

Influence of Mathematics on the Process of Music Composition in 20th Century

In this report I would like to overlook shortly the problem of interaction between mathematics and music, to investigate and show implications of mathematical elements in musical material. This problem runs in different forms of manifestation since Antiquity. The music I mention as a branch of science on purpose, since firstly I look at the *quadrivium* formed by the sciences in Antiquity; it means the music was alongside with and equivalent to other exact sciences, such as arithmetic, geometry and astronomy.

When nowadays talking about the structural and symbolic relation between the numerals and musical sound and their interaction in the process of composition, we may define cases of numeral expression, distinctive to particular period, and certain canons of numerological manipulations. For example, Pythagorean system of musical intervals and mathematical proportions mark the period of Antiquity. This system reflected an opinion that numerical proportions influence overall organization of the universe. It gained response in world-view of Renaissance, since this period "revitalized" the philosophy of Antiquity's beauty and its material expression, i.e. relations of proportions, expressed by mathematical symbols and incarnated in various fields of art, such as architecture, literature, fine arts and music. Typical musical example of this period is Guillaume Dufay's motet *Nuper Rosarum Flores*, which repeats the measurements of Florence Cathedral by its forms and proportions of rhythmical measures. Mysticism of the Middle Ages determined sacralization of the culture itself and the music, thus gave the religious symbols prominence (including numbers, provided with symbolic meaning). Musical period of Baroque is characterized by eminently sacral tradition of Christian numerology, which reaches mystic world-view of the Middle Ages and based on it composing tradition (there, J. S. Bach's oeuvre is full of manipulations of mathematical calculations and symbolical codes, thus turning it into an example of chrestomathy). The proportions of form architectonic, representing Classicism, and widely perceptible "square, quadrate principle" showed harmony of mathematically balanced form elements. Stephanie Mason indicates the synonym of the music of 18th century was "resonant with mathematics" (Mason, Saffle, Schütz, 1988: 790), still Romanticism, that followed the Age of Enlightenment, differed by eminently blossomed anti-rationalism ("mind can be wrong, but feeling – never"); Yuri Cholopov notices the culmination of antagonism between mathematics and music during this period (Холопов, 1982: 78).

It could be stated that music was believed to be an object of science in the beginning of 20th century. For example, Igor Stravinsky stated, "The particularity of a musician's intellection differs few from mathematical intellection". So here we try to analyze what forms are used for the expression of interaction between mathematics and music in the frames of modern music compositions; how the compositional numerological experience of previous epochs is synthesized in music of 20th century.

It is to be noticed that expression of numerical composition possibilities in the music of 20th century synthesizes all previous periods. But interactions between art of sounds and number construct become eminently miscellaneous and coexist as complex layer of different numerological traditions: the music of 20th century is full of numerological symbolism of various religions; here you may find harmony proportions of the universe, Sectio aurea rules of numerical progressions (Fibonacci) and confrontation of symmetry and asymmetry in levels of polyrhythmic and polymetrics.

For example, the **principles** of number magic of the Middle Ages dictated composing process in John Tavener's *The Protecting Veil* (1987) for violoncello and orchestra. After Marianne Tatom a fragment of score from an example shows how tone scale for violoncello part is constructed according to the logic of magic numbers square (Tatom, 2000: 7) (Example 1).

Example 1. Magic square ciphers and a section from John Tavener's *The Protecting Veil* (1987), part 4, Cello melody.

Magic square and its transcription into number progressions

S	A	T	O	R	1	2	3	4	5
A	R	E	P	O	2	5	6	7	4
T	E	N	E	T	3	6	8	6	3
O	P	E	R	A	4	7	6	5	2
R	O	T	A	S	5	4	3	2	1

Scale with tonal center C and numerical equivalents:

C	D	E	F	G	A	B	C
1	2	3	4	5	6	7	8

Part 4 "Incarnation", rehearsal numerals 47-49

Influence of number squares's logic is observed in course of Lithuanian composer Šarūnas Nakas' composition *Ziqquratu* (1998). Here the law of square of two numbers (5 and 7) determined the organization of rhythmic parameter, whereas ziggurats (stepped pyramids) allegorized by graphical schemes dictated the tone scale of a composition. Incidentally, the composer personified the cabalistic numerical manipulations, because you may see a cryptographic interaction between magic squares chosen and composers name: the sum of letters is equivalent to numbers 5 and 7 (ŠARŪNAS=7 and NAKAS=5). Another example shows the influence of magic square to the rhythm of violin part (Example 2).

Example 2. Magic squares of numbers 7 and 5 and examples from Sarunas Nakas' *Ziqquratu* (1998): Violin part's rhythm and magic square of 5.

Basis of rhythm – magic squares of numbers 7 and 5

2	5	3	4	2+5;3+4=7	4	1	3	2	1+4;2+3=5
5	2	4	3	ŠARŪNAS	1	4	2	3	NAKAS
3	4	2	5		3	2	4	1	
4	3	5	2		2	3	1	4	

Violin part, 1-4 bars

A numerological symbolism with eminently wide expression is found in the music of 20th century. There are separate cases to be mentioned about the introduction of Christian numerology into the musical production. For example, Olivier Messiaen's constructive piano cycle *Vingt Regards sur l'Enfant-Jésus* (1994) is based on sacral topic, composition *La Transfiguration de Notre Seigneur Jésus-Christ* (1965–9) gives symbol of seven prominence, opus *Couleurs de la Cité céleste* (1963) is encoded with numeric symbolism of Revelation book. A symbol of cross is exalted in Sophia Gubaidulina's composition *In croce* (1979), and mystic of number seven in music piece *Семь слов* (1982). Annette Veit states to envisage numeric symbols of the Bible in these scores: Arnold Schönberg's *Jakobsleiter* and Paul Hindemith's *Psalmensymphonie* (Veit, 1991: 77).

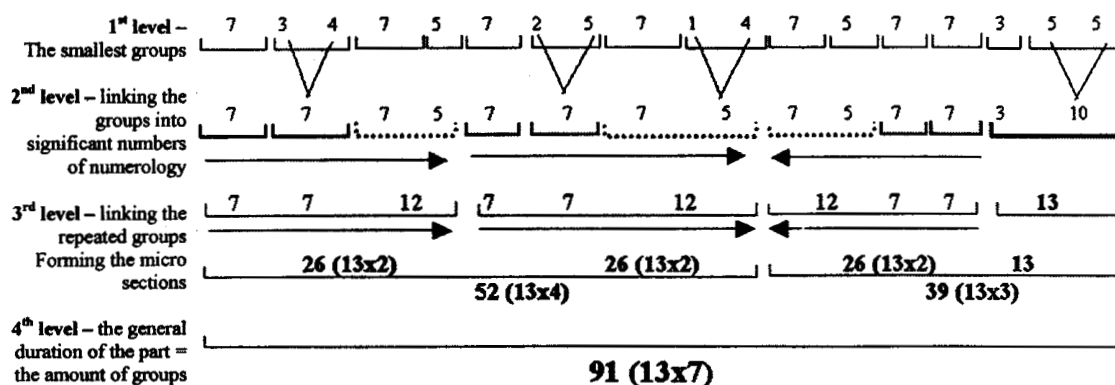
The spirit of Bible is prompted by numerical ciphers, found in Lithuanian composer Bronius Kutavičius' tetralogy *Jeruzalės vartai* (1991–1995). Another Kutavičius' composition – Second string quartet *Anno cum tettigonia* (*A year with grasshopper*, 1980) shows rehabilitation of symbols of cosmologic universe organization, that are related to phenomenon of seasons, in the matter of music: four seasons are symbolized by tone scale of organ part, run in a phonogram, overall twelve tones used in the composition or twelve beats of a bell match the number of months in a year, the rhythmic picture is determined by 7 days of a week, whereas the sum of composition bars equals to 365 days in a year.

Lithuanian composer Snieguolė Dikčiūtė in her composition *Septynių tiltų misterija* (*Mystery of seven bridges*, 1991) combined Christian and Pagan traditions through the prism of numerical symbol approach. Religious symbols are encoded in the name already – a bridge as a link between two worlds and eminently sacral Christian symbol – number 7, whereas the combination of these two elements is detected in Lithuanian folklore also. Thus the mentioned above number on purpose became a factor of composition structure, tone scale and rhythm.

Numeric allegories in music of 20th century manifest in individualized shape. For example, well known Alban Berg's *Concert for violin* (1935); the interpretation of numbers, found in its score is associated to dedication to "dead angel" – girl Alma Mahler. Imprint of number symbolism is mentioned in George Crumb's compositions *Makrokosmos I* (1972) and string quartet *Black Angels* (1970). The latter composition marked the end of war in Vietnam, so it was sensed with numerical ciphers in musical score: pitch, duration, relation between the parts, amount of instruments and other parameters were determined by two significant symbols – numbers 7 and 13. Composer used these numbers for creation of numerological plan of the composition – Program. For example, a manipulation with these numbers manifested after the analysis of rhythmic picture from the first part of quartet (Example 3).

Example 3. The plan of rhythm in George Crumb's *Black Angels* (1970).

1st Part "Threnody I: Night of the Electric Insects", combining the particular five note groups.



After detailed investigation of John Cage's *Ryoanji* (1983–5) it was observed that composer encoded numerical symbols of famous Japanese garden of sand and stones in the part for percussions and the sheet of score interpreted as a visual garden plane.

A number in the musical composition of 20th century functions in shape of various **numerical proportions or progressions**. For example, an influence of arithmetical proportion, expressed by a formula 1:2:3, is identified in Steve Reich's composition *Clapping Music*, whereas reference of rate in *Music for pieces of wood* was determined by ratios of harmonic proportions 3:4:6. There, three numerical formulas 5:4:3, 1:1 or 1:2:3 are noted in the titles of Sigfried Thiele's three part composition for oboe, violoncello and piano *Proportionen* (1971); those formulas determine grouping of beats and instrumentation. In the following example you may see the segments of scores, where grouping of rhythmic values determined by formula of numbers is shown (Example 4).

Example 4. Extension of number proportion 3:4:5 in the 1st Part of Sigfried Thiele's *Proportionen* (1971).

1st Part "Subjectum", the last bar
Rhythmic organization by the numbers 3:4:5

Segmentation of 12
of 12

2 3 4 5 6 7 8 9 10

3 4 5

Tone scale and its intervallic structure influenced by number proportion 3:4:5

3 : 4 : 5 Amount of semitones

m3 d3 g4

For example, in the final bar (bar 112) of the first part "Subjectum" with the numerical insertion 5:4:3 a succession of 12 tone series is "sheathed" into the rhythmic cloth, determined by the mentioned above proportion retrograde 3:4:5. As you can see, these numbers also determined the intervallic structure of tone series. Furthermore, S. Thiele organizes polyrhythmic episodes of composition on the basis of this numeric formula (Example 5).

Example 5. Polyrhythmic episodes in Sigfried Thiele's *Proportionen* (1971), formula's 5:4:3 variants.

1st Part, 29-30 bars

32-33 bars

89-90 bars

augend

At this point I would like to mention Conlon Nancarrow's *Studies for player piano*, where the use of polymetrics and polyrhythmic could be characterized as whole encyclopedia. The composer often invoked even very complicated mathematical ratios in order to implement them into the production. For example, *Study* No. 27 called "Canon 5%-6%-8%-11%", irrational and transcendental expressions of numbers are detected in *Studies* No. 33 and No. 40. In the *Study* No. 37, which is composed as a canon, the composer wrote tempos of 12 voices in ratios of numbers, that are shown in the example: $150-160^{5/7}-168^{3/4}-180-187^{1/2}-200-210-225-240-250-262^{1/2}-281^{1/4}$. Kyle Gann characterizes the last *Study* as one of the most wonderful expression of rate process in the music of 20th century (Gann, 1995: 193). It is known, that Nancarrow was eminently concerned about Henry Cowell's tractate *New Musical resources* (1930, it is stated, that the walls of Nancarrow's studio were patterned with Cowell's schemes, diagrams and charts for a long time) (Gann, 1995: 194), in mentioned above tractate, therefore, you may find the beginning of this number sequence: this is an equivalence of numerical relations of chromatic 12 tone scale (Example 6).

Example 6. Polyrhythmics in *Studies for player piano* by Conlon Nancarrow influenced by complicated mathematical proportions.

Study for player piano N. 27 "Canon 5%-6%-8%-11%"

Study for player piano N. 33 "Canon $\frac{\sqrt{2}}{2}$ " *Study for player piano* N. 40a "Canon $\frac{e}{\pi}$ "

Study for player piano N. 37 proportions of tempo of twelve voices

150 - 160^{5/7} - 168^{3/4} - 180 - 187^{1/2} - 200 - 210 - 225 - 240 - 250 - 262^{1/2} - 281^{1/4}

and equivalents to well tempered chromatic scale in :

281 ^{1/4}	15:8	si	B
262 ^{1/2}	7:4	si	B flat
250	5:3	la	A
240	8:5	la	A flat
225	3:2	sol	G
210 when 150:1	7:5	fa#	F sharp
200	4:3	fa	F
187 ^{1/2}	5:4	mi	E
180	6:5	mi	E flat
168 ^{3/4}	9:8	re	D
160 ^{5/7}	15:14	do#	C sharp
150	1:1	do	C

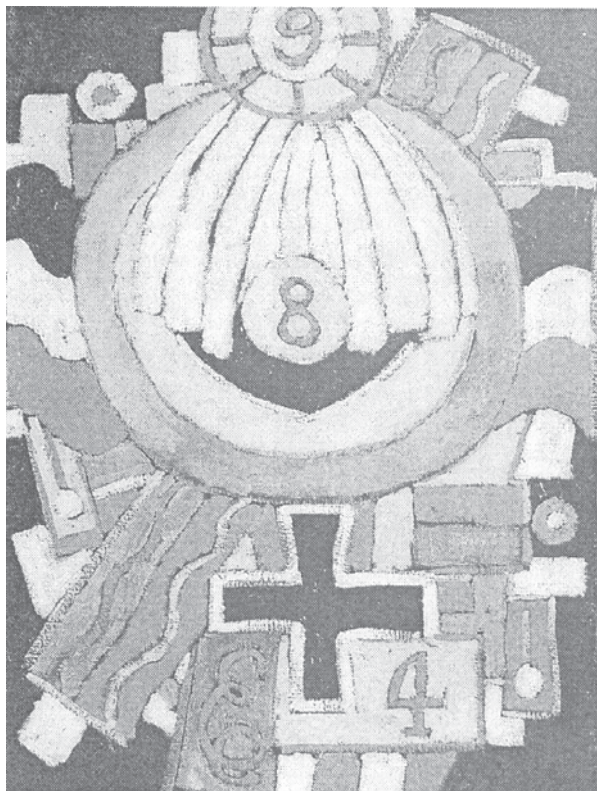
There, even György Ligeti, when composing the illusion of chaos in the first etude for piano *Désordre* (1985), chose polymetrics as a composing instrument in order to obtain parallel between symmetry and asymmetry. Morton Feldman, when creating an impression of a "violated" symmetry in his composition *Crippled symmetry* (1983) supplied one more version of symmetry phenomenon. John Cage composed *First Construction* structure with the aid of symmetrically set sequence of numbers 4-3-2-3-4. Likewise musicologist Gražina Daunoravičienė observed that Lithuanian composer Osvaldas Balakauskas has used in his *Second symphony* symmetrical sequences of numbers from 2 to 9 and backwards (together with another series 5-3-2-3-5) that influenced the rhythmic organization, segmentation of form into parts and composition of tone series.

If we talk about response of **numerical progressions** in the music, firstly we think about Fibonacci's phenomenon of number sequence that was expressed in the compositions of 20th century music in eminently various shapes. Belos Bartók's oeuvre is referred as a chrestomatic example of this phenomenon (for example, Erno Lendvai, who investigated the groups of sounds in organization of composition *Allegro barbaro*, 1911, states to have established the Fibonacci sequence). This numerical sequence intrigued Sophia Gubaidulina in her composition *Слышу... Умолкло...* (1986) – 1st, 3rd, 5th and 7th part meter crotchets are written in Fibonacci numbers 144-89-55-34. The metric organization in Karlheinz Stockhausen's *Klavierstück IX* (1961) is based upon the Fibonacci numbers; furthermore, group proportions in the play of this composer *Zyklus* (1959) are settled according to the numbers 1, 2, 3, 5, 8. Fibonacci progression is used in György Ligeti's play for harpsichord *Continuum* (1968) in the level of length parameter, whereas Cristobal Halffter dedicated to this phenomenon a composition for orchestra *Fibonacci* (1969).

We may state, that when using number series an individualized position of contemporary composers manifests also. For example, musical matter is constructed according to the composers' generated numerical series in Luigi Dallapiccola's play *Colore*. Analogically Lithuanian composer Remigijus Merkelys in his productions used progressions of numbers deduced himself; those were supported by prime numbers.

But alongside the phenomena that synthesize traditions of numerological music composition distinctive to earlier epochs, a new music mathematization tendency points out in the compositional practice of 20th century music also. This practice is interconnected with manifestations of **modern mathematic theories**. Also it is noticed an application of alternative scientific and mathematical terminology to compositional processes of music of 20th century. For example, Christine Burns notes the terms "system" and "mapping" used by composers Milton Babbitt, Otto Laske and Barry Truax (Burns, 1994: 3).

As we talk about implications of mathematics in the world of contemporary music, analogous phenomenon in other arts and sciences is observed too. In the first part of 20th century a trend of **structuralism**, which has disgorged into various humanitarian spheres – philosophy, psychology,



Example 7. Numerals in the fine arts. Marsden Hartley's *Portrait* (1914). Illustration from *Magie der Zahl in der Kunst des 20. Jahrhunderts*. Hrsg. von Karin v. Maur. Mit Beitr. von Ina Conzen. Ostfildern, 1997

linguistics, anthropology and so on, shows up. An example shows that creators choose a number as a theme for paintings or an object of image. For instance the elements of portrait consist not only of graphical symbols but also of numbers in the painting by Marsden Hartley. The second example is taken from artist Paul Klee's cycle of paintings that are unified by an idea representing the particular numbers. As well the artwork by Jasper Johns fixates the perspective conception of computer images where we may penetrate several versions at one time (Example 7).

Accordingly the structural elements of other arts and sciences disgorge into music of 20th century. It is evident an influence of structural linguistics to computer music because the algorithmic L-system (or Lindenmayer system) formulas based on the rules of formal grammar may be applied in the sphere of music composition. For instance, Kevin Jones analyses stochastic generative schemes and paradigms of Chomsky grammars that are used for composing music by computer (Jones, 1981). Charles Ames points out his piece *Crystals*, which he has composed applying mathematical modeling schemes based on Gestaltpsychology idea (Ames, 1982). One of the ways looking for music indeterminacy by John Cage he used astronomy science as a composing tool. The structure of *Atlas Eclipticalis* (1962) is based on ast-

ronomical charts: the notes were marked right on the spots of stars after laying the sheet of score onto star chart (Maurer, 1997: 2). The digital sequences of Earth magnetic field's fluctuations after converting them into sounds with the aid of computer were chosen as a base for audio material in *The Earth's Magnetic Field* (1970) by Charles Dodge (Alpern, 1995: 1). Morton Feldman offered an original decision of music composition's mathematization because he used numbers as notation symbols in several compositions. This composer was interested in the idea of music indeterminacy and in such scores he has marked only the quantity of tones and approximate tone pitch. The sketchbooks with digital notation are seen in such works as *IXION* (1958) and *Intersections II, III and IV* (1951–53) (Example 8).

Example 8. Numeral notation in Morton Feldman's *IXION* (1958). 1st page of score

Though the most complicated manifestation of mathematization in 20th century music compositions is influenced by implantation of modern mathematic theories. That for example an application of algorithmic procedures, recursive models, fractals, theories of chaos and Markov chains to music creation. As the first experiment of algorithmic computer composition is considered *Illiad Suite* (1955–56) for string quartet by Lejaren Hiller and Leonard Isaacson. The interval succession was programmed by algorithm of Markov chains (Mason, Saffle, Schütz, 1988; 794). It is well known that Yannis Xenakis was one of the first to begin the experiments with implications of stochastic processes and group theory in music material. The composer has invoked an original computer program of sounds synthesizing GENDYN (GENeration DYNamique or Dynamic Stochastic Synthesis) in his piece *Gendy 3* (1991) (Xenakis, 1992). Musicologist Griffiths points out the analogies with computer images by Mandelbrot in the layers of chromatic successions that he observed in the 6th etude for piano *Automne à Varsovie* (1985) by György Ligeti (Griffiths, 2001, Ligeti, 694). After investigating the piece by Charles Dodge *A Fractal for Wiley Hitchcock* (1989) I determined a fractal principle that was applied to creating process. Dodge composed the elements of tone pitch, rhythm and amplitude of another work – *Profile* (1984) by computer under the algorithm of 1/f noise. After remarks by musicologist Järveläinen Finnish composer Ville Pulkki in his composition *Kuusi* used the graphics of fractal – Koch snowflake that determined the parameter of piece structure (Järveläinen, 2000; 9). The principle of fractal as composing technique's algorithm was realized by Lithuanian composer Vytautas Jurgutis in *Fractals* (1999) (Example 9).

1st note G sharp is the same for all tone scale levels
 2nd note A manifests in four levels

Example 9. Fractal principle forming the 2nd piano melody. Vytautas Jurgutis' *Fractals* (1999)

Under the analysis of John Adams's composition *China gates* (1977) I should define that the parameter of time and relations between separate partitions were modeled using the curve algorithm as a graphical matrix charted in the first page of score. Martin Supper noted that Hanspeter Kyburz for his *Concert for saxophone and ensemble* has used algorithms of Lindenmayer system recursive sequences in the compositional process (Supper, 2000: 51). After Tom Johnson himself for prototype of composer's several works were chosen various mathematical equations. The equations of chaos theory such as Verhulst equation (that expresses the population growth studies) were in service for prototype in Gary Nelson's computer compositions *The Voyage of the Golah Yota* (1993). Nelson used Verhulst equation's diagram that was generate by computer into music sounds (Nelson, 1994).

Conclusion

Obviously the problem field of music and mathematics interaction splays out in 20th century. So after practical remarks and investigations I would like to highlight significant aspects of mathematical influence to 20th century music composition:

- *First*, the experience of compositional practice in earlier epochs is concentrated and synthesized in 20th century music remarkably;
- *Second*, a distinctly individualized composers' attitude and approach to tradition of *numerus sonorus* in music evidences, and
- *Third*, individual purposes of numerical procedures using are determined.

As we see many contemporary compositions hide themselves the way of special numerical "encoding" and ciphers of numerological interpretation that are distinctive in each of them. This aspect of searching the oneness, individuality and originality in every music piece determined that an age-old *numerus sonorus* experience and methods and tools of its implementation manifest in 20th century not only as synthesized but also sometimes as chaotic forms.

On the ground of mentioned above examples we could state, that the variety of numerical manipulations and composing methods in the music of 20th century is determined by subjective factor, often going alongside and even ignoring age-old traditions of numerical methods. The subjective factor of modern numerology manifests by:

- a) Choosing technologies and methods of composing;
- b) Reflecting every composer's different attitude to the possibilities of the same technologies and methods.

However in exceedingly varied and even chaotic numerical techniques of composing music in 20th century I would like to determine two summarizing tendencies of number manifestation:

- *First*, is connected with pure technological aspects of compositional process where the numbers are manipulated as composing implement or as structuralized algorithms during music piece creating without any semantic purpose, and
- *Second*, represents a detection and display of conceptual and semantic number function in music score. In this instance number is no longer composer's "work tool" only but also is a final result of creation process. Number functions both as organizing composition factor and as meaningful, semantic and symbolical idea or content of music composition.

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Santrauka

Matematikos įtaka XX a. muzikos komponavimo procesui

Pranešime tyrinėjama matematikos ir muzikos sąveika, įvairiomis formomis besitęsianti dar nuo antikos laikų. Antikos laikotarpiu gyvavo Pitagoro muzikos intervalų ir matematinių santykių sistema, o viduramžių misticizmas nulėmė tiek pačios kultūros, tiek ir muzikos sakralizaciją, sureikšmino religinius simbolius (taip pat ir skaičius, kuriems buvo suteiktos simbolinės reikšmės). Renesanso pasaulėžiūroje palikusi pėdsaką graikų intervalų racionalizacijos sistema, galima sakyti, atitiko šiai epochai būdingą antikos grožio filosofiją ir jos materialią išraišką – matematiniais simboliais išreikštų proporcijų santykius, jų atgaivinimą ir įkūnijimą įvairiose meno srityse – architektūroje, literatūroje, dailėje ar muzikoje. Muzikinė baroko epocha išsiskiria sakralia krikščioniškosios numerologijos tradicija, atėjusia iš mistiškos viduramžių pasaulėžiūros, ir ja pagrįsta komponavimo tradicija. Klasicizme matomos formos architektonikos proporcijos, plačiai suvokiamas „kvadratiškumas“ rodė matematiškai subalansuotų formos elementų darną. Nors dar XVIII a. muzikos sinonimas buvo „skambanti matematika“, tačiau Švietimo amžių pakeitęs romantizmas išsiskyrė itin suklestėjusiu antiracionalizmu („protas gali klysti, jausmas – niekada“) bei matematikos ir muzikos antagonizmo kulminacija.

Vis dėlto XX a. pradžioje į muziką vėl atsigręžta kaip mokslo objektą (pvz., I. Stravinskis teigė, kad „kompozitoriaus mąstymo specifika mažai skiriasi nuo matematinio mąstymo“), kuriame sukonzentruotas ir susintetintas ankstesnių epochų patyrimas, XX a. garsų meno ir skaitmens konstrukto sąveikų raiškos tampa itin įvairialypės, koegzistuojančios kaip skirtingų numerologinių tradicijų sankloda: XX a. muzikoje daug įvairių religijų numerologinės simbolikos, pasaulio harmonijos proporcijų, skaitmeninių progresijų (Fibonacci, Luco), „aukso pjūvio“ proporcijos, simetrijos ir asimetrijos konfrontacijos poliritmijos, polimetrijos lygmenyse.

Greta ankstesnių epochų savitas numerologines muzikos komponavimo tradicijas sintezavusio fenomeno XX a. išryškėja ir nauja muzikos matematizacijos kryptis, susijusi su šiuolaikinės matematikos teorijomis. Tai inspiravo naujos pakraipos analizės: algoritminių procedūrų, rekursinių modelių, fraktalų, chaoso, tikimybinės Markovo grandžių teorijos taikymo muzikos kūrimui tyrimai (pvz., Y. Xenakis eksperimentavo su stochastinių procesų, grupių teorijos implikacijomis į muzikos audinį; C. Nancarrowo kanonų tempus ar T. Johnsono kompozicijų struktūrą diktavo matematinės formulės; G. L. Nelsono kompiuterinės kompozicijos pirmavaizdžiais tapo granulių sintezės ir chaoso teorijos lygtys; Ch. Dodge'as kūrybos procesui pritaikė fraktalų principus; J. Cage'as ar M. Feldmanas eksperimentavo su tikimybių teorijos apraiškomis muzikoje). Keletą šių aspektų iliustruoja ir pranešime pateikiamos muzikos kūrinių analizės.