

## **Комплексная модель семантического пространства музыки и современный музыкально-образовательный процесс: одна из граней научного и творческого наследия Михаила Борисовича Игнатьева**

O modelo integrativo para o espaço semântico da música e um processo educacional musical contemporâneo: a herança científica e criativa de Mikhail Borisovich Ignatyev

The integrative model for the semantic space of music and a contemporary musical educational process: the scientific and creative heritage of Mikhail Borisovich Ignatyev

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*Recebido em 23 de outubro de 2020*

*Aprovado em 04 de maio de 2021*

*Publicado em 30 de junho de 2021*

### **АННОТАЦИЯ**

Развитие средств вычислительной техники привело к созданию и развитию новых форм обучения музыкальному искусству. Появление и развитие музыкально-компьютерных технологий (МКТ) послужило основой для создания новых форм в учебном процессе, так и новых предметов, возникновения новых дисциплин и новых образовательных направлений в системе современного музыкального образования. Новые предметы – такие как «Музыкальная информатика», «Компьютерное музыкальное творчество», «Компьютерная аранжировка и композиция», «Звукотембральное программирование», «Электронные музыкальные инструменты» многие другие - в полной мере отражают суть произошедших перемен в подходах к изучению музыкального искусства. В статье анализируются возможности включения разработанной при участии выдающегося учёного-кибернетика Михаила Борисовича Игнатьева комплексной модели семантического пространства музыки в современный музыкально-образовательный процесс; выявляется роль учебно-методической лаборатории «Музыкально-компьютерные технологии» Российского государственного педагогического университета им. А.И. Герцена как образовательной структуры, в рамках которой реализуются основные

положения рассматриваемой модели на различных уровнях обучения музыкальному искусству.

**Ключевые слова:** Комплексная модель семантического пространства музыки; Михаил Борисович Игнатъев; Лингво-комбинаторное моделирование; Музыкальное образование; Музыкально-компьютерные технологии.

## RESUMO

O advento da tecnologia da computação levou à criação e ao desenvolvimento de novas formas de ensino da arte musical. O surgimento das tecnologias de computação musical (MCT) foi a base para a criação tanto de novas formas no processo educacional quanto de novos sujeitos, o surgimento de novas disciplinas e novas tendências educacionais no sistema de uma educação musical contemporânea. Esses novos assuntos, como "Informática Musical", "Trabalho Criativo de Música de Computador", "Arranjo e Composição de Computador, Programação de Som e Timbre", "Instrumentos Musicais Eletrônicos" e muitos outros, refletem totalmente a essência das mudanças que ocorreram em abordagens para o estudo da arte musical. Este artigo analisa a possibilidade de incluir um modelo integrativo para o espaço semântico da música, desenvolvido com a participação do destacado cibernético, o cientista Mikhail Borisovich Ignatyev, em um processo educacional musical contemporâneo.

**Palavras-Chave:** Modelo integrativo para o espaço semântico da música; Mikhail Borisovich Ignatyev; Modelagem combinatória-lingüística; Educação musical; Tecnologias de computação musical.

## ABSTRACT

The advent of computer technology has led to the creation and development of new forms of teaching musical art. The emergence of music computer technologies (MCT) was the basis for creating both new forms in the educational process and new subjects, the appearance of new disciplines and new educational trends in the system of a contemporary musical education. These new subjects, such as "Musical Informatics," "Computer Music Creative Work," "Computer Arrangement and Composition, Sound and Timbre Programming," "Electronic Musical Instruments" and many others, fully reflect the essence of the changes that have occurred in approaches to the study of music art. This article analyzes the possibility of including an integrative model for the semantic space of music, developed with the participation of the prominent cybernetics, scientist Mikhail Borisovich Ignatyev, in a contemporary musical educational process.

**Keywords:** Integrative model for the semantic space of music; Mikhail Borisovich Ignatyev; Linguistic-combinatorial modeling; Music education; Music computer technologies.

## Introduction

February 11, 2019, marked the demise of a Russian national par excellence Mikhail Borisovich Ignatyev (1932–2019) was a cybernetist, a scientist, a doctor of technical sciences, academician, laureate of the USSR State Prize and the Prize of the President of Russia, an honored master of science and technology of the Russian Federation, a member of the Council of the Gorky House of Scientists of the Russian Academy of Sciences, the chairman of the Cybernetics department named after the academician A.I. Berg, the chairman of the St. Petersburg branch of the Scientific Council of the Russian Academy of Sciences on the methodology of artificial intelligence, the chairman of the St. Petersburg department of the Russian Pugwash Committee, had passed away.

Mikhail Borisovich Ignatyev has been awarded a “Resident of Besieged Leningrad” medal, as well as a “To the Author of a Scientific Discovery” medal named after P. L. Kapitsa, and other state and public prizes. M.B. Ignatyev is the author of more than 500 scientific publications, including about 20 monographs. His eagerness to create and embrace new ideas, his support for young colleagues, his sensitive attention to and concern for the younger generation, his wisdom, his democracy and his adherence to principles have all contributed to the wide development and interaction of various fields of science both in Russia and abroad.

Ignatyev was one of the academic organizers and the chairman of the organizing committee of the international conference “Computer science at school and problems of sustainable development,” which has been held annually for almost 40 years. Those standing behind the origins of the conference have included academicians Zh.I. Alferov, A.A. Voronov, A.P. Ershov, N.N. Moiseyev, V.V. Okrepilov, A.A. Samarsky, and Yu.V. Matiyasevich. Corresponding members have included S.S. Lavrov, V.K. Abalakin, R.M. Yusupov, world chess champion M.M. Botvinnik, and many other famous Russian and foreign scientists, and representatives of science, technology and culture. The conference has been attended by several generations of schoolchildren, students and specialists from Russia and other countries. Issues of the

interaction of information technology and artistic and creative activities have occupied important places among the conference themes. Upon the initiative of M.B. Ignatyev and through the sponsorship of the St. Petersburg State University of Aerospace Instrumentation, students were prepared to discuss the specialization "Computer technologies in art and mass media," in which lecturers and graduates of the Rimsky-Korsakov St. Petersburg State Conservatory took an active part.

We regard the article "Linguistic-combinatorial modeling of music" (IGNATYEV and MAKIN, 2019) written by M.B. Ignatyev together with the student of the St. Petersburg Music College named after M.P. Musorgsky A.I. Makin, published in the proceedings of the 18th International Research and Practice Conference "Contemporary Musical Education - 2018: Creation, Research, Technology" as his scientific will, summing up the results of his creative activity in the musical and educational fields and providing impetus for their further prospective development.

## **Methods and Approaches**

### **An Integrative Model of a Semantic Space of Music: Common Regularities of the Model under Consideration**

"A modern level of developing the study of art, psychology, exact and computer sciences allows us to take a new step forward in a comprehensive research of regularities of music and its perception and to form an integral model of the figurative content of music assuming that assumes a widespread application of accurate research methods. The basis of the proposed model is a multidimensional semantic space of music, in which separate combinations of measurements correspond to different levels and areas of music semantics (including the logic of a musical composition and diverse forms of musical synesthesia)," state the authors of the report "An integrative model of a semantic space of music" (IGNATYEV *et al.*, 2000), offering one of several possible versions of such a model. The development of this model summarizes the experience of Russian and foreign art studies and includes elements that are new in both content and structure.

Continuing the idea expressed above, the authors note: “In the interpretation of this model, an important place is given to considering the process of forming the general structure of such a space in its specific manifestations in practice, which requires the use of combinatorial methods to characterize the interaction of various components of this structure. Details of the structure of specific musical and synesthetic figurative representations use the tool of soft computing” (IGNATYEV *et al.*, 2016). The authors of the article note that “with the help of the presented model, it becomes possible to study in detail regularities of the interaction of various levels of the figurative content of music that have not previously undergone an extensive systematic research, as well as regularities of the interaction of figurative and semantic spaces of generators (composers and performers) and recipients (listeners) of music pieces. Thus, a number of historical models of a music space (for example, circular models of tone rows and rhythms in the medieval theory of the music of the Middle East countries) obtain a rational reasoning and a perspective of entering a more multifaceted semantic whole” (IGNATYEV *et al.*, 2016).

For the first time, the idea of considering an integrative model of a semantic space of music and its main structural components was made public in our country in the report at the 7th International Scientific Conference “High technologies of education and science,” which was held in St. Petersburg in 2000. “Each piece of art is filled with uncertainty, which allows pieces of art to live for a long time. Nowadays, the computer has become a powerful tool in hands of music composers, in hands of creators of new architectural projects and virtual reality objects, but at the same time, there are complex problems in arranging soft computing and modelling processes of music perception. The solution to these problems is sought in structuring the uncertainty, in joint modeling of generators and recipients of pieces of art” (IGNATYEV *et al.*, 2000).

Each work of art is saturated with uncertainty, which allows works of art to live for a long time. Currently, the computer has become a powerful tool for composers, creators of new virtual reality objects, but at the same time, complex problems arise in organizing soft computing and modeling the processes of musical perception, which, in particular, were considered by the scientist. M. B. Ignatyev searched for the solution

to these problems in the structuring of uncertainty, in the joint modeling of generators and receivers of works of art.

The linguistic-combinatorial approach for modeling poorly formalized systems, its application in the study of music and composing new pieces of music allows you to build a music constructor. Using this method, sound generators with uncertainty are synthesized, collective interactions in music are explored. First of all, systems are described using natural language. A way of transition from description in natural language to mathematical equations is proposed (for more details see (IGNATYEV and MAKIN, 2019; IGNATYEV *et al.*, 2000; IGNATYEV *et al.*, 2016)). For example, let's say there is a phrase

$$\text{WORD1} + \text{WORD2} + \text{WORD3} \quad (1)$$

In this phrase, words are indicated and only their meaning is implied, which is not indicated in the current structure of natural language. It is proposed to introduce the concept of meaning in the following form:

$$(\text{WORD1}) * (\text{SENSE1}) + (\text{WORD2}) * (\text{SENSE2}) + (\text{WORD3}) * (\text{SENSE3}) = 0 \quad (2)$$

We will denote words as  $A_i$  ("appearance"), and meanings as  $E_i$  ("essence"), \* means the operation of multiplication. Then equation (2) can be represented as

$$A_1 * E_1 + A_2 * E_2 + A_3 * E_3 = 0 \quad (3)$$

Equations (2) and (3) are models of the phrase (1). The formation of these equations and their equalization to zero is a polarization operation. The linguistic-combinatorial model is an algebraic ring (operator ring), where three operations are used - addition, subtraction and multiplication in accordance with the axioms of algebra, and we can solve equation (3) either with respect to  $A_i$  or with respect to  $E_i$  by introducing the third group of variables - arbitrary coefficients  $U_s$ :

$$A_1 = U_1 * E_2 + U_2 * E_3$$

$$A_2 = - U_1 * E_1 + U_3 * E_3 \quad (4)$$

$$A_3 = - U_2 * E_1 - U_3 * E_2$$

or

$$E_1 = U_1 * A_2 + U_2 * A_3$$

$$E_2 = - U_1 * A_1 + U_3 * A_3 \quad (5)$$

$$E_3 = - U_2 * A_1 - U_3 * A_2$$

where  $U_1$ ,  $U_2$ ,  $U_3$  are arbitrary coefficients that can be used to solve various problems on variety (3). If equations (4) or (5) are substituted into equation (3), then it identically vanishes for any  $U_s$ . Uncertainty was first introduced constructively in quantum mechanics.

Linguistic-combinatorial modeling consists in the fact that in a specific subject area, keywords are allocated, which are combined into phrases of the type (1), on the basis of which equivalent systems of equations with arbitrary coefficients are constructed. Linguistic-combinatorial modeling includes all combinations and all solutions and is a useful heuristic when studying music and creating a new piece of music. The use of this method allows us to go further in solving problems associated with mathematical methods of studying music, illustrated by the shifted Pascal triangle, which is associated with the Fibonacci numbers and the Golden ratio (IGNATYEV and MAKIN, 2019).

M.B. Ignatyev's linguistic-combinatorial approach is an algebraic theory of meaning. Linguistic-combinatorial modeling is a development of the quantum mechanical approach, which was formulated in the 1920s. It considered uncertainty as the most important aspect. The American professor Lotfi Zadeh, who introduced the concept of fuzzy sets and who discussed the elements of linguistic-combinatorial modeling, took the next step in this direction. There are other approaches to this problem, for example, logical and mathematical.

According to the scientist's idea, linguistic-combinatorial modeling in music (see more details in (IGNATYEV and MAKIN, 2019)), like any other form of art, should be in the zone of adaptation maximum, and the master's art is to ensure the materialization of the structure with such uncertainty in the form music, poetry, sculpture and architecture, for which spaces of meanings are built, which are compared. The considered problems also raise the question of the impact of a piece of musical art on the listener.

The learning process is the study of texts. That is why the famous thesis of Maturana arises - the observer says everything that is said. We cannot take the observer out of the parentheses of the description of the process of cognition, since this description invisibly contains a description of the internal state, the internal mental

organization of the observer, which recursively occurs throughout life (U. Maturana "Biology of cognition. Language and intelligence", 1996).

Modeling the processes of perception of works of art is one of the key components of the further formation of an integrated model of the semantic space of music (detailed in (IGNATYEV *et al.*, 2016)), an important integration step on the way of scientific and educational interactions in the era of the formation and development of digital arts.

## Literature Review

The formation of an integrative model of a semantic space of music was preceded by a complex, multifaceted scientific search, the results of which are associated with the names of leading scientists, mathematicians, and musicians, foremost of whom were L. Euler and I. Xenakis (see details in works (GORBUNOVA and ZALIVADNY, 2019; XENAKIS, 1963; GORBUNOVA and ZALIVADNY, 2012; EULER, 1739)).

A number of models of a music space proposed by mathematicians and musicians (including E. Kurth, C. Osgood, A. Moles, K. Stockhausen, J. Xenakis, B. Galeyev, and others) in the first and second halves of the twentieth century became the precursors to the combination and creation of a new, comprehensive model of a semantic space of music. In connection with the creation of this comprehensive model, the problem of the relationship of spatial and temporal characteristics of musical systems of various levels and scales was also considered.

The research results were further developed thanks to the collaboration of the electronic music studio of the St. Petersburg State Conservatory named after A.N. Rimsky-Korsakov, the Department of Computing Systems and Networks of the St. Petersburg State University of Aerospace Instrumentation, and the "Music Computer Technologies" Education and Methods Laboratory of the Herzen State Pedagogical University of Russia. This cooperation was reflected in a number of publications on the theme under consideration (see, for example, (GORBUNOVA and ZALIVADNY, 2017)).

The value of music as a message led naturally to the determination of a semantic interpretation of the phenomenon of a music space as well as music time. This determination does not exclude the possibility of studying its other aspects, for example, those relating to the field of art morphology. In this regard, the idea of a real music space as expressed in a number of works is of significant interest (see, for example, (ZOBOV and MOSTEPANENKO, 1974)). The geometry of such a space, apparently, differs from regularities characterizing stereophonic parameters of music, although in a number of respects it is undoubtedly close to the latter. In turn, a semantic approach to the phenomenon under consideration led to the highlighting of spatial aspects of music, since the psychological presentation of the “apparent present” is associated with the exposition of an integral music image, which is the starting point of its further evolution. The need for attention to the spatial aspects of music was subsequently confirmed by simulating the results of such an evolution, a process that is actually observable.

Publications (GORBUNOVA and ZALIVADNY, 2017; ZOBOV and MOSTEPANENKO, 1974), in addition to providing general regularities of the proposed model, also contain examples of the application of these regularities to specific historical materials (from antiquity up to the present). These applications have confirmed positive properties of this model, also convincing of its further promising opportunities.

Various aspects of forming and developing an integrative model of a semantic space of music are considered and analyzed in a number of our works (see, for example, articles (ALIEVA and GORBUNOVA, 2016; ALIEVA and GORBUNOVA, 2017)). In 2012, the publishing house of the Herzen State Pedagogical University of Russia issued the collection of articles “An integrative model of a semantic space of music” (GORBUNOVA *et al.*, 2016), which presents various aspects of this model developed by the authors of the articles included in it. This collection was the evidence of a certain stage in developing the model; it takes into account some previous research experiments carried out in this focus area in theoretical musicology and a number of related science disciplines.

In developing a mathematical tool of the proposed comprehensive model, the search for a match to some specific logical and technological generalizations of the theory of music was of a certain difficulty, which required a modification of a number of initially presented dependencies. “Modeling processes of the perception of pieces of art is an important step towards the integration of scientific and educational forces. Linguistic-combinatorial modeling represents mathematical models only for a small number of real systems” (IGNATYEV and MAKIN, 2019).

Articles (ALIEVA and GORBUNOVA, 2017; ALIEVA *et al.*, 2017) analyze possibilities of using the model when creating intelligent systems for cataloging and analyzing music of world nations on the basis of conceptual provisions that form the basis of a comprehensive model of a semantic space of music; they also note the need to develop ways of an adequate transition from a description in a natural language to mathematical research methods and presentation of results. This transition is complicated. Here is how M.B. Ignatyev describes this process in his article: “First of all, systems are described using a natural language.” <...> The article shows that “a work of art should be in the area of an adaptation maximum and the master’s art is to ensure a structure materialization with such an uncertainty in the form of music, poetry, sculpture and architecture, for which spaces of meanings are created and compared” (IGNATYEV and MAKIN, 2019).

M.B. Ignatyev also pays attention to the impact of a piece of art on the listener (let us remember L. Euler and his “*Tentamen novae theoriae musicae ex certissimis harmoniae principiis delucide expositae*” - see (GORBUNOVA and ZALIVADNY, 2019; EULER, 1739)). “This work is inspired by creative contacts with many representatives of culture - with litterateurs, professors B.F. Yegorov and Yu.M. Lotman, together with whom it was possible in the nineteen seventies to develop a new scientific field of ARTONICS, with representatives of cinema, which made it possible to create more than 20 films, with representatives of theatre and music art,” M.B. Ignatyev writes (IGNATYEV and MAKIN, 2019).

Many scholars, representatives of basic sciences and fine arts have been looking for different ways of interaction between natural and humanitarian fields of knowledge, including a famous mathematician Hermann Weyl (see (WEYL, 1968)),

ISSN: 1984-6444 | <http://dx.doi.org/10.5902/19846444>

Russian scholars and researchers A.V. Shubnikov, V.A. Koptsyk (see: (SHUBNIKOV and KOPTSIK, 2004) and other works), R.G. Barantsev, P.A. Kudin, Yu.N. Rags *et al.*

Thus, the book “History of Semiodynamics. Documents, Discussions, Comments” by R.G. Barantsev, a mathematician and philosopher of St. Petersburg, one of the leading Russian specialists in the field of synergetics, a Professor of the Department of Mathematics and Mechanics of the St. Petersburg State University, a laureate of the USSR State Prize (1973), a member of the St. Petersburg Mathematical Society (since 1960), of the Executive Committee of the International League for the Protection of Culture (since 1996), of the Scientific Council of the Union of Scientists of St. Petersburg (since 1999), of the Russian Academy of Natural Sciences (since 2003), of the St. Petersburg Philosophical Society (since 2004), published in 2005 is intended for everyone who is interested in the contemporary history of science and works in line with the evolutionary and synergetic paradigm. “Semiodynamics, studying qualitative changes of integral formations in a character representation, was an immediate precursor of the synergetic paradigm. Appeared at the Leningrad University in 1980, it has been forced to advocate its right to exist for many years. The history of this struggle is presented <...> in documentary materials of that time,” the author writes (BARANTSEV, 2006). His works show how a discovered methodology developed by semiodynamics finds its application in modern synergetics.

A major contribution to forming an integrative model of a semantic space of music was made by a Doctor in Art History, Professor of the Herzen State Pedagogical University of Russia P.A. Kudin. His work *Proportions in the Picture as Musical Concord* (KUDIN, 1997) introduced significant elements into the semantic model being formed.

The synaesthetic nature of musical thinking creates prerequisites not only for expanding and enriching possibilities of music with the participation of music and computer technologies, but also for its entry into the sphere of other arts and scientific fields (which is confirmed by the practice of recent decades). In the Education and Methods Laboratory "Music Computer Technologies" of the Herzen State Pedagogical University of Russia a group of scientists engaged in researches in this focus area was formed.

The work (GORBUNOVA and CHIIREV, 2019) reflects the results of the semantic and structural analysis of interactions of elements of an integrative model of a semantic space of music; this result has been brought up to a level of the software implementation of theoretical systems under consideration, the computer model of the described phenomena allows to observe characteristic features of the system behavior in practice. Elements of this kind of modeling were partially described earlier, for example, in (PETUKHOV, 2008; IGNATYEV *et al.*, 1999): “Structural features of the “auditory-visual section” of the model provide an opportunity for a practical computer-graphic modeling of music forms using methods for representing three-dimensional spaces in virtual reality systems” (IGNATYEV *et al.*, 2016). According to results of researches conducted in this focus area related to the further study of a comprehensive model of a semantic space of music and various applied aspects of its use, staff members of the Education and Methods Laboratory "Music Computer Technologies" of the Herzen State Pedagogical University of Russia prepared the monograph "Music, Mathematics, Computer Science: a Semantic and Structural Analysis of the Interaction" to be published.

## Results and Discussion

### Sound Generators with Uncertainty

Music is an art form that affects a person through specially organized sound sequences. As a sound source, a person, first of all, used *own* vocal apparatus, his own ability to generate sounds. A hearing aid for the perception of sounds is closely related to the parameters of this generating system, in particular, both the hearing aid and the voice aid operate in the same frequency range.

Subsequently, people invented artificial instruments for producing sounds in this range - strings, percussion, and winds. Currently, electronic musical instruments (EMR) (GORBUNOVA, 2018a, 2018b) or digital synthesizers, controlled sound generators, which take into account both the traditions of musical performance and creativity, and the new possibilities of computer technology, have appeared.

The behavior of any sound generator is most adequately described using differential equations. The developed method for constructing systems with uncertainty makes it possible to build generators with uncertainty, which is removed by setting the values of arbitrary coefficients. For example, a two-dimensional generator is described using two differential equations

$$dX1/dt = U1.f1(X1,X2), dX2/dt = - U1.f2(X1,X2)$$

where U1 is an arbitrary coefficient, by controlling which you can change the generation rate, that is, the frequency of the sound, keeping its frame. The three-dimensional generator will be described using the equations

$$dX1/dt = U1.g11(X1,X2,X3) + U2.g12(X1,X2,X3)$$

$$dX2/dt = - U1.g21(X1,X2,X3) + U3.g22(X1,X2,X3)$$

$$dX3/dt = - U2.g31(X1,X2,X3) - U3.g32(X1,X2,X3)$$

where U1, U2, U3 are arbitrary coefficients, by controlling which you can adjust complex sound characteristics.

In a similar way, you can build multidimensional sound generators, set the sound on a sphere, on a paraboloid, etc. With such a sound generator, the composer must work in the space of arbitrary coefficients, or a special translator must translate a piece of music from the language of ordinary notes into the language of arbitrary coefficients. Each of the variables can be identified with the musical characteristic of a particular hero, in this case, on the surface - on the territory, for example, of a multidimensional sphere, a musical drama can be played out.

To build a system of wandering sound in a room, each of the variables can be closed to a specific speaker and the listener will be geometrically oriented to one or another place-source of sound, depending on the composition. It should be noted that all non-electronic instruments emit a fading sound, and great composers have expressed their dissatisfaction with them. EMI are continuous generators of nonlinear oscillations, which did not exist before, which opens up interesting prospects. It is necessary to carry out interesting studies of generators with uncertainty, methods of performing musical works on them and the impact on listeners.

In music theory, there are numerous prerequisites for the use of soft computing (see, for example, in (GORBUNOVA and ZALIVADNY, 2016a)). They create especially

ISSN: 1984-6444 | <http://dx.doi.org/10.5902/19846444>

broad opportunities for studying synesthetic patterns of music perception, including their sociological aspect. At the same time, on their basis, it is possible to model musical synesthesia as by means of computer technology as a particular case of virtual realities and, thereby, use music as a source of such realities. The author of the article had the opportunity to be convinced of the fruitfulness of the results of such modeling, analyzing the already existing (including pre-computer) practice in this area (light-music films by O. Fischinger, B. Galeev, graphic models of musical phrases in S. Eisenstein's article "Vertical mounting") and making their own experiments in representing the works of N. Rimsky-Korsakov, C. Debussy, I. Stravinsky, A. Schoenberg in the form of multicolored graphic structures. In his works, Ignatyev considers specific examples of the use of the linguistic-combinatorial approach for modeling a duet and a trio, a quartet - up to a symphony orchestra (for more details see (IGNATYEV and MAKIN, 2019; IGNATYEV *et al.*, 2000; IGNATYEV *et al.*, 2016)).

The formation of ideas about an integrated model of the semantic space of music is an important step towards the integration of scientific and educational interactions in the era of the formation and development of digital arts.

### **An Integrative Model of a Semantic Space of Music: Application Experience in a Contemporary Musical Educational Process**

We should note main trends of using an integrative model of a semantic space of music in education.

- In the book "Symmetry" (WEYL, 1968), intended for a wide range of readers - teachers and students, mathematicians and non-mathematicians, for people interested in natural sciences, and people interested in human sciences, Hermann Weyl (1885–1955), one of leading mathematicians of the 21th century, a deep and versatile scientist who made a great contribution to "pure" mathematics and to the field of its applications, in particular, in recognizing the importance of a mathematical idea of symmetry for both mathematics and art studies, states the content of generally accessible lectures read by him in 1951 in Princeton (USA). Philosophical and methodological orientations of the thinker and teacher are formulated

- Music computer science (musical informatics) as a separate field of knowledge was formed in the 70s of the 20th century; it is also a kind of a precursor of an integrative model of a semantic space of music, one of its essential components. Teaching the discipline “Musical Informatics” in Russia began to be gradually introduced into the educational process at the end of the 20th century. So, by the mid-1990s music computer science was taught in a number of musical educational institutions of the country, including the Moscow State Conservatory named after P.I. Tchaikovsky (the musicologist Yu.N. Rags, the mathematician and programmer A.V. Kharuto), the Novosibirsk State Conservatory named after M.I. Glinka (A.P. Mentyukov, G.V. Mikhailenko), the St. Petersburg State Conservatory named after A.N. Rimsky-Korsakov (the musicologist M.S. Zalivadny, the mathematician and programmer I.V. Petryayevsky), the Gnesins Russian Academy of Music (the mathematician and programmer, musicologist V.S. Ulyanich).

The course “Musical Informatics” as an educational discipline is studied by students at universities in many countries of the world. However, in Russia there is still no regulated system of teaching it; there is no established, formed representation or definition of the concept of “musical informatics” in its educational and informative aspects – a detailed analysis of the situation is given in a number of our works (see, for example, (GORBUNOVA *et al.*, 2020)).

A significant contribution to understanding foundations of a comprehensive model of a semantic space of music in a contemporary musical educational process was made by the Doctor in Art History, Yu. N. Rags (see (RAGS, 2003)).

M.B. Ignatyev writes in the article “Linguistic-Combinatorial Modeling,” “In the 90s, a joint computer laboratory was successfully operated in the St. Petersburg State University of Aerospace Instrumentation and the St. Petersburg State Conservatory named after A.N. Rimsky-Korsakov”. As a result, in the nineties, the specialization “Computer Technologies in Art and Mass Media,” was developed within the specialty [22.01]: *Computing Machinery, Complexes, Systems and Networks*, The educational process was established, and our students began to successfully participate in art exhibitions and contests to actively develop the world’s cyberspace and distribute achievements of Russian culture around the world” (IGNATYEV and MAKIN, 2019).

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Elements of using a comprehensive model of a semantic space of music in a contemporary musical educational process are considered in works (GORBUNOVA and KAMERIS, 2019; ALIEVA *et al.*, 2019a; GORBUNOVA and HINER, 2019; GORBUNOVA and PETROVA, 2019).

The development of information technologies in music, the formation of an integrated model of the semantic space of music is a complex problem that can be solved in the process and on the basis of the integration of sciences and arts and a general, synthetic, or rather, synesthetic theory. First of all, this is possible and should be done through the development of the educational system, covering various, including global processes and phenomena and affecting a variety of social groups. The formation and development of modern music-computer technologies (MCT) made it possible to consider the problem in a complex manner (see, for example, (GORBUNOVA, 2019c, 2019d)).

Both information technologies in music and their attributes used in the process of teaching various musical disciplines, taking into account or based on the use of MCT, EMI, musical and sound-timbral programming, confirm the stated provisions. In 2002, the first in Russia, Education and Methods Laboratory "Music Computer Technologies" was established at the Herzen State Pedagogical University of Russia. The main tasks of the Laboratory "Music Computer Technologies" included the problems of researching fundamental scientific, methodological, and methodological solutions to the use of modern information technologies in music and music education. One of the main trends in the development of the system of modern music education was determined by the formation of key positions and the development of an integrated model of the semantic space of music, built on the use of MCT and aimed at using it in the musical educational process.

Staff members of the Education and Methods Laboratory "Music Computer Technologies" at the Herzen State Pedagogical University of Russia developed, licensed, and implemented the following programs in the pedagogical process:

= *A professional and educational profile for training Bachelors of artistic education "Music Computer Technologies"*, to which applicants in various regions and various educational institutions of Russia have been admitted since 2004. Programs

have been developed and classes are given for students of music faculties in pedagogical higher educational institutions in the following disciplines: “Computer Music,” “History of Electronic Music,” “Technologies and Teaching Methods (in disciplines of the training profile: Music Computer Technologies),” “Architectonics of Sound,” “Fundamentals of Studio Sound Recording,” “Information Technology in Music,” “Technology of Musical Styles,” “Fundamentals of Composition, Knowledge of Instruments and Computer Arrangement,” “Traditional and Computer Orchestrating,” “Technologies of Studio Sound Recording,” “Methods and Practice of Teaching Electronic Composition and Arrangement,” “Teaching Methods of Playing the Electronic Musical Instrument,” “Standard Software for Professional Activities of a Musician,” “Traditional and Electronic Knowledge of Instruments,” “Musical Computer,” “Basic Electronic Musical Instrument,” “Additional Musical Instrument (Electronic),” “Electronic Synthesizer,” “Electronic Ensemble,” “Music Computer Practicum,” etc.

= *A Master's program, “Music Computer Technologies in Education”,* which was developed and implemented in the pedagogical process in 2006.

= *Professional retraining programs:*

- “Teaching Musical Disciplines Using Music Computer Technologies in Educational Institutions.”

- “Teaching Electronic Musical Instruments in Educational Institutions.”

- “Information Technology in Music and Music Education.”

- “Technologies for Creating and Artistic Processing of Sound Information.”

= *Professional development programs,* including:

For children's musical schools and children's schools of arts:

“Music computer technologies”, “Methods of teaching musical disciplines using music computer technologies”, “Computer Music Creative Work”, “Methods of Teaching Electronic Musical Instruments”, “Music Arrangement in Electronic Musical Instruments”, “Distance Musical Education”, “Information Technology in Music”, “Electronic Musical Instruments”, “Information Technology in Musical Education”, “The Higher Class Performance and Arrangement on a Synthesizer”, “Sound Design”, “Applied Audio Engineering”, “Fundamentals of Musical Programming”, “Sound and Timbre Programming,” “Modern Methods of Teaching Musical Disciplines Using Music

Computer Technologies”, “Methods of Teaching Music for People with Reduced Capabilities (of Vision and/or Hearing) Using Music Computer Technologies”, “Tablet Computer and Mobile Technologies in Musical Education”, “Interactive Network Technologies in Teaching Music”, etc.

For sound engineers:

“Musical Audio Engineering”, “Technologies for Creating Audiovisual Projects”, “Digital Technologies in Modern Concert Practice”, “Concert Audio Engineering”, etc.

At the St. Petersburg State Conservatory named after A.N. Rimsky-Korsakov, M.S. Zalivadny developed the course “Mathematical Research Methods in Musicology”, which uses elements of an integrative model of a semantic space of music and which is applied in the process of teaching students of musicological and composer faculties of the conservatory.

These academic disciplines, and a number of others, constitute an effective basis for implementing the concept of an integrative model of a semantic space of music in the system of a contemporary musical education.

At the moment, staff members of the Education and Methods Laboratory "Music Computer Technologies" of the Herzen State Pedagogical University of Russia, in collaboration with musicologists, researchers from the St. Petersburg State Conservatory named after A.N. Rimsky-Korsakov and a group of scientists, musicians and mathematicians from the Republic of Azerbaijan (The Music Academy named after Uzeir Gadzhibekov and the National Academy of Sciences of Azerbaijan, Baku) are making developments in the field of creating an intelligent system for cataloging and analyzing music of world nations and mathematical research methods in musicology (see, for example, works (ALIEVA and GORBUNOVA, 2016; ALIEVA and GORBUNOVA, 2017; ALIEVA and GORBUNOVA, 2017a; GORBUNOVA and HINER, 2019)), which are a continuation of the problem of using theoretical foundations of an integrative model of a semantic space of music in a contemporary system of music education.

As a conclusion, we cite words of Mikhail Borisovich Ignatyev, formulated in his report at the 18th International Research and Practical Conference “Contemporary Musical Education – 2018: Creativity, Research, Technology” on December 7, 2018:

ISSN: 1984-6444 | <http://dx.doi.org/10.5902/19846444>

“Composition and logic aspects of this model in an obvious form contribute to the identification of regularities of an active-creative perception of music, which is essential for forming a creative thought in general. Structural features of the “auditory-visual section of the model provide an opportunity for a practical computer-graphic modeling of music forms using methods for representing three-dimensional spaces in virtual reality systems. Results of such a presentation can find their application in the fields of art studies, psychology, general and musical education” (IGNATYEV *et al.*, 2016).

## Conclusion

Mikhail Borisovich Ignatyev was a great Russian scientist in the sphere of cybernetics. He intensively assisted to the co-operation between the fields of artistic and scientific creative activities. He was the initiator of an agreements on co-operation between the different artistic, scientific and technical institutions of higher education. One of the results of these activities was the working up of the proposed integrative model for the semantic space of music, etc.).

Elements of this model were applied in the contemporary musical educational process, for example, educational specialty “Computing Machinery, Complexes, Systems and Networks”, which is taught in the disciplines “Computer Music Technologies,” “Computer Technologies in Art and Mass Media,” “The Sound Studio” at the St. Petersburg State University of Aerospace Instrumentation. Some elements of this model are included in the courses being held at the Education and Methods Laboratory “Music Computer Technologies” of the Herzen State Pedagogical University of Russia (for example, the disciplines “Musical Programming,” “Music Computer Technologies,” “Musical Audio Engineering,” “Musical Informatics,” “Information Technology in Music,” etc.).

The role of information is constantly growing, the term “information society” has emerged. Due to the exhaustion of the planet's material resources, people will have to immerse themselves even more in virtual worlds of different levels. This is already being done by means of the press, radio, television, and computer systems imbued with art. The musical infrastructure of the world is being formed, and now you can listen

to music anywhere in the world at any time. Each person now, thanks to the development of MCT, EMI, virtual synthesizers of various levels, musical software and hardware complexes, can not only listen to music, but also compose it. Another side of this process is the emergence of a sense of collegiality, which is so necessary in our time for people from different countries, continents, social groups.

We are convinced that the components of Ignatyev's research heritage have wide perspectives in music, fine arts and other hard-to-formalized regions of human knowledge, such as linguistic combinatorial modeling in music and linguistics, problems of forming a professional musician's cognitive hearing, fuzzy methods of pitch analysis in music, and many others.

## Acknowledgment

The author appreciates:

- A Candidate of Art History, Senior Researcher at the St. Petersburg State Conservatory named after A.N. Rimsky-Korsakov M.S. Zalivadny, who proposed in 1987 a draft named "integrative model for the semantic space of music" in the report "Measuring the Semantic Space of Music" at the seminar "Synthesis of Arts in the Era of a Scientific and Technical Revolution", held in Kazan in the framework of the All-Union School-Festival *Light and Music*;

- A Doctor of Physical and Mathematical Sciences, Professor of the St. Petersburg State University Yu.M. Pismak for valuable recommendations on developing details of a logic and technological tool characterizing various aspects of a semantic model under consideration;

- A Candidate of Art History, Professor of the St. Petersburg State Conservatory named after A.N. Rimsky-Korsakov L.M. Maslenkova for helpful advice and discussions;

- A staff member of the Scientific Music Library of the St. Petersburg State Conservatory L.A. Miller for the opportunity to get acquainted with little-known valuable materials on the history of music theory.

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