Harmonic pulsation and serial density

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Background in musical structures. One of the key factors of musical form generation is the harmonic pulsation. Its acceleration, as a rule, accompanies the processes of development, and it also often indicates the beginning of the developing section of a musical form. The form-generating opportunities of harmonic pulsation can be tracked by applying the technique of eventive density calculation, described earlier (Kulichkin & Zubareva, 2004).

Background in applied mathematics. The tensity function in a musical piece may be determined as Fuzzy set $\mathbf{F_N}$ = ($\mathbf{F_P}$, $\mathbf{H_P}$, $\mathbf{R_P}$), where $\mathbf{F_P}$, $\mathbf{H_P}$ and $\mathbf{R_P}$ are Fuzzy sets describing the number of texture, harmony and rhythm «events» per time unit (their density). The density of rhythmic events is determined using the quantity of attacked sounds, the density of harmonic events – based on the number of accord changes, and the density of texture events – as an average degree of accords' consonance/dissonance (Kulichkin & Zubareva, 2005).

Aims. The object of the present paper if the calculation of harmonic events ($\mathbf{H_p}$) for serial music. Is there a change in harmonies in such musical pieces? Or is such music based on other principles, absolutely alien to all the preceding music?

Main contribution. There is in reality a counterpart of harmonic pulsation for serial music. This is serial density ($\mathbf{H_p}$).

Implications for musical practice. It is known that in serial music everything subdues to the work with a series, but the technique can not (and probably should not) be perceived directly. The aural sense perceives it, most likely, as a certain arrangement of sound events. Thus, we are likely to have discovered the mechanism, by which serial technique manages the "elementary entities of music".

Implications for musicological interdisciplinarity. The results obtained allow us to attribute the analyzed parameters to a general phenomenon studied by various sciences. Thus, physiological data evidences high density of internal apprehension, while linguistics proves the important role of informational density in the conceptual execution of new knowledge. It is quite possible that the examined changes in density of sound events and their consequence, i.e. changes in tensity, belong to the universal means of coding any information (biological, scientific, aesthetic, etc.).

One of the key factors of musical form generation is the harmonic pulsation. Its acceleration, as a rule, accompanies the processes of development, and it also often indicates the beginning of the developing section of a musical form. The form-generating opportunities of harmonic pulsation can be tracked by applying the technique of eventive density calculation, described earlier (Kulichkin & Zubareva, 2004).

Textural density

One of the branches of numerical approaches in modern musicology is connected with studying "objective" properties of a harmonic vertical - "textural density". Paul Hindemith (1940, S. 125-129), who denominated this quality as a "harmonic tension", considered that it depends on the interval composition of chords. He also showed variation of harmonic tension, where tonal relations play no role, and below is a figure, which visualizes such changes:

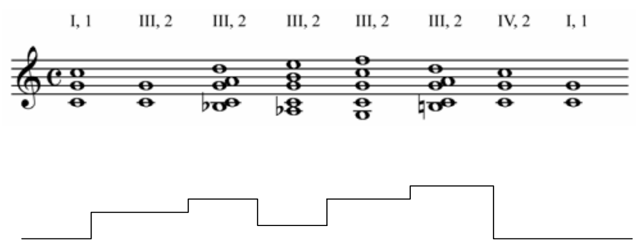

Figure 1. Variation of "harmonic tension" (Paul Hindemith's example).

Later on, using Hindemith's gradation of intervals and taking into account compound as well as simple ones, Russian musicologist

Yuzef Kon derived the formula of chord density (Kon, 1971, p.309):

$$\mathbf{D} = \frac{\sum(\mathbf{I} - \mathbf{Rci})}{\mathbf{R}},$$

where **D** is the general density of a chord, **I** is the index of an interval's density:

Interval	**I**
Tonic	0
Octave	1
Fifth	3
Forth	4
Little sixth	5
Large third	6
Large sixth	7
Little third	8
Little seventh	9
Large second	10
Large seventh	11
Little second	12
Triton	13

Table 1. Values of index of density **I** for various intervals.

R is the register index [Because of down level of computing technology, that Yuzef Kon could use in 1971, he approximated this index by natural numbers, but now it's better to associate **R** with a continuous function, for example – with logarithm of bass pitch]. Whereas we are interested in the eventive dynamics, that is, the value of D in a unit of time, Yuzef Kon's formula has to be modified in the following manner:

$$\mathbf{D} = \frac{\mathbf{D}_1 + \mathbf{D}_2 + \ldots \mathbf{D}_n}{\mathbf{n}^i},$$

[The row (1, 2, ... n) designates the number of elements in a textural figure]

Dynamics of event density

As textural density we can register the changes of inter-disposition of tones within a sound construction and the updates of tonal composition of the harmonic vertical. Thus, these three parameters (textural density, rhythmical pattern and harmonic pulsation) gain the status of musical events (Kulichkin & Zubareva, 2005). The analysis of the event pattern allows drawing some conclusions about the role of density and its changes in the processes of formation.

In mathematical terms, the dynamics of event density (as well as changing "the impression of tension") in musical composition may be regarded as a "class of bars" with a continuum of grades of membership (depending on the level of tension). Such classes are known as fuzzy sets. [A fuzzy set **A** in **X** is characterized by a membership function $\mathbf{f_A(x)}$ which associates with each object **x** in **X** a real number in the interval [0, 1], with the value of $\mathbf{f_A(x)}$ at x representing the "grade of membership" of **x** in **A**.] (Zadeh, 1965, p.339). We have introduced the following fuzzy sets uniting the values of a certain parameter, having impact on event density:

$$\mathbf{R} = \left\{ \mathbf{f_R(i)} / \mathbf{i} \; ; \mathbf{i} = \overline{\mathbf{1, n}} \right\}$$ – Rhythmical pattern;

$$\mathbf{H} = \left\{ \mathbf{f_H(i)} / \mathbf{i} \; ; \mathbf{i} = \overline{\mathbf{1, n}} \right\}$$ – Harmonic pulsation;

$$\mathbf{T} = \left\{ \mathbf{f_T(i)} / \mathbf{i} \; ; \mathbf{i} = \overline{\mathbf{1, n}} \right\}$$ – Textural density;

where **i** – is the number of a bar, **n** – is the total number of bars, $\mathbf{f_R(i)}$, $\mathbf{f_H(i)}$ and $\mathbf{f_T(i)}$ – are membership functions:

$$\mathbf{f_R(i)} = \frac{< \textbf{Quantity of attacked sounds} >_i}{\max_i < \textbf{Quantity of attacked sounds} >_i}$$

$$\mathbf{f_H(i)} = \frac{< \textbf{Quantity of harmonic events} >_i}{\max_i < \textbf{Quantity of harmonic events} >_i}$$

$$\mathbf{f_T(i)} = \frac{< \textbf{Average textural density} >_i}{\max_i < \textbf{Average textural density} >_i},$$

where each $< \textbf{Average textural density} >_i$ is calculated like **D** (see above).

Thus, the density of rhythmic events is determined using the quantity of attacked sounds, the density of harmonic events – based on the number of accord changes, and the density of texture events – as an average degree of accords' consonance/dissonance (Kulichkin & Zubareva, 2005).

Serial density

The object of the present paper is the calculation of harmonic events (**Hp**) for serial music. Is there a change in harmonies in such musical pieces? Or is such music based on other principles, absolutely alien to all the preceding music?

There is in reality a counterpart of harmonic pulsation for serial music. This is serial density:

$$\mathbf{S_p} = \left\{ \mu_s(\mathbf{i})/_{\mathbf{i}}\ ;\mathbf{i} = \overline{\mathbf{1,n}} \right\},$$

$$\mu_s(\mathbf{i})/_{\mathbf{i}} = \frac{<\mathbf{Number\ of\ serial\ tones}>_i}{\mathbf{\max_i} <\mathbf{Number\ of\ serial\ tones}>_i};$$

where **<Number of serial tones>** – the quantity of non-recurrent sounds of a series in a bar.

Let us demonstrate our approach to the interpretation of results on the example of Piece of Anton Webern (Fig. 2, 3).

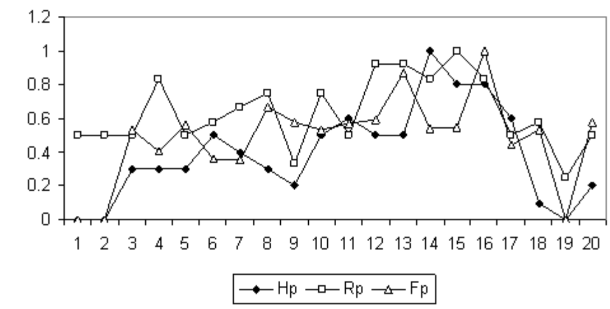

Figure 2. Anton Webern. Piece for piano. Rhythmic (**Rp**), harmonic (**Hp**) and Texture (**Fp**) events.

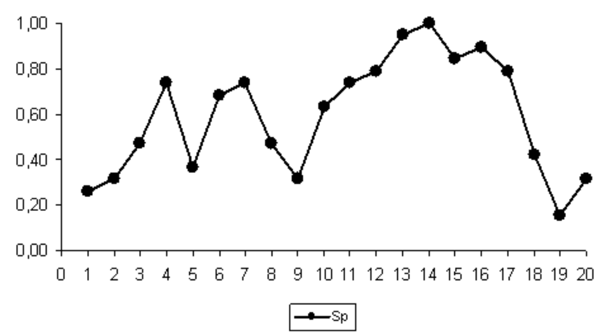

Figure 3. Anton Webern. Piece for piano. Serial density (**Sp**).).

Results and conclusion

The similarity of two curves – harmonic and serial – is logical, as the vertical consists of the series sounds, and therefore each simultaneous combination of voices is a meaningful unit of musical texture. However, in this case the form-generating load is laid on the serial density, whereas it is the series, which is the constructive dominant of dodecaphonic music.

It is known that in serial music everything subdues to the work with a series, but the technique can not (and probably should not) be perceived directly. The aural sense perceives it, most likely, as a certain arrangement of sound events. Thus, we are likely to have discovered the mechanism, by which serial technique manages the "elementary entities of music".

The results obtained allow us to attribute the analyzed parameters to a general phenomenon studied by various sciences. Thus, physiological data evidences high density of internal apprehension, while linguistics proves the important role of informational density in the conceptual execution of new knowledge. It is quite possible that the examined changes in density of sound events and their consequence, i.e. changes in tensity, belong to the universal means of coding any information (biological, scientific, aesthetic, etc.).

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