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A method of simulation on an electronic computer is described, in which a set of formalized values of parameters is fixed in correspondence to a certain research object. The following computer programs are constructed for the composition of song melodies, harmonization of melodies analysis of harmonizations (this programme acts as an examiner) and composition of musical variations. The latter realizes a component of heuristic activity - transposition of the invariant form (structure) to different contents. These programs confirm the hypotheses concerning certain laws used by man in creative work intuitively. To make an objective evaluation of machine music and compare it with composer music a special experiment has been conducted by a method which eliminates the influence of the psychological set (bias) of the experts. Examples of computer melodies are given in a musical notation.

§ 1. In the study of certain psychological object the following problem arises: to what extent the knowledge of or information on the object, produced consciously (e.g. obtained in a psychological experiment) is relevant to the understanding of this object. In other words, is this knowledge sufficient to imitate the object?

It is not always that in his heuristic activity man uses only consciously-produced parameters. When dealing with difficult problems he introduces subconsciously additional factors that he cannot be aware of, although they often play an essential role.

Electronic-computer simulation is a reliable method of verifying hypotheses concerning laws governing research object. Simulation is reproduction or imitation of certain aspects of the object under study, that is those aspects that interest the researcher. In computer simulation the machine program includes regularities obtained in analysis of experimental data. The computer, naturally does not use anything above that, anything that is subconscious.

Simulation is carried out in three stages:

1) On analysis of the object the laws of its structure are found out. Besides, the laws and principles of the

structure and development of the object may be formulated on the basis of hypothetical conceptions of this objects.

2) Synthesis is reproduction or imitation of the object on an electronic computer with the help of a program which includes the laws discovered on during analysis.

3) Estimation of the machine results consists in determining the extent of adequacy of the model to the study object, that is the extent of similarity between machine and human actions or results. This is the only criterion of a) perfection of our algorithm, b) correctness of the adopted principles of simulation, and c) extent of knowledge of the study object. At this stage our ideas on the laws of the object are verified.

Thus in electronic-computer simulation it is objectively confirmed whether the machine (the program, to be more exact) possesses sufficient knowledge to imitate object on the study.

Simulation should be distinguished from synthesizing, which is not intended to attain similarity with an object.

Experiments in simulating some functions of composer and musicologist on "Ural-2" and BESM-6 computers were conducted in three stages correspondingly. Further they are commonly described. For more detailed information on the research methods and results the reader is referred to the author's monograph (1) and articles (2,3).

§ 2. Let us examine a method of simulation of musical composition based on algorithmization of the laws and rules of composition. Simulation is based on a probability process subject to definite regularities.

The method of organization of the algorithm is based on the principle of hierarchy of various musical concepts. Several conceptions must be introduced here.

Any musical composition is characterized (both syntactically and semantically) by a certain set of parameters $P_1, P_2, \dots, P_k, \dots$, embodying laws and means of composition. The parameters may indicate: range of melody, measure, distribution of frequencies of intervals, number of degrees in an octave, etc. Every P_k

parameter assumes several values: $P_1, P_2, \dots, P_k, \dots$. The value of a parameter is a definite number or numerical structure, a concrete law of distribution of frequencies of interval, and set of chords - out of an aggregate of those permissible in the program. The type of composition means the qualitative characteristics, or certain distinguishing musical features typical of an aggregate of compositions (style, genre, emotional tenor, etc.). The type may be "dancing music", "Waltz", "Strauss waltz", "width", "melodiousness", etc.

It will be established in analyzing a number of compositions of some type that not all the parameters are equally characteristic of the whole type. If a parameter assumes only one (essential) value we shall refer to it as an essential parameter, of which there may be several in every type of composition. If a parameter assumes different values in different compositions of one type it is inessential and we shall call it an inessential parameter. An essential parameter for dancing music is, for instance, the measure, which is in waltz $3/4$ and in charleston $4/4$. An example of an inessential parameter for waltz is "number of unstressed notes". An essential parameter for a Russian folk song is "sequence" (movement of the melodic figure up or down by a few degrees with retainment of the same rhythm and interval relations), with the value of "absence of sequence". Thus the essential values of parameters are the indispensable characteristics of the compositions of a given type.

Let $M = M(P_1, P_2, \dots, P_k, \dots)$

be an ordered set of various parameters. The simulation of a T type of composition is based on the assumption: any type of composition is characterized by a definite set of values of parameters

$M_c = M(P_{1ac}, P_{2bc}, \dots, P_{kcc}, \dots)$,

where P_{kcc} is a definite value of parameter P_k selected from a multitude of permissible values. Inessential parameters are designated in zero values. Thus the qualitative characteristics of the composition (Tc type) is set up in correspondence to a formal-quantitative characteristic (set of values of M_c parameters).

To simulate compositions of a definite Tc type certain numbers - encoded values of parameters - are fed into the corresponding cells of the computer's memory. In this way the computer is assigned a certain list of rules and means of composition by which the composition produced must be governed. The fixed codes automatically "set-up" or form the program. Out of all the programmed values of each parameter only one, assigned, value is selected. If the value of a parameter was not given, then during the

setting up of the program it is selected from an aggregate of programmed values at random, that is by means of the generator of random numbers. It follows that not all of the programmed laws are used in synthesizing the given composition but only a part of them. This part is designated M_c set, which determines the Tc type of the composition. The programs developed by this principle illustrate the process of quantity (set of values of parameters) transforming into quality (type of music).

The M_c set - list of the laws and means of composition used by the computer, that is the structure of the composition is printed along with the machine composition. This makes it possible to conduct various psychological experiments in perception of music. It also allows for solution in principle the major problem of musicology - to find the relation between the structure of the music and its influence on the emotional state of the listener. Let us designate this method M-method, for short.

The M-method of simulation is a way of replacing the direct analysis of the study object (with unknown characteristics) with a formalized analysis of the synthesized object (the laws and structure of which are known), that is to realize the method of analysis by means of synthesis. A special program may be used to add new values to the programmed values of parameters, that is to extend the multitude of the preset laws and means of composition. This enables us to synthesize compositions of new types - new synthetical structure and musical styles, different from those analyzed.

§ 3. The principles of the M-method were used in setting up the following machine programs.

1. Composition of melodies is simulated in the form of a musical period in key major or minor. The sounds of the melody answer the rules of its four aspects: rhythmic, melodic, harmonic and structural. These rules establish the various durations, interval-pitch relations, stable and unstable sounds of the scale, repetitions of melodic and rhythmic figures as well as the segmentation of the melody into its separate constructs - phrases, motifs. The selection of the form of composition (a period of 8 or 16 bars) is motivated by a desire to make a more detailed study of the rules of the melody which is a finished musical piece of minimum extent (1).

2. A composition in song rhythm is programmed - a sequence of durations corresponding to a definite poetic metre: a sequence of stressed and unstressed syllables of a poem. A combination of this program with a program for composition

of a melody provides the possibility of simulation of song melodies to a given text in verse, or a song (see (1)).

3. The program of harmonization of a given melody in quadri-voiced chords (triads and seventh chords in basic form and their conversions) imitates the solution of school problems. The programme covers study material of the one and a half semesters of music college. Such problems are solved in music college by means of the rules of harmonization outlined in text books on harmony. However, the absence of precise definitions and constructive procedures makes the process of harmonization largely intuitive. But in programming formal clarity must be introduced in the logical interrelation of the various elements and means of harmonization. Besides, the solution of the problem of harmonization is not unique, there is the problem of finding an optimal (by certain criteria) solution.

The structure of the algorithm makes it possible to simulate different types of harmonization (for instance, different in the extent of complexity) because a provision is made to a programme by arrangement of a set of values of M_c parameters, corresponding to the set of rules and means of harmonization (see (1)).

4. The program for analysis of solutions of students' problems in harmonization and for detection of errors acts as examiner and is a prototype of a reaching system. By "errors" are meant forbidden or undesirable sequences of chords or voices e.g. chord, nonsensical from the point of view of the program. When an error has been detected its specifics and location in the composition are indicated. The possibility of assigning a set of values of M_c parameters (that is a list of rules the violation of which in the initial solution is considered an error) provides for analysis of solutions of problems of varying degrees of complexity of harmonization. In other words, the programme produces various requirement to students after one month of study or on completion of the whole term of study (see (1)).

5. The machine composes one-voice variations on a given musical theme. On the basis of musical material this program realizes one component of heuristic activity, in this case, transposability, a fundamental property of structure. Transposition or transfer of invariant forms is to be observed in transformation of any nature. In this is embodied the integrity of structure which cannot be broken up into elements.

Very often when listening to a tune and its variation we detect the connection between them intuitively. This is so because the variation retains all the

unchanged elements or the invariants of transformation. But in variation they are masked by the changed rhythm, meter, key and the melodic line itself. These masking elements often make the tune unrecognizable. The M-method of simulation identifies the invariants and the masking elements, as well as the mechanism of transposition of invariants in the variation of the melody (see (2,3)).

Computer variation by the M-method makes it possible to reconstruct the mechanism by which the given composition was created, to follow step by step the whole process of transformation of the given theme into the given variation, and to demonstrate the intermediary results of the consecutive stages of transformation and deformation of the melody (see (3)). Figure 1 presents the melodies composed under this programme by BESM-6 computer of the Computation Centre, USSR Academy of Sciences. It will be noticed that melody No. 1 completely coincides (except for the first note in the last bar) with the popular "Melodyshnaya" song (from the film "Volga-Volga") by the Soviet composer Dunaevski. The synthesis of this melody by the computer confirmed our assumptions concerning the nature of its connections with the original theme, the ways of transformation of this theme into the melody of the "Melodyshnaya", as well as concerning the mechanism of creation of melodies of this syntactical structure (the melody of a popular song). For it is only by this process that a machine melody coinciding with the given well-known melody could have been produced.

§ 4. The proximity (or similarity) of the machine result and the study object is the criterion of perfection of the algorithm and the degree of knowledge of this object. What is important is not the absolute quality of the machine results (of music, for one) but a maximum degree of coincidence of these results with the object in the respects being studied during the process of simulation. The problem of evaluation of the machine results and of their comparison to the object simulated is a very complex one, especially in the case of works of art. Evaluation here is influenced by many factors, including public opinion, readiness to contradict, and particularly psychological set or bias, that is a prejudice against the work being evaluated.

The author has devised a method of sociological examination of evaluations made by listeners of machine music. The problem of evaluation of machine compositions and their comparison with composer music can only be dealt with on the basis of a questionnaire. This problem is tied in with listeners' psychology, that is their inability to evaluate the compositions objectively if they know beforehand



Figure 1

that melody No. 1 is machine-produced, and melody No. 2 was composed by man. Just as it is impossible to appraise objectively a popular melody. Psychologically it is quite natural. Therefore to be able to make an objective comparison the listeners must not know what they are evaluating at the given moment, machine- or man-produced music.

A special experiment is needed to make a sociologically objective evaluation of the computer's compositions and compare them with the objects of simulation. The purpose of the experiment is to eliminate the psychological set (bias) of the experts, to confuse them so that they will not know what they are dealing with, whether it is a work of the computer or man. Besides, that experiment is also to obtain an objective evaluation of machine compositions as compared to composer's works, that is to indicate their quality.

Melodies of well-known Soviet composers published in selected song books and melodies composed by "Ural-2" computer under the above programme were selected for the experiment. The melodies were played in an arbitrary order, unknown to the listeners who were to evaluate them by a five-point scale and write the number of points in the blanks of the form. The experiment was conducted in different socio-musical groups with approximately the same level of musical education. They were students of the Moscow Power Institute, students of the Gnesins Music Teachers Training Institute, participants in

the symposium "Problems of Artistic Perception" (the sitting of the symposium was concerned with music perception), senior-grade school pupils, mathematicians, participants in the Methodological Seminar of the Steklov Institute of Mathematics of the USSR Academy of Sciences and the Computation Centre of the Academy, employees of cultural establishments and others - more than 600 people in all. A similar experiment was also conducted on the basis of a programme broadcast by the home service of Radio Moscow on August 25, 1973.

Just as in any sociological study objective conclusions were made on the basis of averages of subjective evaluations of the participants in the mass experiments. The processing of experimental data yielded different characteristics (see (1)). The adopted method was found correct as it made it possible to eliminate the psychological bias we have mentioned. It was established in a series of experiments that the machine compositions scored more points (by various criteria) than composer music. The following table shows how melodies were evaluated by one criterion by the musically well-educated group of students of the Gnesins Institute:

Author	Evaluation				
	5	4	3	2	1
Machine	76	253	204	22	5
Composers	61	243	247	31	8
Am = 3.67; Ac = 3.51					

The table gives the number of 5-, 4-, 3-, 2-, 1-point evaluations of the machine and composer melodies: Am and Ac are average evaluations of the melodies.

The results of this experiments prove the following fact: in computer simulation of some types of music, such as composing melodies of popular songs, the results obtained by the machine are not only comparable to human works but are even superior to them in quality. This is indicative of the fact that the mechanism of creation of such forms of music has been studied to a very high degree, and proves the correctness of the chosen principles of simulation.

It is important to bear in mind that the melodies of professional composers used in the experiment are the result of human professional activity which is called creative.

References

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