Mathematical Methods of Research in Musicology: An Attempt of Analyzing a Material from Contemporary Historical Heritage (Reflections on Xenakis' book Musiques formelles)

Irina B. Gorbunova, Mikhail S. Zalivadny and Irina O. Tovpich

***Abstract*—The article analyzes the mathematical interpretation of logical regularities in music, made by the outstanding French composer and architect of Greek origin Iannis Xenakis (1922 – 2001) in his main work on theory of composition. The authors of the article use the settled approaches to studying the structure of messages by set theory, theory of probabilities and theory of information. These approaches allow to elicit Xenakis' most significant contributions to the solution of the aforementioned problem that are essential for contemporary theory of music and practical composition.**

***Keywords*— Iannis Xenakis, mathematics and music, set theory, theory of information, theory of probabilities.**

I. Introduction

Logical regularities in the structure of music works have become a subject of purpose-oriented education of musicians since the middle of the 19th century. In the theoretical works of music belonging to that time* one may find some elements of set theory, the sense of which was not realized by readers of those days due to the fact that mathematics and music theory were following different paths in many respects. Nowadays, in connection with development of the computer music technologies [1] as one of the most important spheres in professional activities of a contemporary musician, the necessity of forming an adequate idea of logical regularities in music has become quite evident as a necessary element of education for musicians of various profiles and specialties. In correspondence to this, training of specialists competent in this field in contemporary musical institutions acquires the status of a question of essential significance.

Among the tasks of teaching in this direction, an important place is occupied by mastering of mathematical methods in studying music that are available in theoretical works of various historical periods. The formation of academic courses devoted to this subject constitutes one of the urgent problems of contemporary musical education, because the basic ideas concerning the sphere of relations between mathematics and music are now being constantly implemented in hardware and software means destined for various aspects of musical activities – composing, performing, studying music etc.

The fundamental ideas that may constitute the basis of such courses are present in a number of well-known theoretical works on music**, among them the book Musiques formelles (Formalized music) by Iannis Xenakis [2] being of particular significance. The most fundamental ideas of the book are concentrated in the chapters that constitute the first edition of the book (Paris, 1963). These ideas may be distributed among the following fields of mathematics (resp. 'headings'): set theory, theory of probabilities and theory of information.

II. Set Theory

Xenakis' book presents in a developed form the possibilities of this mathematical field in their application to the logical regularities of music. The correspondence of the set theory apparatus to the peculiarities of music as a semiotic system being characterized by its iconic-sign properties (that do not exclude its other semiotic aspects) is also evident owing to the fact that such properties find their equivalents in the form of spatial (graphic) images that give the book a kind of 'multi-media' appearance. The introducing of set theory apparatus into the theory of music, carried out by Xenakis, allows eliciting some its premises in the history of theoretical studies on music, beginning from the Antiquity (e. g. the Antique letter notation). It also allows integrating theoretical expressions of different aspects of musical sound system (pitch, duration, loudness etc.) into a unified and compact logical form ('multi-dimensional' in spatial terms). In this respect, Xenakis' book makes an important contribution to the development of multi-dimensional technique of composition (founded by Xenakis' teacher, Olivier Messiaen, just in the middle of the 20th century [3]). It is also necessary to note that the derivative characteristics of logical aspects of music (e. g. density [4]-[5], tension [6]-[7], 'sound temperature' [2] etc.), according to the apparatus demonstrated by Xenakis, may be taken out to separate dimensions of the multi-dimensional mathematical space. Some of these characteristics (e. g. 'harmonic tension' of chords) played an important role in comprehending the new logical regularities in music of the 20th century, as well as in giving 'orderliness and clarity' (according to the Sergey

Irina O. Tovpich, PhD Student, The Herzen State Pedagogical, University of Russia, Russia

Irina B. Gorbunova. Department of Information Technology, Institute of Computer Science and Technological Education of the Herzen State Pedagogical University of Russia and Educational and Methodological Laboratory Music Computer Technologies of the Herzen State Pedagogical University of Russia, St. Petersburg

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Taneyev's well-known words [8]) to their application in practice.

III. Theory Of Probabilities

Owing to Xenakis' creative practice, the stochastic method of composition, based on fundamental theses of this branch of mathematics, acquired a worldwide fame. The elaboration of this method (as well as the studies of musical statistics appearing a 'symmetrical' process in music research) constituted an important step in realizing the logical system of music as the 'unity of number, time and random' (according to the idea expressed in the 1920s by the famous Russian philosopher Alexey Losev [9]). It may be said that Xenakis' main historical merits in this respect consist of unifying the general principles of the method (previously known from the works by Claude Shannon [10], John Pierce [11], Lejaren Hiller & Leonard Isaacson [12]) with high level of musical composition technique.

IV. Theory Of Information

Information aspects of logical structure of music are characterized by Xenakis on the basis of statistical theory of information known from the works by Claude Shannon. Besides that, owing to 'double' application of matrices as instrument for evaluating the information effect of combining various musical elements (e. g. in the chapters devoted to Markov chains and musical games), Xenakis' book contains in fact the premises for synthesis of statistical and non-statistical (based on set theory) approaches in studying the phenomenon of information. The authors of the article suppose that one of the new steps in solving this problem of synthesis in its application to musical logic may consist in of introducing the system of 'banality deductions' (according to the frequency of repetitions of an element or a combination of elements) subtracted from the meaning of the values that characterize the variety of interrelations between the elements in different musical structures (at more length see [13]).

The idea of 'pleasantness' (suavitas) of sound combinations (i. e. subjective evaluation of their variety by a recipient) that is similar to the notion of information was proposed in the 18th century in Leonhard Euler's book Tentamen novae theoriae musicae ex certissimis harmoniae principiis delucide expositae [14] as well as in some of his other works***. Analyzing various aspects of that idea, the author of the book undertakes remarkable efforts for evaluating the results of unifying sound combinations in various modes and keys, as well as the results of transition from one key to another (see also [15]). This idea stands very close to the later-proposed notion of information that is essential for aesthetical evaluation of various phenomena; moreover, the meaning of this notion (as well as Euler's category of 'pleasantness') is not limited by the sphere of logic, it includes also a lot of more specific semantic contents. It is well-known that, besides this (general philosophical in essence) meaning of the notion of information, the attempts of its studying and practical application allowed very soon to elicit such aspects of this notion that evidently belong to the sphere of musical aesthetics [10]; [11]; [16].

V. Fuzzy Sets Theory And Zone Nature Of Musical Hearing

The results of using mathematical methods in musicology in the first two thirds of the 20th century got a new impulse for their further development, owing to the fuzzy sets theory (and some derivative ideas in the field of soft computing) **** that gave also certain possibilities of eliciting its premises in music theory and some other musicological disciplines.

In the middle of the 20th century, several worth-while ideas that contained numerous potentialities for studying the factors of indeterminacy in the system of musical thought and in some respects anticipated analogous ideas in exact sciences were proposed in musicology and some related branches of research. Thus, on the edge of the 1940s and 1950s Russian acoustician and music theorist Nicholas Garbuzov suggested the theory of zone nature of musical hearing that embraces all the basic properties of sound [17]. According to this theory, each elementary unit of music corresponds in practice to a number of close-standing sound characteristics (pitches, durations, loudness degrees, tone-qualities) that form together a strip, or a zone of values. The limits of each zone may eventually change, as well as the number of zones.

Approximately in the same times, a group of American composers (John Cage, Earle Brown, David Tudor a. o.) suggested a number of propositions that introduced the factor of indeterminacy into logical structure of music that later became well-known all over the world under the names of aleatoric and sonoristic ('timbre-music') techniques of composition*****. Some aspects of these propositions stand close to Garbuzov's zone theory, but, on the whole, they are connected, first and foremost, with musical performance and suppose much larger pitch and duration zones. Practical implementations of these proposals (aesthetical characterizing of which stands beyond our task) stimulated, in particular, the process of realizing the details of logical indeterminacy present in musical traditions themselves (parts of indeterminate-pitch percussion instruments, various kinds of embellishments, dynamic shading, articulation etc.).

VI. Method Of 'Semantic Differential'

The method of 'semantic differential' (founded by Charles Osgood and his assistants) [18], originated from studying the regularities of sight-and-hearing synesthesia, had also being formed in the 1940s – 1950s. This method constituted an important step forward in exploring the field of synesthetic images in music, owing to their grouping on the basis of structured scales of differences. Besides the possibilities of statistical generalization of data characterizing the synesthetic perception of music by different listeners (the fact that is also connected with the factor of indeterminacy in the contents of music), the method assumes the element of indeterminacy in the structures of the scales themselves. In this connection, one may speak about zone nature of musical synesthesia. Each differential (a unit of differing) is presented in these scales by a segment of straight line (between the opposite notions as its limits) that may also be interpreted as a zone of synesthetic imaginations. The process of differing such imaginations is possible both on the basis of qualitative and quantitative differences, and so it does not demand an obligatory equality of segments in length.

From the viewpoint of logical organization of music, it is possible to produce a modification in the apparatus proposed by the founders of this method, regarding not the segments (‘differentials of semantic scales’), but the points of their junctions as the fundamental bearers of musical meaning; of course, placing of such points assumes also some fluctuations within the limits of a certain strip (zone). This modification imparts to the scales of the synaesthetical meaning of music elements a kind of similarity to the scales of logical elements of music known from music theory and corresponding to various properties of sound (a well-known example: pitch scales), that also assume the fluctuations in distances between their elements (e. g. the scale of intervals in Taneyev’s book Convertible counterpoint in the strict style [19]). An original variant of method in studying the synesthetic regularities of music (with open internal structure of scales and qualitative differences between the elements themselves) was proposed in 1970s by Bulat Galeyev in application to the field of sight-and-hearing musical synesthesia [20].

The aforementioned ideas and methods form the evident premises for application of the apparatus of fuzzy and ‘rough’ sets (that had not existed at the moment of suggesting the majority of these ideas) in musicological studies (besides the apparatus of theory of probabilities and mathematical statistics known earlier and having found its application in the 1950s and 1960s). However, they still do not give a comprehensive idea of the elicited forms of indeterminacy manifestations in musical thought (in particular – in its synesthetic sphere). More complete number of forms of such nature is noticed in earlier research works by Ernst Kurth [21] and Joseph Schillinger [4], devoted to regularities of space-and-hearing synesthesia in melodic movement. Both researchers mark out the significance of separate tones of melody as the points that designate the moments of change in the direction of movement (‘the borders of individual phases’, ‘the highest points of linear curves’, etc.). Schillinger, besides that, points out the dependence of character of lines in visual images proper to musical synesthesia upon the manner of articulation (curvilinear trajectory – legato, rectilinear trajectory – non legato, pointed structure – staccato). The specific character of curves (or broken lines) in such cases is not regulated strictly, and this fact allows us to speak about a kind of ‘zone geometry’ as well as about fuzzy functional dependences that characterize the interrelations between the sound and visual elements in musical synesthesia.

These theoretical ideas and generalizations appear to be very remarkable as the basis of mathematical studying of various components in the system of musical thought, including its synesthetic aspects. The latter sphere of the music system is very important for modeling of synesthesia as particular case of virtual realities by means of computer technologies and, thus, by interpreting musical images as a source of such realities [22]. In connection with the ideas of direct participation of visual imagery in music owing to the technical possibilities of computer technologies [23], such kind of modeling acquires an essential significance not only for synthetic forms of art with music as part of them, but also for the art of music itself.

The elaboration of individual regularities in composition, as well as of those in their totality, constitutes a certain contribution into disclosing the notion of harmony. As far as the function of harmony is fastening, connecting a certain number of elements, in order to coordinate them synergistically for the implementation of a joint task, it is the mathematical theory of groups that acquires a particular importance in musical teaching with using information technologies, in unifying computers and art. In a well-known work on theory of groups, devoted to the problems of principles and methods of symmetry in various fields of art, we may read the following: “The notion of symmetry enters the art criticism by means of the notion of structure. Art as an imagery form of knowledge of reality must reflect and reflects in fact its structural aspects. Structureness is sufficiently general regularity, a form of existence and movement of matter, and so the products of research and artistic creation work are subordinated to this regularity. It is well-known that the works of art – literature, poetry, music, painting, architecture – have a complex artistic structure and represent an organic interweaving and interpenetration of individual components of artistic expression” [24].

VII. Conclusion

A number of pedagogical experiments concerning the subject of this article (lectures, seminars, practical academic tasks) have been implemented in the process of holding the courses Mathematics and Computer Science at the Department of Music of the Herzen State Pedagogical University of Russia and the optional course Mathematical Methods of Research in Musicology for students of the Rimsky-Korsakov State Conservatory of St. Petersburg. The ideas of Iannis Xenakis’ book having been analyzed in the article constitute the basis of practical academic exercises in musical mathematics within the limits of the courses. Among such exercises, there is interpretation of musical settings in form of set algebra operations, studies in practical modeling of regularities proper to the statistical distribution of characteristics of musical logic, calculation of information meaning of various manifestations of these regularities with application of well-known formulae of theory of information, etc. Moreover, some complex cases of this kind having been analyzed by Xenakis (e. g. those that suppose the presence of continuous random values modeling of which respectively demands the application of differential and integral calculation apparatus) may appear in the role of optional elements of the course subjects, being introduced eventually, e. g. in connection with the specific problems that might arise in the process of students' research and practical creative work concerning the basic academic disciplines of music. These problems are analyzed more extensively by the authors of the article in the following works [25 a. o.].

The ideas stated in the proposed article have found their more complete implementation in the academic course entitled 'Information Technologies in Music' that is one of the basic courses for students of the Herzen University Music Department specializing in the direction 'Artistic Education' within the limits of professional education profiles 'Music Computer Technologies' and 'The Art of Music' [26]; [27].

For implementing the program of this course, the authors of the article have prepared the educational text-book Information Technologies in Music [28]–[32] that contains the analyses of the interaction principles and forms concerning music, mathematics and computer science in their historical development (including its contemporary stage), as well as some recommendations for academic courses devoted to application of mathematics and information technologies in the fields of musicology and practical composition.

APPENDIX

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**** L. A. Zadeh, "The concept of a linguistic variable and its application to approximate reasoning", Information Sciences, 8-9 (1975-76); Soft Computing, Third International Workshop on Rough Sets and Soft Computing, San Siego, CA (USA), 1995, etc. 'Rough set', the term for designating the set containing only extreme meanings of all values that belong to a fuzzy set.

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Irina B. Gorbunova was born in Saint Petersburg (Leningrad). DipMus, Special Music Higher School of the St. Petersburg State Conservatory named after N.A. Rimsky-Korsakov; BSc in Computer Science: Information Technology, Computer Science and Multimedia, Leningrad State University, Ussurisk State Pedagogical University; MA in Education, the Herzen State Pedagogical University of Russia; PhD in Information Technology and Pedagogic Sciences, the gogical University of Russia, St. Petersburg, 1989; Doctor degree: Doctor of Pedagogic Sciences and Information Technology, the Herzen State Pedagogical University of Russia, St. Petersburg, 1999. Dr. Gorbunova, Full Professor, PhD in Sc., Doctor of Pedagogic Sciences, Chief Researcher of the Educational and Methodological Laboratory *Music Computer Technologies* of the Herzen State Pedagogical University of Russia, St. Petersburg.

She was on a number of business trips abroad, among them working trip to the USA (1999); lecturing and giving research and practice seminars in Hungury (2003, 2005, 2017); business trip to the UK (2016); she was a member of the Jury of national and international competitions of musical creativity, including *Bridge of Friendship* (Dortmund, Germany, 2011), etc. Work experience; 1990 – 2010 - Associate Professor, Professor of the Department of Information Technology of the Herzen State Pedagogical University of Russia, St. Petersburg; 2010 - present - Full Professor of the Department of Information Technology, Institute of Computer Science and Technological Education of the Herzen State Pedagogical University of Russia, St. Petersburg; 2002 – present - Chief Researcher of the Educational and Methodological Laboratory *Music Computer Technologies* of the Herzen State Pedagogical University of Russia, St. Petersburg. She has more than 300 scientific publications, among them are monographs *Music Computer Technologies: Historical-Theoretical and Practical Aspects*, St. Petersburg: Publ. house "SMIO Press" (2007, *560 pp*.) and *Music Computer Technologies: The Problem of Modeling the Process of Musical Creativity*, compiled with participation of S. V. Chibirev , St. Petersburg: Publ. house of the Herzen State Pedagogical University of Russia (2012, *160 pp.)*; course book *Information Technology in Music*, vol. 1 – 4: vol. 1, *Architectonics of musical sound* (2009, *175 pp*.), vol. 2, *Musical Synthesizers* (2010, *205 pp*.), vol. 3, *Music Computer* (2011, *411 pp*.), *Music, Mathematics and Computer Science*, vol. 4, compiled with participation of Mikhail S. Zalivadny (2013, *181 pp*.), St. Petersburg: Publ. house of the Herzen State Pedagogical University of Russia. Her research activities include such directions as: MCT in professional music education (as a means to expand creative opportunities); MCT in general musical education (as one of the means of education); MCT as a means of rehabilitation of people with disabilities; MCT as the new direction in preparation of specialists of humanitarian and technological profile; MCT in the field of digital arts; MCT in information technology, psychoacoustics and musical acoustics; system of training arrangements and the art of performing skills on electronic musical instruments. Her circle of interests also includes the problems of interrelation of natural and technical sciences and humanities, as well as the possibilities of applying the results of such interrelation for the purposes of music education and upbringing. She also takes part in working out the specialized software for computer music devices and in application of this software in pedagogical processes. Her developments and researches also belong to the field of musical pedagogics and musicology, musical Informatics, computer modeling of processes of musical creativity, timbre programming, art of performing skills and arrangement on electronic musical instruments, creative work in the field of computer music, mathematical methods in musicology.

Prof. Dr. Gorbunova is Chairman of the Organizing Committee of the international research and practice conference *Contemporary Music Education*, Chairman of the Organizing Committee of the international research and practical conference *Music Computer Technologies in the System of Contemporary Education*. Dr. Gorbunova is a member of the Jury of national and international competitions of musical creative works, including *Electronic Palette* (Saint-Petersburg), *Music and Electronics* (Moscow), *Music of the XXI Century* (Moscow / Saint-Petersburg), International Festivals and Competitions *Musical Electronics and Multimedia* (Moscow / Saint-Petersburg), *Clarine of the XXI Century* (Saint-Petersburg), *The World of Art without Borders* (Saint-Petersburg, Russia - Szeged, Hungary), *Bridge of Friendship* (Dortmund, Germany), All-Russian Competition of Electroacoustic Music *DEMO* (Saint-Petersburg). She is a member of Editorial Boards of International Journals: *Music Scholarship / Problemy Muzykal'noj Nauki* (SCOPUS), *The World of Science, Culture, Education / Mir Nauki, Kul'tury, Obrazovaniya*, Electronic international scientific journal of music and sound in electronic mass media, film, Internet, and multimedia *MEDIAMUSIC*. Prof. Dr. Gorbunova has developed first ever course in Music, called Music Computer Technologies, which has been offered under the Bachelors of Arts and Sciences (BASc), , which in 2004 carried out student recruitment in different regions and educational institutions of Russia and she also leads post-graduate courses "Music Computer Technologies in Education" available under the MA in Music Education, since 2006. Prof. Dr. Gorbunova supervises a number of doctoral and post-doctoral students (more than 30) and lectures on Music Computer Technologies and Information Technology in Music. She supervises research in various directions, among them there are: *Theory and history of culture, Music Art, Information system and processes, Theory and methodology of professional education, Mathematical modelling, numerical methods and program systems, Theory and methods of education and upbringing (in Music, Informatics, natural sciences)*. The research results of Prof. Gorbunova were published in over 300 refereed publications including 48 books and 255 papers in journals and conference proceedings. Awards and honors: 2003 - Gold medal of the all-Russian Exhibition Centre (former VDNKh); 2005 - Silver medal of the all-Russian Exhibition Centre (former VDNKh); 2009 - Gold medal of the all-Russian Exhibition Centre (former VDNKh); 2009 - Diploma of the winner in the nomination «New educational technologies in ICT environment» of the all-Russian creative contest of scientific-technical solutions, educational products and services in the field of Informatization of the innovative-educational complex «Music computer technologies in the system of modern education»; 2010 - Grand Prix of International Congress-exhibition «Global Education - Education Without Borders»; 2010 - Diploma of the 11th all-Russian forum «Educational environment - 2010» for the project «Digital educational resources «Music computer technologies in education» in nomination of «Creative Competition of scientific developments, innovative solutions and programs in the field of higher vocational education» and many others; 2011 - Laureate of the Prize of the Government «For Outstanding Achievements in the Field of Higher and Secondary Professional Education»; 2013 - Honorary Worker of Higher Professional Education of the Russian Federation.