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Complex network structure of musical compositions: Algorithmic generation of appealing music

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ABSTRACT

In this paper we construct networks for music and attempt to compose music artificially. Networks are constructed with nodes and edges corresponding to musical notes and their co-occurring connections. We analyze classical music from Bach, Mozart, Chopin, as well as other types of music such as Chinese pop music. We observe remarkably similar properties in all networks constructed from the selected compositions. We conjecture that preserving the universal network properties is a necessary step in artificial composition of music. Power-law exponents of node degree, node strength and/or edge weight distributions, mean degrees, clustering coefficients, mean geodesic distances, etc. are reported. With the network constructed, music can be composed artificially using a controlled random walk algorithm, which begins with a randomly chosen note and selects the subsequent notes according to a simple set of rules that compares the weights of the edges, weights of the nodes, and/or the degrees of nodes. By generating a large number of compositions, we find that this algorithm generates music which has the necessary qualities to be subjectively judged as appealing.

1. Introduction

A key finding in the research on complex networks is that most man-made networks involving couplings of different systems as well as networks involving connections of people are naturally connected in a scale-free manner, which means that the number of connections follows a power-law distribution [1]. In the past decade, the study of complex networks in physics has aroused a lot of interest across a multitude of application areas. Scale-free power-law distribution is a remarkable property that has been found across of a variety of connected communities [2–6] and has been shown to be a key to optimal performance of networked systems [7]. Recently, some work has also been reported on the applications of network analysis in the areas of linguistics, literature and arts [8–10].

Music is a form of creative art which is often identified as a signature of a particular composer, a group of people, a country or a culture at different times in history. People from different parts of the world and in different eras have their own music. One fundamental question of interest is whether these different music types share similar properties, and the implication of this question is that we wonder whether a common process/rule exists in the human brain that is responsible for composing music. Obviously, the converse of the question is equally important, i.e., whether distinguishing properties can be identified for music of particular types, genres and/or composers.

In this paper we construct networks for music and exploit some network properties for composition. We specifically analyze classical music from Bach, Chopin and Mozart, as well as Chinese pop music, and conclude that similar network

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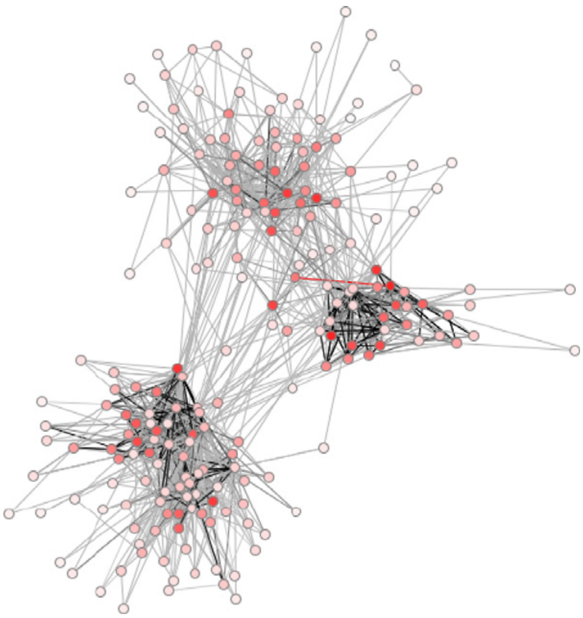

Fig. 1. A sample network from Bach's violin solos. Darkness of coloring of nodes indicates relative degrees, and darkness of coloring of edges indicates relative weights.

properties are shared by all of these different types of music. In particular, we show that the power-law degree distribution and small-world phenomenon are displayed universally in music. We conjecture that "good" music should necessarily display these universal features, and thus, preserving these properties forms the basis of artificial composition. We also propose a simple algorithm that preserves the universal network properties for re-composing music from networks.

2. Network construction for music

Music is basically a series of acoustic elements forming a constant stimulus meaningful or appealing to human brains. Our aim here is to model the acoustic elements and connections among them as a network and to study the properties of the network formed in order to find hidden properties of music. In this paper, we consider the musical note as the basic acoustic element.

A musical note is a sign used in modern musical notation to represent the relative pitch and duration of a sound. *Pitch* represents the perceived fundamental frequency of a sound [11]. In the standardized pitch system (A440 system) [12] a pitch, p, is related to frequency, f, by

$$p = 69 + 12 \times \log_2 \left(\frac{f}{440\ \text{Hz}} \right), \quad p \in \mathbb{N}. \tag{1}$$

Assuming that the frequency perception range of human ears is from 20 Hz to 20 kHz, the total number of pitches perceived is 120, from $p = 16$ to 135. For each pitch, only about 20 time durations are commonly used (e.g., semibreve, dotted minim, minim, dotted crotchet, crotchet, dotted quaver, quaver, dotted semiquaver, semiquaver, demisemiquaver, etc. [13]), and hence there will be about 2400 music notes.

The two basic elements of a network are the *node* and the *edge*. To construct a network for a given piece of music, we need to define nodes and edges. A piece of music can be considered as a sequence of notes, and we may thus naturally take every individual note that appears in a piece of music as a node, and edges can be defined by connections from one note to another chronologically as the music is played. Suppose, in a piece of music, the notes start at $t_0, t_1, t_2, \ldots$ (the unit being a quarter-note). Suppose note-i and note-j start at time t_i and t_j, respectively, where $t_j > t_i$. If no other note starts within (t_i, t_j), then note-j is said to co-occur with note-i and a co-occurring edge is defined from note-i to note-j. The duration of the co-occurring edge from note-i to note-j is $\delta t = t_j - t_i$. Every time when note-j co-occurs with note-i with duration δt, the weight of this co-occurring edge is increased by 1.

Using the aforementioned procedure, we are able to construct a weighted and directed network from a given piece of music. Fig. 1 shows a sample network modeled from Bach's violin solos.

3. Network analysis

Selected works of Bach, Chopin and Mozart, as well as collections of works by Chinese pop musicians Jay Chou and Teresa Teng, are analyzed. Our aim is to identify any common, or otherwise distinguishing, features in these works. In order to