Revised Selected Papers

Accademia Musicale Studio Musica
Michele Della Ventura, *editor*

2020

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Preface

This volume of proceedings from the conference provides an opportunity for readers to engage with a selection of refereed papers that were presented during the International Conference on New Music Concepts, Inspired Education and New Computer Science Generation. The reader will sample here reports of research on topics ranging from a diverse set of disciplines, including mathematical models in music, computer science, learning and conceptual change; teaching strategies, e-learning and innovative learning, neuroscience, engineering and machine learning.

This conference intended to provide a platform for those researchers in music, education, computer science and educational technology to share experiences of effectively applying cutting-edge technologies to learning and to further spark brightening prospects. It is hoped that the findings of each work presented at the conference have enlightened relevant researchers or education practitioners to create more effective learning environments.
This year we received 57 papers from 19 countries worldwide. After a rigorous review process, 24 paper were accepted for presentation or poster display at the conference, yelling an acceptance rate of 42%. All the submissions were reviewed on the basis of their significance, novelty, technical quality, and practical impact.

The Conferece featured three keynote speakers: Prof. **Giuditta Alessandrini** (Università degli Studi Roma TRE, Italy), Prof. **Renee Timmers** (The University of Sheffield, UK) and Prof. **Axel Roebel** (IRCAM Paris, France).
I would like to thank the Organizing Committee for their efforts and time spent to ensure the success of the conference. I would also like to express my gratitude to the program Committee members for their timely and helpful reviews. Last but not least, I would like to thank all the authors for they contribution in maintaining a high-quality conference and I hope in your continued support in playing a significant role in the Innovative Technologies and Learning community in the future.

March 2020

Michele Della Ventura

Michele Della Ventura

Conference Chair

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Computer Science

3-Dimensional Motif Modeling for Music Composition

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Abstract. This paper discusses a principle of handling notes and motifs in 3-dimensional (3D) space as a technique towards a new method of music composition. In European classical music, a relatively small number of motifs are repeatedly used to form entire music pieces or movements by repeating, imitating and transposing the primary motifs. Moreover, these motifs are sometimes inverted, reversed, lengthened or shortened. To generalize this principle of motif manipulation operations, we begin with a short discussion of a 2-dimensional affine transformation representation, and develop this idea into a formalization of notes in a music score as triplets of the onset time, pitch and note duration, equivalent to vectors (x, y, z) in 3-dimensional space. Thus, a set of notes, often referred to as a motif, subject, object, fragment, chord, figure, *etc.* depending on the context, can be represented by a set of points forming an object in 3-dimensional space. Rotation of such an object yields countless variants of note sequences from various rotation angles. This new approach was applied to music composition of several pieces for performance in commercial concerts, some being scheduled for publication.

Keywords. 3-dimensional note space, melodic motifs, rotation, affine transformation, music composition

1 Introduction

In the long history of music, one major principle of composition has been the systematic manipulation of characteristic patterns of multiple notes (often referred to as motifs, motions, figures, phrases, patterns, components, series, objects or music material, depending on the music analysis context) by repeating, imitating, transposing and repeatedly placing them in the piece based on some underlying musical structure. Most music pieces, simple or complex, classical or modern, employ this basic principle explicitly or implicitly, to provide the piece with a specific character, unity and variety. Most existing music pieces are influenced by this imitation principle to varying degrees. The employed operations are often traced and analyzed in musicology and repeatedly used in composition by composers. Systematic creation and development of the basic patterns is an inevitable (training) discipline in music composition and new approaches to this process are always being sought after by modern music composers.

Various pattern manipulation operations were developed in western classical music. Patterns are often inverted, reversed, expanded, compressed and decorated. One extreme example of retrograde (time reversal of motifs) can be observed in Rondeau 14, "Ma fin est mon commencement" ("My end is my beginning") by 14th-century composer Guillaume de Machaut [1], and numerous examples of such elaboration are found in J. S. Bach's "Musikalisches Opfer" (BWV1079) [2] and "Die Kunst der Fuge" (BWV1080) [3]. These systematic operations on patterns of note sequences were sought after until recently, e.g., in Arnold Schoenberg's 12-tone theory (dodecaphonic compositions) [4] where inversion, retrograde and retrograde inversion are applied to 12-tone motifs, as well as in total serialism [5] by Milton Babbitt, and a musical set theory by Howard Hanson [6] which provided concepts for categorizing musical objects and describing their relationships.
Summarizing the authors' view of the history of note pattern manipulation, there is a firm principle of having patterns developed systematically with several operations and placing the yielded patterns all across the music piece.
This paper discusses a mathematical generalization of notes and their patterns and manipulation operations through 3-dimensional formalization to enable a novel approach to motif development for music composition, and presents some examples of music pieces composed in our on-going project, which were performed in several commercial concerts of artistic modern music.

2 Geometrical formalism of music notes

2.1 Repetition, imitation, transposition, inverse and retrograde

Fig. 1 shows a typical example of precise motif analysis of J. S. Bach's Invention No. 1 in C-dur (BWV 772). To simplify the following discussion, we use the word "pattern" to refer to a set of multiple notes, instead of motif, phrase, subject, figure, object, chord, passage, *etc.*. Fig. 2 shows the simplified structure in terms of similar patterns, where the pattern labeled "1", consisting of 7 notes, is imitated, shifted in time by 2 beats, transposed down by an octave, and placed at the position labeled "2" in the bass staff. It is also duplicated, shifted by 4 beats, transposed up by fifth and placed at label 3. At labels 5 and 7, the same motif is duplicated, inverted, transposed up, and placed on the treble staff. Such operations are commonly used in music composition. These pattern operations are even clearer visible in the piano-roll representation of Fig. 3, where the primary pattern 1 is copied and pasted to 2, 3 and 4, inverted and pasted to 5 and 7, and partly copied, lengthend to double length and pasted to 6 and 8.
In this exmple, patterns 5 and 7 result from mirror image operations on the primary pattern 1 along the horizontal axis, *i.e.*, a line symmetry mirror operation, in addition to slight adjustments fitting the mirrored pattern to the underlying diatonic scale. Though not included here, retrograde is the line symmetry mirror operation with respect to the vertical axis. Furthermore, retrograde inversion is the point symmetry mirror operation, which is equivalent to 180-degree rotation in the 2-dimensional piano-roll

plane.
Our primary motivation of this research is to generalize these operations to provide music composers with a new method of developing the original pattern.

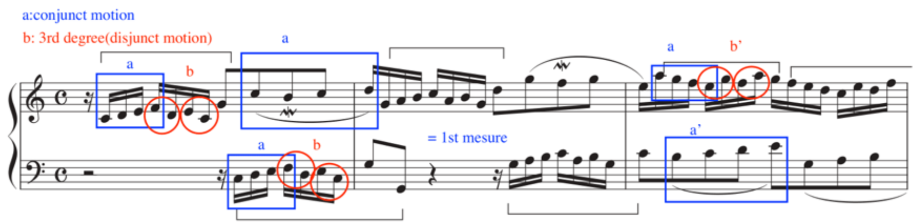

Fig. 1. Precise motif analysis of J. S. Bach: Invention 1 in C-dur, BWV 772.

Fig. 2. Simplified structure of J. S. Bach: Invention 1 in C-dur, BWV 772: red – fundamental form of the "motif" (*or* phrase, figure, pattern, subject, *etc.*); blue – inversion; green – augmentation.

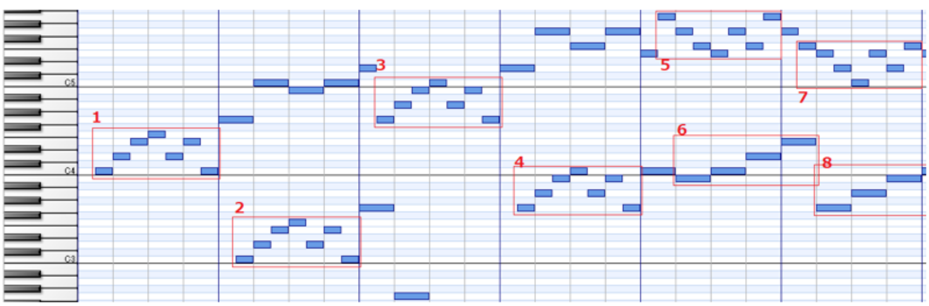

Fig. 3. Piano-roll representation of the notes of Fig. 1 and 2.
(Vertical thick lines represent every two beats.)

2.2 Affine transformation representation of pattern operations

In the geometric piano-roll representation in 2 dimensions, one can use any time scale for the x-axis, such beats or miliseconds, and any pitch scale for the y-axis, such as MIDI note numbers or cents, depending on whether score-oriented or physically considered. The above mentioned pattern operations including repetition, transposition, inversion, retrograde, augmentation, *etc.* and their combinations can be represented by affine transformations where any point vector $\boldsymbol{p} = (x, y)^T$ of the primary pattern "1" in the piano roll is mapped to $\boldsymbol{p}' = (x', y')^T$ in the modified pattern, using a matrix $\boldsymbol{A} = \begin{pmatrix} a_{xx} & a_{xy} \\ a_{yx} & a_{yy} \end{pmatrix}$ and a transposition vector $\boldsymbol{t} = (t_x, t_y)^{\boldsymbol{T}}$ as follows:

$$\boldsymbol{p}' = A\boldsymbol{p} + \boldsymbol{t}$$

or, equivalently,

$$\begin{pmatrix} x' \\ y' \\ 1 \end{pmatrix} = \begin{pmatrix} a_{xx} & a_{yx} & t_x \\ a_{xy} & a_{yy} & t_y \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ 1 \end{pmatrix}$$

where t_x and t_y denote the time shift and pitch transposition from the primary pattern, respectively. Simple repetition and transposition corresponds to using an identity matrix, *i.e.*, $A = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$, inversion (*e.g.*, patterns 5 and 7) to $A = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$, retrograde to $A = \begin{pmatrix} -1 & 0 \\ 0 & 1 \end{pmatrix}$, retrograde inversion to $A = \begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix}$, and double-length augmentation (*e.g.*, patterns 6 and 8) to $A = \begin{pmatrix} 2 & 0 \\ 0 & 2 \end{pmatrix}$. In particular, if the (x, y) coordinate origin is set to the beginning of the score and the pitch of C4, and x- and y-axes are scaled in beats and semitones, respectively, every point $\boldsymbol{p} = (x, y)^{\boldsymbol{T}}$ of pattern 1 is mapped to a point $\boldsymbol{p}' = (x', y')^{\boldsymbol{T}}$ in pattern 5 by:

$$\begin{pmatrix} x' \\ y' \\ 1 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 8 \\ 0 & -1 & 21 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ 1 \end{pmatrix}.$$

By setting a_{xy} and a_{yx} to non-zero values, the conventional motif operations can be generalized to rotation by an arbitrary angle θ, corresponding to $a_{xx} = \cos\theta,\ a_{xy} = \sin\theta, a_{yx} = -\sin\theta,\ a_{yy} = \cos\theta$. Retrograde inversion can be regarded as the special case of $\theta = \pi$. Additionally, skew and shear can also be included in the general affine tranformation as a homomorphism for projection tranformation, a bijection that maps lines to lines. Introducing rotation by arbitrary rotation angles leads to a new approach of systematically deriving countless variants from the original motif.

3 3-dimensional formalization of notes and figures

3.1 Vector representation of notes

To simplify the above geometrical formalism of motif operations and provide more freedom, we introduce a 3-dimensional note representation. A note in a conventional music score of pitched music can be specified as a triplet comprising onset time x, pitch y and duration z, *i.e.*, as a "note vector":

$$P = (x, y, z)^T$$

which is interpreted as a point in 3-dimesional vector space (ignoring non-pitched notes, dynamics, articulation, tempo, lyrics, timbre, grace notes and other additional information as in Fig. 2). This implies that any conventional music score (or any portion) consisting of N notes placed on a staff is equivalent to a set of N note vectors,

$$M = \{ P_i = (x_i, y_i, z_i)^T \mid i = 1, \cdots, N \}.$$

Typically, if M represents a single-voice continuous melody, x and z are not independent as $x_i + z_i = z_{i+1}$, but non-continuous melodies, multiple voices and chords require independent x- and z-values. For mathematical consistency, negative duration is defined as shifting the note onset back in time by $-z_i$, *i.e.*, swapping note onset and end with the actual note duration being $-z_i$.
In this formalism of notes, any entire or fragmental phrase, figure or motif can be represented by a set of vectors and interpreted as an object in a 3-dimensional (hereinafter "3D") "note space." This enables geometrical manipulations of music as discussed in the following.

3.2 Notes and pattern operations

For demonstration of the 3D note space formalism, pattern 1 in Fig. 2 consisting of $N = 7$ notes can be written as follows:

$$\begin{aligned} M_1 = \{ &(0.25, 0, 0.25)^T, (0.5, 2, 0.25)^T, (0.75, 4, 0.25)^\mathrm{T}, (1, 5, 0.25)^\mathrm{T}, \\ &(1.25, 2, 0.25)^T, (1.5, 4, 0.25)^T, (1.75, 0, 0.25)^T \} \end{aligned} \tag{1}$$

with scaling of x and z in beats and y in down-shifted MIDI pitch so that the central C4 corresponds to 0.

Since pattern 2 in the same figure starts 2 beats later and 12 semitones lower than the primary pattern P_1, it is written as follows:

$$M_2 = \{ (x_i + 2,\ y_i - 12,\ z_i)^T \mid (x_i, y_i, z_i) \in M_1 \} = T(2, -12, 1)\, M_1$$

where $T(u, v, w)$ represents a transposition operator that adds u, v and w to x, y and z components, respectively. Similarly, transposed and imitated phrases are represented by:

$$M_3 = \{ (x_i + 4, y_i + 7, z_i)^T \mid (x_i, y_i, z_i) \in P_1 \} = T(4, 7, 1)\, M_1$$
$$M_4 = \{ (x_i + 6, y_i - 5, z_i)^T \mid (x_i, y_i, z_i) \in P_1 \} = T(6, -5, 1)\, M_1$$

and inverted phrases by:

$$M_5 = \{ (x_i + 8,\ 21 - y_i,\ z_i)^T \mid (x_i, y_i, z_i) \in P_1 \} = T(8, 21, 1)\, K(1, -1, 1)\, M_1$$
$$\begin{aligned} M_7 &= \{ (x_i + 10,\ 17(or18) - y_i,\ z_i)^T \mid (x_i, y_i, z_i) \in M_1 \} \\ &= T(10,\ 17(or18), 1)\, K(1, -1, 1)\, M_1 \end{aligned}$$

where $K(a, b, c)$ represents a multiplication operator to multiply x, y and z with factors a, b and c, respectively, for each element of the operand set of note vectors and "or" represents a slight modification in pitch to adjust the resulting note set to the tonality or scale. Moreover, augmented patterns are represented by:

$$M_6 = \{ (2x_i + 9, y_i - 1(or2), 2z_i)^T | (x_i, y_i, z_i) \in M_1 \text{ and } i < 5 \}$$
$$= T(9, -1,2)\ K(2,1(or2),2)\ M_1(\text{first four notes})$$
$$M_8 = \{ (2x_i + 9, y_i - 5, 2z_i)^T | (x_i, y_i, z_i) \in M_1 \text{ and } i < 5 \}$$
$$= T(9, -5,2)\ K(2,1,2)\ M_1(\text{first four notes})$$

Note that M_5 and M_7 contain negative y-coefficints (= -1) and M_6 and M_8 include non-trivial x-coefficients (=2).

Thus, the music example of Fig. 2 can be represented by $S\,M_1$ in terms of pattern utilization, where the music structure S is denoted independetly from the pattern as follows:

$$S = 1 + T(2, -12,1) + T(4,7,1) + T(6, -5,1)$$
$$+T(8,107,1)K(1, -1,1) + T(9,1,2)K(2,1,1) + T(10,25,1)K(1, -1,1)$$

The detailed motif analysis in Fig. 1 can be formalized mathematically likewise.

3.3 Motif as a 3-dimensional object

Being represented by a set of 3-dimensional vectors, a pattern forms a 3D object, which we call "3D motif" in this paper, consisting of N vectors:

$$M = \{ (x_i, y_i, z_i)^T, \qquad i = 1, \cdots, N \},$$

The inverted form of pattern M can be understood as the mirror image of the original pattern across the x-axis and algebraically represented as:

$$P' = \{ (x_i, -y_i, z_i)^T, \qquad i = 1, \cdots, N \}$$

ignoring the offset components. The retrograde form is the 180-degree rotation around the y-axis, *i.e.*, point-symmetrical rotation of the motif, and algebraically represented by:

$$P'' = \{ (-x_i, y_i, -z_i)^T, \qquad i = 1, \cdots, N \}$$

where the negative note duration means shifting the note onset back in time by z_i from the onset time $-x_i$, *i.e.*, $P'' = \{ (-(x_i + z_i),\ y_i,\ z_i)^T, i = 1, \cdots, N \}$. The retrograde inversion of pattern P can be understood as the mirror image across z-axis and is algebraically represented as:

$$P''' = \{ (-x_i, -y_i, -z_i)^T, \qquad i = 1, \cdots, N \}.$$

Augmentation (doubling note lengths) is represented by:

$$P'''' = \{ (2x_i,\ y_i, 2z_i)^T, \qquad i = 1, \cdots, N \}.$$

3.4 Rotation of a 3D motif

Since any 3D object can be rotated freely in the 3D space, the rotation angle can be generalized to not being limited to 180 degrees. This idea yields a new approach to pattern manipulation. If the object is rotated by rotation angle θ around a rotation axis of declination ϕ and elevation ψ from the x-axis, any 3D point vector $\boldsymbol{p} = (x, y, z)^{\boldsymbol{T}}$ is moved to another point $\boldsymbol{p}'$ by:

$$\boldsymbol{p}' = R(\varphi, \psi, \theta)\, \boldsymbol{p}$$

where $R(\varphi, \psi, \theta)$ is the rotation matrix given by Rodrigues' formula [7]:

$$R(\varphi, \psi, \theta) = \begin{pmatrix} \cos\theta + n_x^2(1-\cos\theta) & n_x n_y(1-\cos\theta) - n_z\sin\theta & n_x n_z(1-\cos\theta) + n_y\sin\theta \\ n_y n_x(1-\cos\theta) + n_z\sin\theta & \cos\theta + n_y^2(1-\cos\theta) & n_y n_z(1-\cos\theta) - n_x\sin\theta \\ n_z n_x(1-\cos\theta) - n_y\sin\theta & n_z n_y(1-\cos\theta) + n_x\sin\theta & \cos\theta + n_z^2(1-\cos\theta) \end{pmatrix}$$

and the unit vector directing the rotation axis is given as:

$$n_x = \cos\varphi\cos\psi, \qquad n_y = \sin\varphi\cos\psi, \qquad n_z = \sin\psi\,.$$

Retrograde is a special case that $\varphi = \frac{\pi}{2}$, $\psi = 0$, and $\theta = \pi$ while inversion and retrograde inversion are combinations of mirror imaging and rotation.
When generalizing the rotation angles (not limited to 90 or 180 degrees), any combination of 3 general rotation angles (φ, ψ, θ) yields a corresponding pattern. Thus, the orginal motif in the music score is equivalently represented by a 3D motif, $P = \{\, (x_i, y_i, z_i)^T,\ i = 1, \cdots, N \,\}$, which can be rotated according to the 3 angles (φ, ψ, θ) in 3-dimensional space to result in another 3D motif, $P' = \{\, (x_i{}', y_i{}', z_i{}')^T,\ i = 1, \cdots, N \,\}$, equivalently representing a variant of the original motif. Some "quantization" is involved such that fractional pitch values are rounded to an available (performable) pitch or to a reasonable pitch according to the diatonic scale, the tonality or the chord, and onset timings are represented by conventional note notation.
Small rotation angles are expected to result in a motif that is similar to the original motif, while large rotation angles may result in significantly different motifs. This principle is a generalization of conventional pattern inversion and retrograde operations and holds high potential for generating countless motif variants possibly preserving some common features drived from the original pattern.
By including parallel shift in the 3-dimensional space, the 3-dimensional affine tranformtion comprising rotation and shift can be given in the following form:

$$\begin{pmatrix} x' \\ y' \\ z' \\ 1 \end{pmatrix} = \begin{pmatrix} r_{xx} & r_{yx} & r_{zx} & t_x \\ r_{xy} & r_{yy} & r_{zy} & t_y \\ r_{xz} & r_{yz} & r_{zz} & t_z \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix}$$

If the upper-left 3×3 submatrix of the above is the Rodrigues' rotation matrix and

$\left(t_x, t_y, t_z\right)^T$ is the displacement vector, this formula is the general expression of composition based on the 3D rotation of the given original motif. If the above 12 matrix components are freely manipulated, the deformation of the 3D object can include skews and shear, not being limited within translation (parallel shift) and rotation.

3.5 Motifs derived from molecular models

Once it is understood that any set of notes can be represented by a 3D object consisting of N points, patterns can be derived from real 3D objects. One typical 3-dimensional object consisting of a certain number of points is the chemical structure of molecules containing 3-dimentional coordinates of constituent atom centroids. If molecular data with atom centroid coordinates (x_i, y_i, z_i) to form 3D objects is available, such as MOL data [8], these 3D objects can be rotated according to Eq. 2 to yield modified patterns for the chosen set of angles (ϕ, ψ, θ).

Fig. 4 illustrates the molecular model of ethyl alcohol (C_2H_5OH) rotated by 0, 10, 20, 30 and 90 degrees around the axis with declination ϕ =45 degrees and elevation ψ =45 degrees. In the left column of Fig. 4 one can see the rotated molecular model. The center column shows a projection of the constituent atom coordinates onto the treble staff. The molecular dimensions in nm are properly scaled such that y-values fit into a pitch range of MIDI pitches (C4-A5) when projected onto the treble staff, and such that x-values fit the preferred time interval (depending on the planned tempo). The right column displays the obtained note patterns derived from this procedure, although z-values are not used here. These figures were quantized with a vertical resolution of 32th note length and a horizontal resolution of semitone distance.

Atom labels are given for a possible use for timbre. z-values are represented as dynamics (ppppp – ffffff) instead of note duration for composition purpose. These figures show that a small change in the rotation angles θ causes a slight change in the resulting pattern, whereas a large rotation results in a large change in the resulting pattern. This means that, from a single pattern, an infinite number of its variants can be autmatically produced, though they may be "quantized" to an finite number due to time and pitch resolutions according to the diatonic scale, tonality, chord, and rhythm.

In summary, the 3D principle is a productive approach enabling to produce new patterns automatically and systematically from an original 3D object using real-valued sets of rotation angles (ϕ, ψ, θ).

4 Composition samples based on the 3D principle

The 3D principle was applied to composition for commercial concerts and publications.

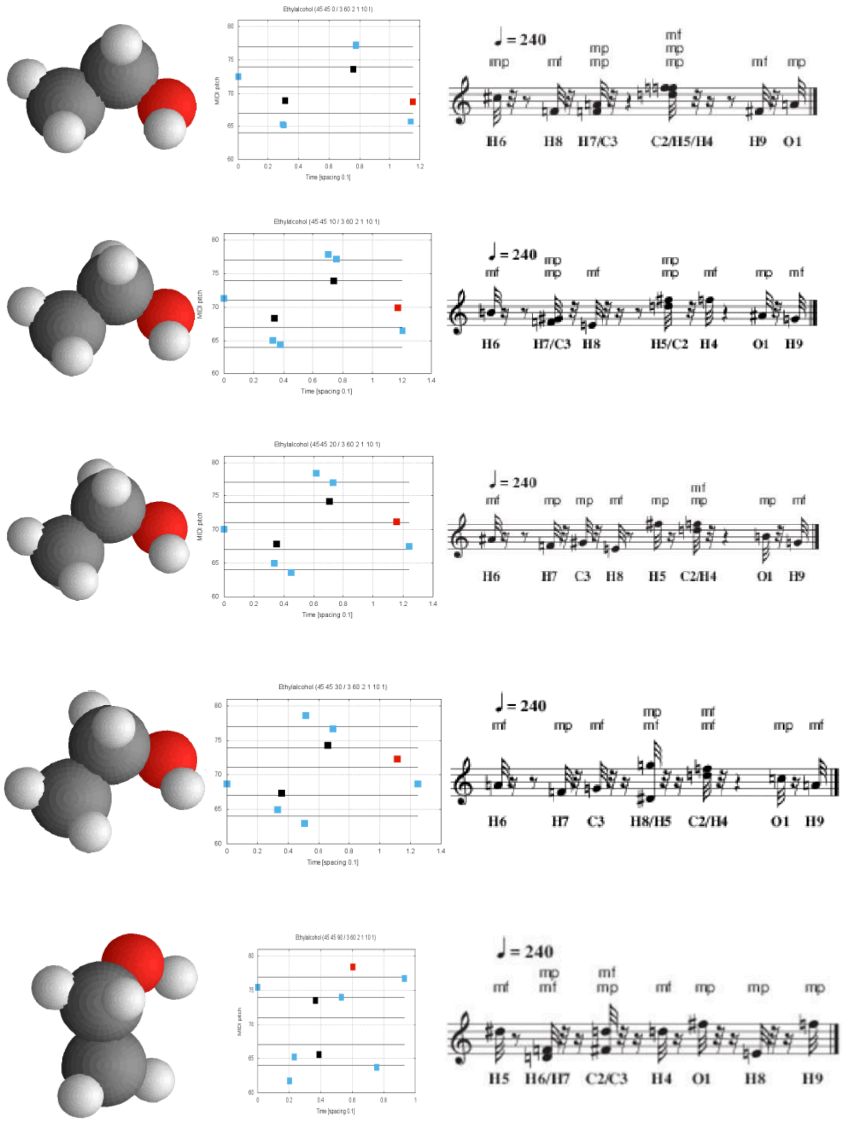

Fig. 4. Rotation of the molecular model of ethyl alcohol for generating motifs.
Left: Rotated molecular model of ethyl alcohol ($\theta = 0, 10, 20, 30$ and 90 $degrees$).
Center: x-y plot of atom centroids of the molecule projected onto the treble staff.
Right: Derived score from the plot; Note duration ignored.

Fig. 5 shows the opening of a piece composed by one of the authors (H. Kaneko). A 3D object representing a molecular model of Vitamin C ($C_6H_8O_6$) generates changing note onset time, pitch and dynamics (instead of note duration) corresponding to (x, y, z)

values as it rotates, resulting in a variety of chords. Since they do not follow any musical rules such as functional harmony in tonal music, 3D-generated chords have no functionality and may result in chaotic sounds as in serial music. To cope with this problem, Fig. 4 employed y-scaling according to a harmonic partial numbering to guarantee the harmonicity of the resulting sound. This idea was inspired by the concept of spectral music initiated by Gerard Grisey and Tristan Murail.

Another 3D-based composition is shown in Fig. 6 entitled “Dance of molecules – composition for 3D modeling” for viola solo. This was derived from the molecular model of anthocyanin (Fig. 6).

Fig. 5. Hitomi Kaneko (2019): “Vitamin C” - Composition by 3D modeling V – for two saxophons.

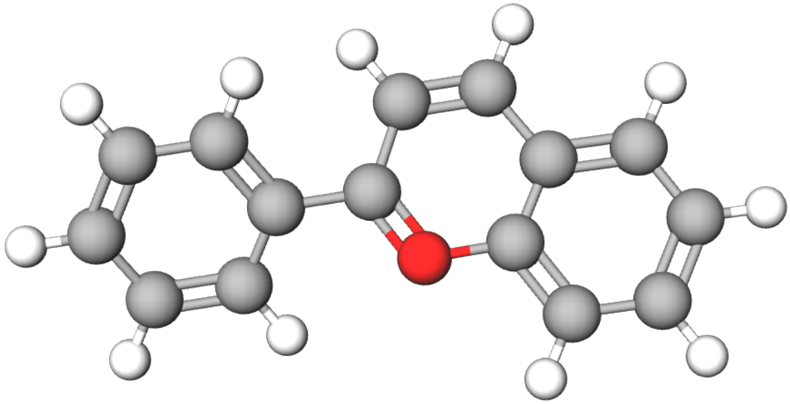

Fig. 6. Molecular model of anthocyanin.

5 Future extensions and open issues of 3D music motif modeling

The presented geometrical formulation of notes and patterns is quite simple and straight forward, and there are possible future extensions and issues to discuss.

1) Isometry in 3D space:
   Scaling between 3D coordinates and music notes can be arbitrary and depends on the composer's preference. If a meaningful scaling is sought, an objective answer may be found through psychoacoustic equivalence relationships between the time difference and the pitch difference. Concisely: What is the ratio between a pair of sounds with time spacing x and pitch spacing y such that these spacings are perceived as equivalent by humans?
2) z-values:
   In the above discussion, z is originally defined as the note duration, while it can be replaced by another property, *e.g.,* dynamics, timbre, articulations, *etc.* because note onset time is of great significance whereas duration is less so. Mathematically, if the 3D framework is maintained, z could be anything.
3) More general 3D operations:
   As the 3D operations discussed in this paper are mainly rotations of 3D objects, other operations such as skew, shear and mirror images can be included based on 12-degree-of-freedom 3-dimensional affine transform, though intuitive understanding may become harder for human composers. Just as rotation and parallel shift discussed in this paper, mirror images, skew and shear can be separately discussed to develop new techniques for music composition.
4) 3D angle vectors:
   The triplet of relevant angles (ϕ, ψ, θ), *i.e.*, declination, elevation and rotation, forms a 3-dimensional vector. If the angle vector smoothly moves in the 3-dimensional space, the object turns accordingly and yields real-valued variants of the original pattern.

5) Multiple 3D objects:
Multiple objects can be introduced into the same 3-dimensional space and rotated independently to generate a large variety of 3D music.
6) Higher dimensions:
3D modeling naturally further suggests generalization to a higher-dimensional space. This may lead to a "method of composition using series of pitches, rhythms, dynamics, timbres or other musical elements" (quoted from the Wikipedia article on "Serialism"). The relationship between 3D motifs and serialism may be an interesting research topic.
7) 3D software tool for public use:
Sharing a toolkit or a web-based tool for 3D motif operations for public use may be useful for music composition based on the 3D principle in music writing and in algorithmic composition.

6 Conclusion

This paper introduced a principle of 3-dimensional (3D) modeling for mathematical handling of notes and motifs. Notes represented as 3D points, and motifs as objects comprising multiple such 3D points. Rotation was then discussed to generalize the existing operations of retrograde inversion of motifs to any rotation angle around any axis. Molecular models were used as 3D objects to derive motifs from, based on which music pieces were composed. Extensions of this model and related future issues were discussed.

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