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Music Composition Using Markov Models

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ABSTRACT

Music is a creative form of art. At the same time music compositions are bound by a set of rules within which there is creative expression. Music composers have experimented with various rule-based methods for compositions. With the advent of computers, methods based on statistics and randomness became popular. One of the commonly used statistical tools that lends itself well to algorithmic music is stochastic processes. And in particular, Markov chains have been the subject of many experiments and analysis related to music. This paper presents the creation of a melody by using stochastic modeling. Homogeneous Markov chains with discrete states have been used to define models based on a song belonging to a particular genre. Transition probabilities of the Markov models corresponding to musical notes and beats have been estimated using maximum likelihood estimation. Further, these estimates of transition probabilities have been used to simulate chains of musical notes and beats leading to an original melody or musical piece in the same style or genre as that of the original song.

KEYWORDS: Simulation of musical notes, algorithmic music, Markov chain, musical note transitions.

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1. INTRODUCTION

Music and mathematics have been closely linked ever since the time of the ancient Greeks [16]. Many concepts of music theory are based on mathematical notions [7, 12, 13]. According to Proclus the ancient Greek philosopher, 'Arithmetic studies quantities, music the relation between the quantities'. Ideas of using randomness, probability and statistics for music were explored by music composers and musicologists [4,6, 8, 18]. This is because music can be thought of as being probabilistic. For example, certain note sequences, chord progressions are likely to occur more frequently than others. A common statistical methodology used in analysis of music is stochastic process and in particular Markov Chains. The present paper traces the history and development of stochastic music and Markov Models in music through a literary review. In the second part of the paper, homogeneous Markov chains with discrete states have been used to define models based on a song belonging to a particular genre. Transition probabilities of the Markov models corresponding to musical notes and beats have been estimated using maximum likelihood estimation. Further, these estimates of transition probabilities have been used to simulate chains of musical notes and beats leading to an original melody or musical piece in the same style or genre as that of the original song.

2. STOCHASTIC PROCESSES AND STOCHASTIC MUSIC

Families of random variables which are functions of time are known as stochastic processes [15]. The set of possible values or events of a single random variable taking random values of a stochastic process $\{ X_n, n \geq 1 \}$ is known as its state space. The state space is discrete if it contains a finite number of points, otherwise it is continuous [15]. A random variable in music composition could be defined as a musical parameter like pitch, dynamics or duration. The set of total events that each variable or parameter can assume form the state space E. Thus, $E = \{e_1, e_2, \ldots\ldots e_i, \ldots., e_n\}$, where e_i represents the i^{th} value of the parameter and it can assume a total of n values. Here, n is the order of the state space.For example, if dynamics, pitch and duration are three parameters, their state spaces are defined as:

E_{dyn} = { pp, p, mp, mf, f, ff }, E_{pitch} = {the major scale of C}, E_{dur} = { crochet, quaver, semiquaver}

A combination of events from the three spaces will give the parameter space. For each note a combination may be chosen at random using random number generation technique. An example of a simple melody is given in Table 1. With many parameters being controlled and with careful definition of each state space, the resulting sound over short periods will sound far from chaotic and may produce pleasing and original patterned sequences [11].

Table 1. A simple melody sequence in C Major using equally likely event space.

Note no.	Pitch	Duration	Dynamics
1	C	Crochet	pp
2	E	Quaver	P
3	D	Crochet	mp
4	F	Semiquaver	mf
5	E	Quaver	mf
6	G	Crochet	f
7	F	Quaver	mf
8	A	Crochet	f
9	G	Quaver	mf
10	B	Crochet	ff

In practice, certain events may have a higher likelihood of occurrence than other events. In such cases, random distribution with weights assigned to the events in terms of probabilities can be used. The events that are more likely to occur are assigned a higher probability of occurrence, leading to what can be called stochastic music. The following example has been cited by Jones to demonstrate this [11].

For the parameter pitch, consider the state space $E_{pitch} = \{ A, B, D, F^{\#}, G^{\#} \}$ if the composer decides to use many A's, few D's and very few B, $F^{\#}$ and $G^{\#}$, then a possible probability assignment is given in Table 2.

Table 2. Probability Assignment of Events.

Event	A	B	D	$F^{\#}$	$G^{\#}$
Probability	0.6	0.05	0.25	0.05	0.05

A probability assignment can be used in a computer program to generate a random sequence of notes forming a melody. This method can be modified by defining each event in the space stochastically making it more powerful. This will be discussed in the next section.

Conversely, it is also possible to analyze musical pieces by assigning probabilities for various events in a piece and counting the number of occurrences of each event. This opens up the possibility of analyzing, studying and comparing musical pieces. Jones [10, 11] has used these techniques to analyze musical pieces by Handel and Bach. A further improvement of this technique can be achieved by using probability distributions like Binomial, Poisson and Normal distributions. Jones [11] successfully demonstrates the use of these techniques in a musical orchestra piece called 'Firelake'. He conducted an experiment in which while introducing the work to the orchestra he mentioned that one section out of the seven sections was written with computer assistance without revealing which one. When asked to suggest which section was computer generated, none of the musicians could identify it correctly indicating that the piece despite being based on probability and random numbers, blended well with the rest of the composition.

3. APPLICATIONS OF MARKOV CHAINS IN MUSIC: A LITERARY REVIEW

Markov chains are now extensively used in many diverse areas such as biology, physics, economics and engineering to name a few. Beran [3] explains the motivation of using Markov Chains in music in the following words, 'Musical events can often be classified into a finite or countable number of categories that occur in a temporal sequence. A natural question is then whether the transition between different categories can be characterized by probabilities. In particular, a successful model may be able to reproduce formally a listener's expectation of "what happens next", by giving appropriate conditional probabilities. Markov chains are simple models in discrete time that are defined by conditioning on the immediate past only'. Markov Chains use transitions between notes and sequences to analyze, identify or create musical pieces.

One of the earliest works in relating statistics to music is by Hiller in 1956 [9]. Hiller along with Leonard Isaacson created the Illiac Suite later called the string quartet No. 4 which consisted of four movements created through four different experiments. In the fourth part he used probability and Markov chains to create the composition. Hiller's work is generally regarded as the first ever score to be composed on an electronic computer. Hiller made the use of Markov Chains in stochastic music compositions popular after he used them in his composition. Since then Markov Chains have been used by composers in music in various ways.

After Hiller's pioneering work, Brooks et. al. [5] were one of the first researchers from Harvard University to experiment with Markov Chains for creating new sequences of music. Liu and Selfridge-Field [14] gave a general framework to build up a Markov chain model to identify a music style using a sequence of steps. Based on this framework they developed a scheme for modeling music using Markov chains and applied it to two-way composer identification. Wołkowicz, Kulka, and Kešelj [20] have conducted experiments for composer classification by using rhythmic and melodic features using Markov Models. Pollastri, E. and Simoncelli, G. [17] also used Markov models for composer identification. They studied a dataset of 605 musical themes written by five well-known composers Mozart, Beethoven, Dvorak, Stravinsky and the Beatles and conducted experiments with Markov Chains for abstracting the style of a composer and for recognizing an unknown excerpt. Ames [1], [2] has conducted a detailed analysis of work related automated compositions from 1956 to 1986.

Wadi [19] presents a method based on Markov chains and linear algebra to measure the distance between two similar sounding musical pieces. They have applied the method to analyze similarities between the two songs ‘ice ice baby’ by Vanilla Ice and ‘under pressure’ by Queen and David Bowie. These two songs were the subject of a well-known copyright case which ended with the two parties arriving at an out of court settlement in which vanilla ice ended up paying a considerable amount to Queen and David Bowie for copyright infringement. One of the methods consisted of using transition matrices extracted from the two songs to measure a ‘distance’ between them and then comparing this distance to a ‘maximum value’ distance derived from transition matrices of two very different sounding songs. The second algorithm also used transition matrices and the concept of matrix norm from linear algebra to measure the distances.

4. COMPOSING MUSIC USING MARKOV MODELS: ANALYSIS AND SIMULATION RESULTS

Homogeneous discrete states Markov chains have been fitted for Note/pitch transitions and beat transitions. The note and beat sequences of the song “Country Roads” by John Denver have been taken to formulate the transition probabilities. The song belongs to the genre of ‘country music’. The Markov model for note transitions has 5 discrete states, C, D, Em, F and G, and the Markov model for beat transitions has two discrete states, 2 beats and 4 beats. Transition probability matrices have been estimated for both models by running codes available in the R package “Markov chain”. The R code utilizes Maximum Likelihood Estimation to estimate the transition probabilities. The estimated transition probability matrices for notes and beats are provided in Tables 3 and Table 4. The estimated transition probabilities are further used to simulate note/pitch and beat sequences up to thirty elements, starting from initial states of “G” and “4”. Depending on the initial states, various sequences can be obtained using the same transition probability matrices. Actual note and beat sequences of the song ‘country roads’ used for estimation of transition probability matrices is given in Table 5. The simulated sequences based on the estimated transition probabilities are given in Table 6. On playing these notes and beat sequences on any musical instrument it can be seen that the simulated sequences, although different from the original, retain the original genre/ style of the song.

Table 3. Estimated Note/Pitch transition probability matrix.

	C	D	Em	F	G
C	0	0	0	0	1
D	0.4286	0.1429	0.2857	0	0.1429
Em	0.25	0.5	0	0.25	0
F	1	0	0	0	0
G	0.0909	0.4545	0.1818	0	0.2727

Table 4. Estimated Transition probability matrix for beats.

	2 Beats	4 Beats
2 Beats	0.5833	0.4167
4 Beats	0.2941	0.7059

Table 5. First 30 note and beat sequences of the song 'country roads'.

Noteno.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Note	G	Em	D	C	G	G	Em	D	C	G	G	D	Em	C	G
Beat	4	4	4	2	2	4	4	4	2	2	4	4	4	4	4
Note no.	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Note	D	C	G	G	D	G	C	G	D	Em	F	C	G	D	D
Beat	4	4	4	2	2	4	2	2	4	2	2	2	2	4	4

Table 6. Simulated note and beat sequences generated using the estimated transition probability matrices.

Note no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Simulated Note	G	C	G	G	Em	C	G	G	D	G	G	G	C	G	G
Simulated Beat	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2
Note no.	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Simulated Note	Em	C	G	Em	D	D	Em	D	Em	F	C	G	Em	F	C
Simulated Beat	4	2	2	4	4	2	4	4	4	4	4	4	2	2	2

5. CONCLUSION

This paper presents creation of an original melody using Markov models that can be played on a musical instrument. It highlights some important applications of Markov models with respect to pattern recognition, identification and composition of music. These techniques have tremendous possibilities in terms of future research. An important application of the method of creating or recreating music could be in scientifically studying and preserving traditional indigenous music forms which are increasingly being forgotten. The possibilities are definitely challenging but very promising and offer an exciting area in terms of interdisciplinary research for statisticians and musicologists. As future research, the model fitted here can be improved upon by considering more musical parameters. Also, interactions between different musical parameters can be incorporated in similar models to obtain better results.

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