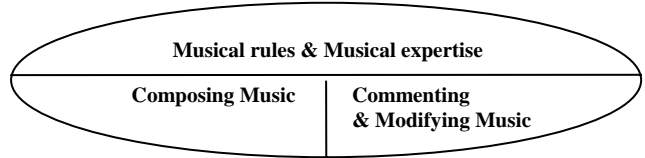


Fig. 2. Agent with Musical Abilities

2.1 Musical Rules

The 4 types of musical rules are introduced in this section.

a) Beat Rule. Inside one bar, there are 4 kinds of beat patterns with 1 strong and 3 weak beats: S(Strong)W(Weak)WW, WSWW, WWSW and WWWS. Usually speaking, a piece of pleasant music has consistent beat patterns across bars. The evaluation of beat is the highest percentage of these 4 beat patterns in all 8 bars. Modification based on beat is to randomly change one disqualified bar's beat pattern into the pattern occurred with the highest percentage.

b) Sequence Rule. We extract 8 pleasant sequences acceptable in many musical forms. These sequences are defined as note intervals, they are: $\{(+1,+1,+1), (-1,-1,-1), (+1,+1,-1), (+1,-1,0), (0, 1,-1), (0,-1,-1), (+2, +2, +3), (-3, -2, -2)\}$. Based on this database, the evaluation of sequence is the percentage of these pleasant sequences in the music. Considering the balance between continuity and novelty, it is not necessary for all 8 bars to be pleasant. A fuzzy evaluation function (see Fig. 3) is adopted to judge it and agents only prefer 3 to 5 pleasant sequences in all 8 bars. If the evaluation is less than 3, the modification of sequence is to change 1 note in an unpleasant sequence to reduce the note-by-note difference between this sequence and some pleasant one in the database; if the evaluation is more than 5, the modification is to change 1 note in a pleasant sequence and make it unpleasant.

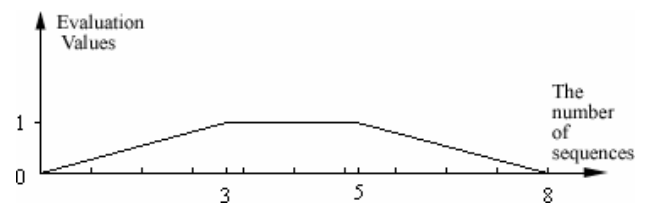


Fig. 3. Evaluation Function for Sequence

c) Jump Rule. Jump, similar to the interval, is the pitch difference between 2 consecutive notes. A reasonable, pleasant jump is usually less than one octave. The evaluation of jump is the percentage of reasonable jumps over all 31 jumps in all 32 notes in the music. Modification of jump is to randomly select a jump larger than an octave and increase or decrease the pitch of one

note in it so that the pitch difference between them is reduced.

d) Interval Rule. 2 types of continuous pleasant intervals, major third and major fifth, are introduced in this model. Intervals inside those 8 pleasant sequences are also pleasant intervals. Considering the balance between continuity and novelty, a fuzzy evaluation function similar to that of sequence, is used to judge the intervals. Agents prefer 40%-60% pleasant intervals among all intervals. If the evaluation is below 40%, one note in a randomly selected unpleasant interval is changed so that the pitch difference is reduced or increased to match one pleasant interval; if the evaluation is above 60%, an opposite operation is executed.

The overall evaluation value of one piece of music is the weighted sum-up of the above 4 evaluation values based on the 4 types of musical rules, which is defined as followed,

$$EV_{final} = (\sum_{i=1}^4 (Weight_i \times EV_i)) / \sum_{i=1}^4 Weight_i$$

where, EV_i is Rule i 's evaluation and $Weight_i$ is Rule i 's weight. If the EV_{final} is lower than a threshold ($_MThres$, say, 0.8), the music is regarded as unpleasant.

The individual difference lies on the fact that each agent can have different weights for his 4 musical rules, and these weights indicate his expertise. The higher the weight, the more professional the agent is on that aspect. During criticizing the music, the agent will modify the music according to his expertised aspect, i.e., the rule that has the highest weights.

Independent music modification based on different expertise may have some contradictory effect, i.e., one piece of music, modified by one agent based on his expertise, may get a worse EV_{final} when evaluated by others with different expertise. Fig. 4 shows an example of this effect, in which, the target music has 6 pleasant sequences (in oval), and modification based on sequence requires destroying one pleasant sequence by changing a note in it (in vertical ellipse). This modification introduces an unreasonable jump (in circle), and agents with expertise on jump may find it unpleasant. Considering this contradictory effect, music modification based on individual's opinion may not always improve the music quality to match the overall evaluation. However, iterative modifications between every pair of agents on different expertise may gradually compromise and increase the average EV_{final} eventually.

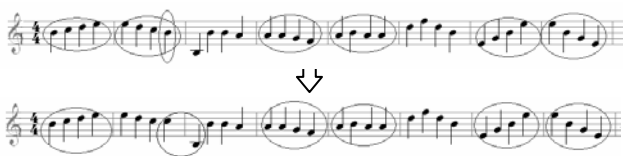


Fig. 4. Contradictory Effect in Music Modification

2.2 Musical communication and social connections

The musical communication with automatic music generation and music modification provides chances for agents to modify other's music and drives the emergence of pleasant music in the whole group. In the beginning of the simulation, all agents randomly initialize their musical expertise and create their own music by choosing some random notes. Based on their own expertise, they get their initial music's evaluation value $EV1$. Then, iterative communications between 2 agents, one as a composer and the other as a commenter, begin.

The communication procedure is summarized in Fig. 5. First, the composer composes his current music to the commenter, and the commenter judges this music based on his expertise. If his evaluation value ($EV2$) is lower than $_MThres$, the commenter regards this music as unpleasant music and modifies it based on his expertise. Then, the modified music is sent back to the composer. Whether the composer accepts the changed music is determined by whether the evaluation value of the changed music ($EV3$) is higher than the composer's $EV1$. If so, the modified music is regarded better and accepted by the composer. Meanwhile, the $EV3$ replaces the $EV1$ as the composer's current music evaluation value. In this situation, the communication is successful because one agent's music is improved. On the contrary, if $EV3$ is smaller than $EV1$, the modified music is rejected by the composer, and he still keeps his original music. In this situation, the communication fails because no improvement for any agent's music is achieved. During the whole communication, both the composer and the commenter have no idea of what expertise the other one has, and the acceptance of the changed music is based on one's own judgement, without influences exerted by other agents or other global information outside that communication, such as whether this music is better for other agents' evaluation.

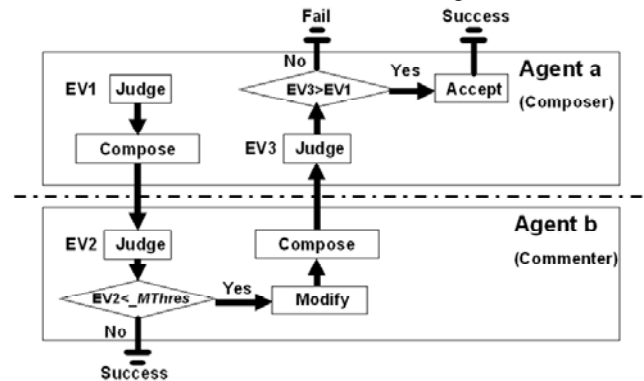


Fig. 5. Musical Communication

Common music interest may decide whom one agent will communicate, and these music interest may influence the forming of social connections in future. In order to test the influence of individual musical interest on the global social structure, 2 communication scenarios are introduced:

Scenario 1: Random communication, not considering music interest. In this scenario, agents are randomly

chosen to communicate and in communications, agents could either be composer or commenter.

Scenario 2: Communication based on connection weights. In this scenario, the personal music interest can influence the social structure by changing the connection weights among agents. An undirected, weighted network is adopted to indicate connections among agents. Connection weights, initialized as zero, indicate the propensity for common musical interest between two agents, i.e., possibilities for one agent's music is pleasant to the other. Since in communications, agents have no idea of what the other's expertise, we assume that the successful communications, in which, the modified music is accepted by the composer, indirectly indicate a common interest between them. Then, after a successful communication, the connection weight between them is increased by a certain step ($_CStep$). Similarly, after a failed communication, the connection weight is decreased by one $_CStep$. After many successful communications, if the connection weight between two agents reaches a threshold ($_CThres$), a permanent connection between them is built up. However, such permanent connection can still be broken if the connection weight drops below the $_CThres$ after many failed communications in future. The connection weights trace the musical interest developed among agents, and in future, the agent will communicate with others who have higher connection weights to him, so that they can develop more common musical interests. Meanwhile, based on these local communications, whether a global structure is triggered can be reflected by the permanent connections among agents.

3 Simulation Results

3.1 Indices for music evolution and social structure

Some indices are defined to trace the music evolution:

- Notes difference: the average note-by-note difference between music of all agents;
- Beats difference: the average beat-by-beat difference between music of all agents;
- Evaluation value (EV): the average EV_{final} for every agent to judge all others' music,

$$EV = \frac{\sum_{i,j} EV_{final} \text{ of Agent } i \text{ to judge Agent } j\text{'s music}}{\text{Number of all possible pairs}}$$

Other indices, adopted from the theory of Complex Networks (Newman 2003; Newman and Girvan 2003), can analyze the social structure:

- Degree distribution (P_k), the distribution of *degree* (the number of permanent connections of one agent) versus the number of agents who have this degree.
- Average shortest path length (L), the average shortest number of permanent connections between every 2 agents in the community.

- Clustering Coefficient (C), the average fraction of *neighbors* (directly, permanently connected agents) of one agent that are also neighbors to each other,

$$C = \frac{1}{K} \left(\sum_i \frac{E_i}{K_i(K_i-1)/2} \right)$$

where K is the number of nodes; K_i is the number of neighbors of node i ; E_i is the number of permanent connections that exist among node i 's K_i neighbors. Agents, connected by permanent connections, can form different *clusters* and the index C can indicate the closeness of agents in these clusters.

3.2 The Emergence of Music and Social Structure

Two questions are discussed in this model. One is that based on general musical rules, different musical expertise and local communications, whether some pleasant music can emerge from random notes after many iterative communications, and how is such emergence process. The other is that whether local music interest can influence the social connections and what global structure is formed based on this local constrain. The simulation results under one set of parameters are shown below. These parameters are set as followed: the number of agents is 100, the number of communication is 50,000, $_MThres$ is 0.8. In Scenario 2, $_CStep$ is 0.1. Results under other reasonable parameter settings are similar.

Fig. 6(a) and 6(b) trace the music emergence in Scenario 1 and Scenario 2. In both figures, the gradual decrease of the notes difference and the change of beats differences trace the music evolution in the group. After a number of communications, the beats difference remains stable, which indicates the completion of beat modification, i.e., every piece of music in the group has consistent beat patterns. In addition, the average EVs of all agents and the average EVs of agents with the same expertise are shown in both figures. A similar increase tendency of EVs is shown, which indicates the transition from random note strings with low EVs to some pleasant music with higher EVs . Three stages of music evolution are indicated by the change of EV :

- Stage 1, from 0 to 5,000 communications: the sharp increase period of EV . In the beginning, small changes of random note strings can efficiently increase EV ;
- Stage 2, from 5,000 to 40,000 communications: the stable increase period of EV with some occasional slowing down caused by the contradictory effect;
- Stage 3, from 40,000 to 50,000 communications: the fluctuation or flattening period of EV . Iterative communications can gradually compromise the contradictory effect and further increase EV in a certain level. In most simulations, pleasant musical sequences emerge after sufficient iterative communications among agents.

The common changing tendency of EV as well as other indices like beats difference and notes difference suggest

that in this framework, regardless of the changing rate, better music is certain to emerge after iterative musical communications.

reason for the dissemination and maintenance of various musical styles.

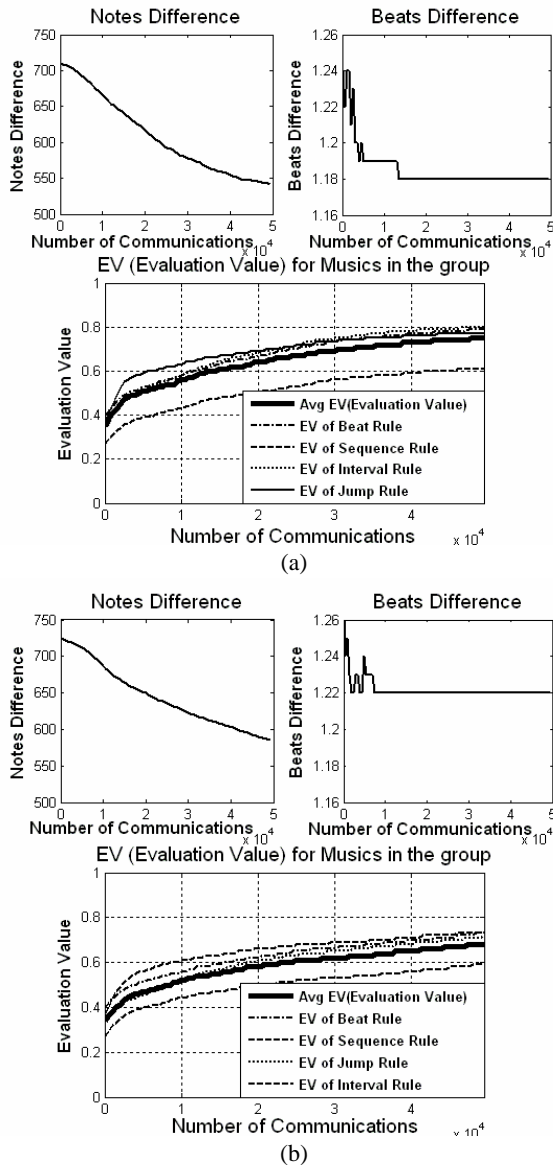


Fig. 6. Emergent Social Structure in Scenario 2.

Comparing the simulation results in the two scenarios, after same number of communications, in average, the final notes difference, beat difference and EV in Scenario 2 are all a little bit lower than those in Scenario 1. This is because that in Scenario 2, agents with the same expertise tend to communicate more with each other and build up common musical interest, and the connection weights among them are high, which in return, result in more communications among them. These selective communications deprive the chances for their music to be modified by others with different expertise. Therefore, although this music may be pleasant to their own, agents with other expertise may regard it as dissonant one. Communications constrained by common musical interest cause a low global EV in Scenario 2. In general, this selective or constrained communication might be a partial

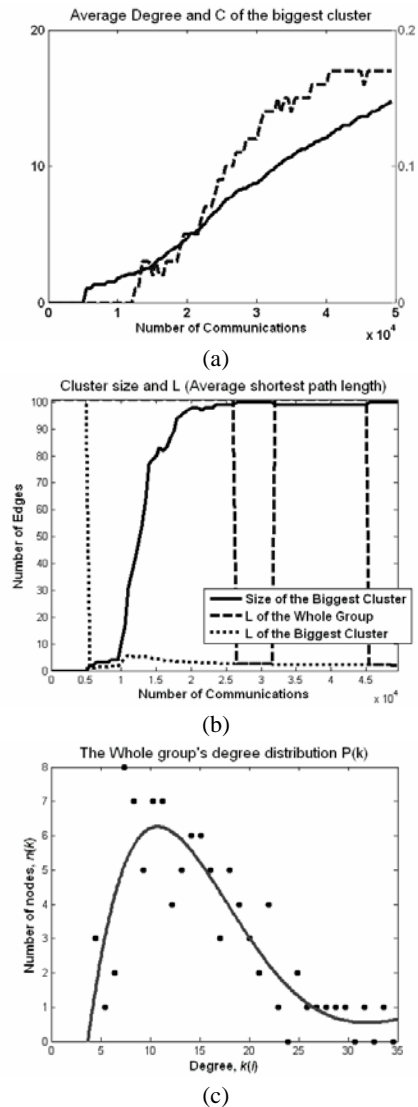


Fig. 7. Social Structure developed in Scenario 2: (a) Average Degree and C (b) Cluster Size and L ; (c) P_k

Some global structure is formed in Scenario 2, indicated by Fig. 7. The gradual increase of the average degree and clustering coefficient C (dashed line) traces the forming of this structure. The average shortest path length of the biggest cluster (dotted line in Fig. 7(b)) is always small, however, once all agents form up a big cluster, the average shortest path length L (dashed line in Fig. 7(b)) of this cluster is also small, compared with the size of the group. Agents with different expertise are difficult to develop some common musical interests. During communications, not all connection weights are high, some are low or near the $_MThres$. A few successful or failed communications among agents with low connection weights can easily connect or disconnect them into the cluster. That is why the L of the whole group is fluctuating. However, the small average shortest path length of the biggest cluster and the exponential distribution of P_k (in

Fig. 7(c)) indicate that the emergent social structure has some Small World characteristics (Newman and Girvan 2003). With no centralized communication scheme, based on local information, a Small World network can be formed. Similar result can be found in other evolutionary models (e.g. Gong and Wang 2005).

Finally, let us compare the emerged music sample with some random note string sample. Fig. 8(a) shows a random note string with no musical beats or rhythm. The line below the note string is the beat pattern in each bar, the black dot is a strong beat and the white one, a weak beat. Fig. 8(b) shows a piece of music evolved in this model. It has consistent beat pattern and continuous notes without many big jumps. The *EV* of it is close to 0.8, indicating that it is pleasant to almost all agents in the community.

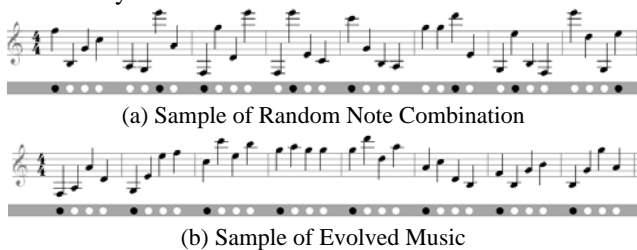


Fig. 8. Music Samples

4 Discussion and Conclusion

The emergence of music-like note sequences out of random irregular notes is traced in a community of interacting agents, based on some general guidance and iterative communications. The emerged music is flexible in structure, but matches the general guidelines. Moreover, the musical communication provides the chance for conventionalizing music among group members, and the common music interest can trigger a Small World structure.

Based on our model and other related work, a trajectory of music evolution could be described as followed: initially, similar to the bird songs (Todd and Werner 1999), based on some cognitive abilities, such as imitation and creation, human might randomly create or occasionally learn some note strings. Then, following some general guidelines and through some social activities, primitive music-like note sequences emerged, as traced in our model. Later on, psychological and cultural factors cast their influence on music, and various musical styles emerged. Compared with other models on individual music development, a distinctive feature of our model is that we extend the music evolution to the community level and discuss the relationship between individual music interest and global social structure.

Besides the conclusion related to the music evolution, this model is also useful to the study of evolutionary computation itself. This model implements an evolutionary process based on local information. All

modifications of music are executed by individual with different expertise based on specific communicational environment, and one agent's modification may breach the other's evaluation. In other words, the music is temporarily, restrictively improved. However, the interacting scheme among agents and the iteration of communication can compromise and improve the global performance eventually. Due to the lack of sufficient information, in many optimization tasks, it may not usually achieve a global improvement instantly, and sometime, the advancement is local and temporary, only fitting in with limited conditions. As long as there are enough opportunities to experience other conditions and there is enough repetition of same conditions, a global optimization can still be achieved. Therefore, how to design an efficient interacting scheme to make sure that enough experience of other conditions and sufficient repetition of similar conditions are crucial in these tasks. In fact, optimization based on local information and repetition of similar situations are already adopted in some optimization methods, such as the Ant Colony Optimization (Dorigo and Stützle 2004), and other artificial life models, such as the Classifier Systems (Holland 2001).

In addition, the computational framework and the communication scenario in our model are instructive to study other cultural phenomena, such as language. In Linguistics, it is widely accepted that language consists of rules focusing on different aspects, such as semantics, syntax and phonology (Chomsky 1995). The evolution of language ascribe to the emergence, acquisition and change of linguistic rules, as well as the production and perception according to these rules. Therefore, the rule-based system and related computational mechanisms (e.g., rule adjustment, strength-based competition) can be adopted to the computational models studying language evolution as well as the human communication system (e.g., Kirby 2002; Wagner et al. 2003; Gong and Wang 2005). Moreover, to a certain degree, language communication resembles the musical communication. In language communication, both the production and the perception are based on local information (the speaker's or the listener's linguistic rules) and there is usually no "telepathic" connection between the speaker and the listener to allow them to notice the other's linguistic rules. And the individual heterogeneity and cultural difference play important roles in shaping both music and language into their common and unique features. As demonstrated in our model that common musical interest can trigger some social connections with specific features, mutual understanding of language can also cast its influence on social structures.

However, there are still differences between musical rules and linguistic rules. For example, in our model, musical rules are derived from cognitive abilities and they are much flexible, while, linguistic rules, partially derived from cognitive abilities, are more strict (Labov 1994).

Based on general musical rules, creation and innovation in music are very common and can be quickly accepted. However, based on strict linguistic rules, creation of new language is relatively slow and the spread of linguistic innovations across the community may be subject to other constraints. Besides these, the most essential difference between language and music is that mutual understanding of language and the consequent cooperation gives language a good surviving factor in human societies. On the contrary, what is the fitness of music in human societies (in animal society, music does have some fitness, e.g., attracting femals to mate and signal mate quality (Miller 2000)) has been questioning cognitive scientists for a long time.

5 Future Work

In the end, some future work in music, psychology and social structure aspects is listed below, which is promising for the current basic model:

- In music aspect, more complex musical forms can be adopted to study the evolution of different music styles and interactions among them;

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- In psychological aspect, psychology responses and cultural influences may provide deep understanding of the relationship between the intrinsic music features and human emotions, and the extrinsic connections between music styles and cultural backgrounds;
- In social structure aspect, music evolution in other structures which are also common in human societies, such as Scale Free networks (Barabási 1999), can supplement the current work. More indices from the theory of Complex Networks, such as the betweenness, the mixing patterns (Panksepp and Bernatzky 2002), can provide in-depth study of the emerging process and analysis of the emerged structures triggered by musical communication.

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