

A Computer Environment for Polymodal Music

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Abstract

An algorithmic composition software named KYKLOS is presented here. It generalises musical scales to apply them in composition as well in performance. A sonic output of the system is described here as polymodal music since it controls four independent voices playing "synthetic modes". KYKLOS is suitable for Computer Assisted Composition for it generates MIDI files to be changed later by the composer. It can equally be used in live performances for a dynamic change of parameters enables music real time control..

INTRODUCTION

Computer Music literature contains a great number of works investigating the creative potential of mathematical structures applied to composition. Further, mathematical structures in Computer Music have become not only an occasional tool to generate new music, but common places to extract basic material and to developed new ideas. Part of early investigations on mathematical structures in music studied scales and modes using Combinatorics, Fibonacci Series and Golden Mean in order to understand compositional processes based on modal concepts (Barbour, 1929). The analysis of Bartok's works is another example of this line of investigation (Lendvai, 1968; Bachman & Bachman, 1979).

Recently, we postulated that several mathematical applications in Computer Music can be understood as *Sound Functors* (Manzolli & Maia, 1998; Maia, Valle & Manzolli, 1998). Here, we continue this exploration on mathematical structures in music. We propose a model to generate scales and modes and a compositional

environment named KYKLOS conceived to work out this sound material. It is an interactive tool for composition.

In following sections we start with musical and mathematical basic concepts and an introduction to the algorithmic mechanism used. Further, we present an interactive concept used to create a compositional environment that is based on a polyphony paradigm. We also describe a graphic interface developed at NICS and general functions of KYKLOS

2 MUSIC PRELIMINARIES

It is well known that “*from roughly 800 to 1500 the Gregorian Modes formed the basis for nearly all western music. Since the music of this period was primarily vocal, the modes reflect the many influences and accommodations of this medium of expression*”(Benward, 1981). These modes summed up 12 (8 Greek modes and 4 other created in the Renaissance) and included not only the major and minor modes, but also several others which have not as strong a sense of gravitation to a tonic note as is the main characteristic of modern major- minor system.

Many composers advocated the use of modes in order to achieve a particular expression to their music. For example, it is well known that Beethoven in his “Missa Solemnis” and in some of his later quartets used Early Greek modes. Also Bartok, in several of his works, used pentatonic scales based on Fibonacci numbers. Messian introduced the “modes de transposition limitéeé” (Messian, 1944) as



presented below.

Figure 1. Messian’s “2e. mode à transpositions limitées (mélodiquement)”

The Italian composer F. Busoni, “*described a method of forming scales by raising or lowering various tones of the scale of C major*” (see Barbour, 1929). He obtained 113 scales and this result was corrected later by Barbour (1929). As mentioned by Barbour, the number of possible scales is given by the combinatorial formula:

$$C(p,11) = 11! / (p-1)! (12-p)!$$

where p is the number of notes on the scale. For example, from 07-notes scales we obtain 462 modes, from 05-notes scales, 330 modes, and so on.

Further, several 'exotic' scales are still in use around the world by different cultures and peoples. For example, some Japanese music is based in two pentatonic scales named *Miyako-bushi* and *Minyō* (see **Fig 2**). There are also examples from African, Latin American and Eastern European music (Fujie, 1992).

Extending the discussion to “*synthetic scales*” defined by Barbour (1929), we implemented an algorithmic system to expand the modal universe. This program was called KYKLOS.

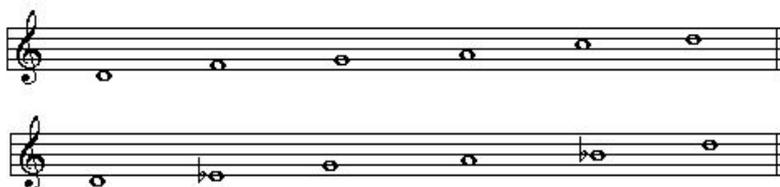


Figure 2. Scale *Minyō* on top and *Miyako-bushi* on bottom

Here we show only a simple model using cyclical permutations on scales and modes. From the point of view of Sound Functors (Manzoli & Maia, 1998), we just mapped the well known group of cyclical permutations on a set of sounds fixed a priori. In our example this set is formed of generalised scales using a MIDI protocol. Of course more complex mathematical and sound models can be used.

2 MATHEMATICAL APPROACH

We define a *mode of n notes* as any subset of n notes, arranged in ascending order, extracted from the chromatic scale (C,C#,D,D#,E,F,F#,G,G#,A,A#,B). For the mathematically oriented reader these modes are nothing more than ordered subsets of the sequence (0,1,2,3,4,5,6,7,8,9,10,11). Let us denote \mathbf{M} as the set of all modes with n , which is a finite set. Consider now \mathbf{M}_n the subset of \mathbf{M} which

contains all modes of n notes (or n -modes for short). So we have $\mathbf{M} = \bigcup_{n=1}^{12} \mathbf{M}_n$. Now, on \mathbf{M}_n we can consider the operation of **cyclical permutations**. For example, if we take a mode of five notes, say (C,D,F,G,A), under cyclical permutations we get four other modes, namely: (D,F,G,A,C), (F,G,A,C,D), etc. Mathematically this is obtained by action of the cyclical group \mathbf{Z}_n . From a musical point of view this is nothing more than an analogy to the *Early Greek modes*. Under cyclical permutations the set \mathbf{M}_n is partitioned in Classes of Equivalence whose elements are then the equivalent modes. The Classes of Equivalence are then denominated *scales*. Loosing speaking, we may say that the modes are cyclical permutations of a particular scale. As in the Greek modes, the starting note of a particular scale cyclical permutation gives the mode's name.

Although Messian was not a professional mathematician, he created an interesting problem in Combinatorial Analysis (see for example R. C. Read (1997)). Read calculated the number of inequivalent n -notes scales under transposition what is a Pólya-type problem in Discrete Mathematics. **Table 1** resumes all "*modes de transposition limitée*" proposed by Messian that is, n -notes scales equivalent to at least one of their transpositions.

Number of notes symmetry	0	1	2	3	4	5	6	7	8	9	10	11	12
1		1	5	18	40	66	75	66	40	18	5	1	
2			1		2		3		2		1		
3				1			1			1			
4					1				1				
6							1						
12	1												1
All scales	1	1	6	19	43	66	80	66	43	19	6	1	1

Table 1. Number of all possible "*modes de transposition limitée*"

To calculate only the total number of modes associated to n -notes is a simpler problem than that one presented by Read (see Barbour, 1929). For any subset of the twelve tones set, our aim was to calculate all possible modes with KYKLOS. Following Barbour these modes are called here *synthetic modes*, thus expanding the chromatic modal universe to its maximal size. In our implementation, we created a routine to calculate all these modes

and to list them. In this sense, we present in the next section a simple computational solution to this problem.

3 COMPUTER IMPLEMENTATION

Using above definitions it is possible to enumerate n-scales as a sequence of integers. Each value in that sequence gives the distance (in half tones) between two consecutive tones. For example, the sequence 3:2:2:3 is interpreted as a pentatonic scale C-Eb-F-G-Bb, and as defined above it is a C mode. The same scale in F mode reads F-G-Bb-C-Eb. So, if we apply cyclical permutations, (n-1)-sequences of numbers should be interpreted as n-modes of tones. With this material at hand and an interactive graphic environment, KYKLOS becomes a tool for algorithmic composition. Our algorithmic implementation is described next.

A n-mode is defined as an array with **n-1** integers $[a_1, a_2, \dots, a_{n-1}]$. Each array generated at **k-th** step can be read as a number $a_1a_2a_3 \dots a_{n-1}$ in decimal representation, where a_i is a integer between 1 and 9. We denote the number obtained at **k-th step** as $(a_1a_2a_3 \dots a_{n-1})^{(k)}$. The rules to implement the algorithm are the following:

- 1) $V_0 = (1, 1, 1, 1 \dots, 1)$ (initial n- mode)
- 2) $\sum a_i \leq 11$ with $i = 1, 2 \dots n-1$ (octave range constraint)
- 3) $V_k = (a_1a_2a_3 \dots a_{n-1})^{(k)} < (b_1b_2b_3 \dots b_{n-1})^{(k+1)} = V_{k+1}$ where $a_j \leq b_j, 1 \leq j \leq n-1$.
- 4) $V_{max} = (13 - n, 1, 1, \dots, 1)$

This algorithm obtains **C(p,11)** different scales in agreement with (Barbour, 1929) up to modes with 2 and 3 notes. This limitation is due to decimal representation we have used in the algorithm. The **Table 2** below resume the results. We include the modes from 2 to 11 notes (from Barbour) for mathematical completeness.

number of notes	2	3	4	5	6	7	8	9	10	11
number of scales	11	55	165	330	462	462	330	165	55	11

Table 2. Relationship between number of notes and number of scales

4 INTERACTIVE SOUND MODEL

Western polyphony evolved upon the use of the major and minor modes. The terminology modal consequently refers to the type of melody and harmony that prevailed in the early and later Middle Ages. It is frequently used in opposition to tonal, which refers to the harmony based on the major-minor tonality, which came later (Machlis, 1990). Before the establishment of tonality, superimposition of modal melodies, disposable on multiple voices, generated chords that pointed to harmony. This is a characteristic of the Western music distinguishing it from others civilisations. Upon these observations as paradigm, we developed an interactive computer system to expand the concept of polyphony to harmonic clusters. Thus, instead of searching for chords, we created a tool to produce harmonic complexity.

Using a set of parameters, we developed an algorithm to generate and to control four independent voices. The voices differ from each other by the following properties: synthetic modes, rhythmic patterns, instrumentation and tempo used. Using KYKLOS' graphic interface, a composer could explore many aspects of modal music in real time. The result of this process is called here *Polymodal Music*.

As the name KYKLOS (Greek for cycles) indicates, there are cycles controlling the process used to generate and modify synthetic modes. Therefore, all modes are presented in ascending order and they are played in sequence originally. If this process were restricted to initial conditions, the composer could not change the mode's original order. Therefore, KYKLOS has a permutation tool based on random process or any change input by the user (see **Fig 3**).

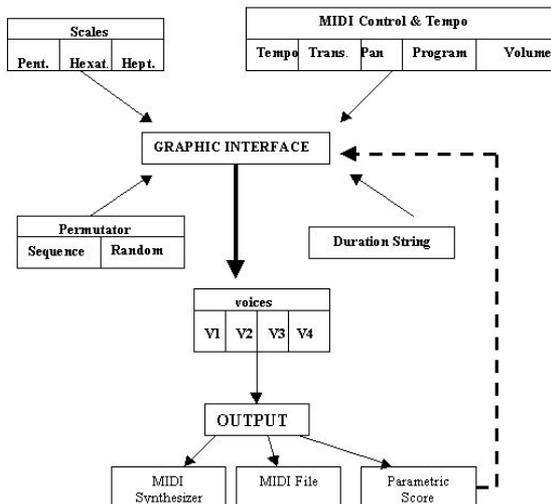
Another of the system's attribute enables dynamic rhythmic control using strings written as sequences of small integers. Each number determines a proportional duration in relation to a voice tempo, and negative values represent rests (see **Fig 3**).

Besides of the sound output produced in real time, there are two types of scores: MIDI file and Parametric Score. In the first one, sequences are recorded and processed later in any sequencer-like software. In the second case, the Parametric Score stores changes made by the user on the graphic interface. This kind of score can be used in interactive performances to integrate pre-recorded sequence with live musicians (see **Fig 3**).

KYKLOS ENVIRONMENT

KYKLOS environment is based on a graphic interface written for a MS-Windows system and it is portable for any PC with any multimedia soundboard running under Windows 3.0, NT, 95 and 98. We present below a diagram of the system functions, menus, control files and output files (**Fig 3**).

KYKLOS initialisation uses a set of text files contain all pre-calculated synthetic modes. It also fills the voices' parametric array with MIDI controllers and other parameters such as pitch shift and voice starting note. As described above, KYKLOS basic material are synthetic modes varying from 5-notes to 11- notes. A composer can assign different number of notes for each voice and consequently it is possible to choose any sub- set mode. Four voices play the chosen modes in a specific rhythmic pattern, volume, pan,



MIDI program, pitch shift, permutation and tempo independently. These all can be changed by the user in real time.

Fig 3. Diagram of the KYKLOS main functions and processes

CONCLUSION AND FURTHER DEVELOPMENTS

We presented the program KYKLOS whose potential is based on the set of all synthetic modes linked to real time exploration of a

graphic environment. The mathematical model presented here could be implemented in other software tools for musical creation such as MAX, for example. Nevertheless, the simultaneous creation of a mathematical model and a computer implementation can be useful for many composers and researchers, as well as the viability of making these tools for the PC computer music community. We intend to provide a computer serial connection between KYKLOS and interfaces such as gloves, interactive tap shoes (Manzoli, Moroni & Matallo, 1998) and the robot Khepera (see detail on the web page <http://www.ini.unizh.ch:80/~jmb/roboser.html>), researches developed at NICS on the Gestures Interface Lab. These will enable to control KYKLOS intuitively using body or machine motion.

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