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A QUANTIFICATION OF THE RHYTHMIC QUALITIES OF SALIENCE AND KINESIS

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From a cognitive point of view, it is easily perceived that some music rhythmic structures are able to create saliences (i.e. pulses perceived as louder). Depending where in a metrical grid these salient pulses are located, a sense of stability or instability will arise. When instability is present in a rhythmic structure one will tend to psychological feel kinesis (i.e. a sense of motion). Salience and kinesis can then be identified as basic rhythmic qualities. Inspired by the theoretical construct Just in Time - an empirical based music theoretical construct for the analysis of rhythm - we decided to quantify some of its analytical output; more specifically the measure of salience and kinesis of a rhythmic sequence. We then developed a web-based tool that calculates the amount of salience and kinesis for a particular rhythmic sequence. We conclude this article pointing how this tool can be used in analysis and music education as well as other possible applications, and future research.

1. INTRODUCTION

Although usually addressed as one of the most important music parametres, rhythm has only received modest attention from the Western music theory. For the last five hundred years Music Theory has been concentrated in developing refined theories of melody and harmony. The problem with rhythm (and metre) theory is that the durational parametres of music have traditionally been seen as ' natural' and self-evident, in contrast to other parametres which stood in need of explanation and formalisation; when theorists tried to address durational issues at all, they did so on the basis of their existing bias towards other parametres rather than by addressing durational issues in their own terms. In our view, the so-called ' naturalness' of the durational parametres of music (i.e. rhythm and metre), has partly played a role against the call for theoretical research on these issues. Even today, the amount of research conducted on issues of rhythm and metre is far less than the one concerning other music parametres.

In order to contribute to a better and consistent understanding of rhythm and metre and their associated music qualities, Just in Time (Lopes, 2003) presented a theoretical construction that assesses some perceptual qualities that may arise from a rhythmic construction: the qualities of salience and kinesis. In a particular rhythmic sequence - a sequence consisting of sounds of different durations within a metrical grid - some pulses are perceived as more accented. Although their sound amplitude might be the same, long pulses and pulses preceded by smaller ones tend to be perceived as ' louder' (Povel and Essens, 1985). The perception of kinesis (i.e. the sense of motion) occurs when a particular rhythmic sequence is composed of pulses on weak metrical points – therefore creating metrical ambiguity/instability. There are basically two kinds of kinesis that can occur in a rhythmic sequence: (1) a stepwise type in which small pulses are grouped in time, such as a sequence of sixteenth notes; or (2) a far-reaching sense of kinesis, triggered by long pulses positioned on weak metrical places. Let us now present the theoretical construct that supports the previous concepts.

2. REVISITING *JUST IN TIME*

Just in Time is a model highly rooted in cognitive principles that was developed in three parts: (1) studying the perceptual behaviour of rhythm and metre as a rhythmic unity – in the shape they are presented to listeners; (2) studying independently rhythm and metre in order to produce two separate taxonomies or operational models; (3) reintegrating rhythm and metre as a perceptual unity (rhythmic construction), in order to measure its perceptual qualities such as salience and kinesis.
In order not to go too much in detail of the work already accomplished, we will only present here the basis for parts 2 and 3 which are the result of the empirical part 1.

THE RHYTHM STRATUM TAXONOMY

During the cognitive process of beat sequence inference, the relative proportion of duration of pulses is what defines the subdivision of beats. For instance, a durational sequence composed of pulses with the duration 250/250/250/250/1000 msec. would be perceived as two 1000 msec. beats, the first starting at the first 250 msec. event, and the second at the 1000 msec. event. Because the duration of the pulses stands in a powers-of-two relation to that of the beats (to be more precise a 1:4 relation), the subdivision of the beat is assessed as binary.

Fig. 1 shows examples of binary subdivision rhythm cells, based on a quarter note beat. It should be kept in mind that the long/short notation relates only to internal relationships within a particular cell; given the infinite number of possible rhythm cells (giving rise to an infinite number of internal organisations), Just in Time adopted a rather open notation, which nevertheless efficiently illustrates the basic organisation of the rhythm cells.

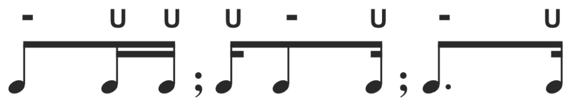


Fig. 1: Internal Organization of Rhythm Cells

By contrast with the rhythm cells shown in Fig. 1, those shown in Fig. 2 do not invoke an internal pulse salience hierarchy; such cells can only be assessed within a metrical context, or through the concept of rhythm motifs, in other words as part of a group of cells.

Fig. 2: Isochronous Rhythm Cells

Fig. 3 shows several examples of ternary subdivision rhythm cells and their internal organisation; these are notated based on beats with the duration of a dotted quarter note.

Fig. 3: Some Ternary Subdivision Rhythm Cells

At a higher level of the rhythm stratum, perceptually identifiable groups of rhythm cells (such as those preceded and followed by clear rests) are called rhythmic motifs. Operating similarly to rhythm cells, rhythm motifs can function as the ultimate means of further accentuation. Fig. 4 shows the accentuation process of two rhythm motifs, again notated based on beats with the duration of a quarter note. In rhythm motif a) the quarter note is extremely accentuated through being preceded by a large amount of small pulses; the large accentuation that the eighth note receives in rhythm motif b) is due not only to the large amount of small beats that precede it, but also to the crescendo of accentuation resulting from the diminution of the pulses' duration.

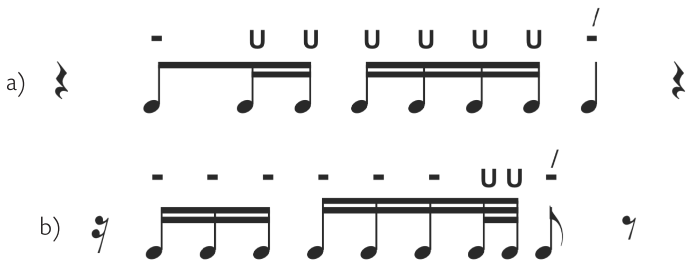
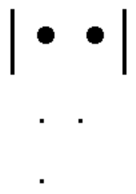


Fig. 4: Accentuation Through Rhythm Motifs

THE METRE STRATUM TAXONOMY

Due to the parsimonious nature of the Human cognitive system (i.e. which firstly tries to infer the simplest organisation to a perceived group of events), regular binary metres tend to play a primary role in the process of metrical organisation in music. Metres of this kind are composed of two beats, with the first beat perceptually accentuated (Fig. 5). It is assumed that the metres discussed in the remainder of this section fall comfortably within the tactus range (e.g. 100 M.M.).



Notation Legend:
| - Measure Line
• - Beat
. - Perceptual Weight
(the more dots the stronger the beat, as in Lerdahl and Jackendoff's (1983) notation).

Fig. 5: Internal Organization of a Binary Meter.

We may conceive a ternary metre as a kind of elaboration of the primary binary organisation to which an extra beat has been added (Fig. 6).

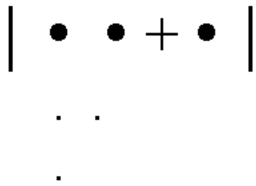


Fig. 6: Derivation of a Ternary Meter.

What weight should then be assigned to the extra beat? The principle of successively weaker beats from the first to the last was confirmed by empirical experiments (Lopes, 2003), and gives rise to the organisation of a regular ternary metre shown in Fig. 7 (Lopes, 2008a).

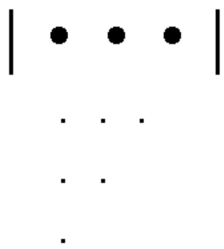


Fig. 7: Internal Organization of a Ternary Meter

One should bear in mind that the Gestalt (Koffka, 1935) cognitive principle of binary and ternary organisation works at all stages of the rhythmic inference process; any organisation derived from each new step of the rhythmic model is at first always measured against a preferable binary or ternary organisation. Therefore, only if it is not possible to base an organisation on a binary and ternary unit is another considered. It comes as no surprise, then, that any metre above the primary binary and ternary metres is liable to be constructed as an elaboration of these.

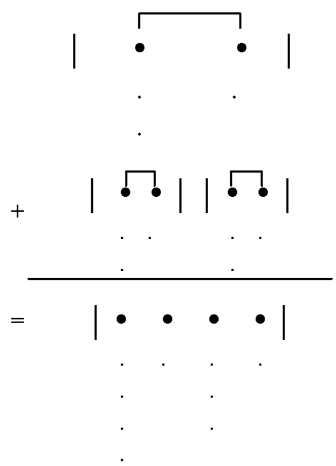


Fig. 8: A Quaternary Meter as a hierarchical Elaboration of a Binary Meter

Although it can in this way be seen as an elaboration of a binary metre, it seems that widespread use of the quaternary metre in different musical cultures and genres has led to its separation from the binary metre and the rise of its own identity. After all, a quaternary metre is different from a binary metre precisely in the alteration of stronger and weaker parts of beats, which give it an additional dimension and complexity of its own.

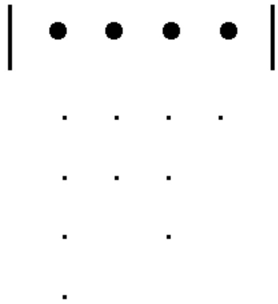


Fig. 9: The Proposed Internal Organization of a Quaternary Meter

To conclude, in order to assess the overall rhythmic salience of a pulse one has to consider three factors. Two of these are related to the rhythm stratum: agogic accentuation (i.e. the duration of a particular pulse), and the accentuation effect due to the action of rhythm cells or rhythm motifs. The third relates to the metre stratum: any pulse placed on a strong metrical point is perceived as stable, so receiving some accentuation and hence becoming more salient. In addition to these three factors, a fourth factor (kinesis), inversely related to stability, will also be addressed.

We will now proceed to show in what ways the above theoretical construction Just in Time is able to ascertain the perceptual qualities present in a rhythmic sequence.

3. ANALYSIS OF A PILOT RHYTHMIC SEQUENCE

Fig. 10: A Rhythmic Sequence

At the tempo of quarter-note equals 100 bpm, well within the tactus range, this sequence starts with a long note on the first beat of a quaternary metre. Positioned on the strongest metrical point of the first measure, the long half-note is perceived as a highly salient pulse, and clearly initialises the overall sequence. The following quarter-note at [1:3][1] is also a rather salient pulse due to its duration and metrical position – the second highest strong metrical point in the measure. Beat four contains two eighth-notes that due to their short duration are assessed as non-salient pulses. From a kinesis point of view, there is an increase of step-wise kinesis due to the decrease of the duration of the notes. This kinetic momentum peaks at [1:4] due to the eighths and clearly resolves at [2:1] – a rather long note on a strong metrical point.

[1] *[measure:beat]*

Another perceptual function of the eighths at [1:4] is to further accentuate the quarter at [2:1]. In this way, the high salience at [2:1] results from the rather long duration of the quarter, its metrical placement on a strong beat, and the further accentuation process. Together with the resolution of the kinetic momentum of the first measure, at this point in the sequence a clear accentuation on the first beat helps to perceptually reassure the intended metre. Due to their rather short duration, the following four eighths initialise another kinetic momentum which resolves on [2:4], and therefore accentuating the dotted-eighth. The short duration sixteenth in [2:4] also imparts some kinesis which resolves on [3:1].

Similarly to the quarter on [2:1], the quarter on [3:1] is also highly salient pulse. The only difference here lies in the fact that the quarter on [3:1] was further accentuated by only one small pulse. Despite this, the intensity of the further accentuation in both cases can be said to be similar: if in the first case the further accentuation is achieved through two quavers preceding a quarter, in second case is through a sixteenth preceding a quarter. Due to Gestalt reasons, the highest the difference in duration between pulses the highest the accentuation the short notes convey on the long notes. The sequence proceeds with an eighth on the first half of [3:2] in line with the regular pace of the quaternary measure and in part of a rhythmic motif with the following four sixteenths that convey an increase of step-wise kinesis and accentuate the quarter at the second half of [3:3]. Although small, this accentuation of a note on a weak metrical point (the second half of beat 3) will release some kinesis. Because the eighth at [3:3] is not followed by a salient pulse the released kinesis will tend to dissipate, revealing a kinetic momentum similar to a jump that fades away instead of returning to ground (Lopes, 2008b). The rhythm cell at [3:4] causes a similar kinetic momentum. This time a very small pulse further accentuates a dotted eighth which is placed on a very weak (thus unstable) metrical point. Just like the previous kinetic momentum, this one also does not resolve since measure 4 starts with a sixteenth note (a small pulse).

In the same way, the beginning of measure 4 also presents an unresolved kinetic momentum. These three kinetic impulses make a highly kinetic motif which started at the middle of measure 3 and continuing through the first beat of measure 4. This continuous instability needs resolution since it may start to perceptually confuse the listener, thus endangering the intended quaternary metrical construct. The resolution of all this, and the returning to stability, starts to take shape right at the end of [4:1] with a group of nine sixteenth notes. Following the unresolved release of kinesis, the step-wise kinesis that the sixteenth notes imply, ground the sequence while at the same time keep on moving it forward. This motion leads the sequence to [4:4] accentuating the quarter. This quarter becomes then a highly salient pulse; not only is a long duration but also is preceded by nine sixteenths. Because the highly salient quarter is placed on a rather weak metrical point it releases far-reaching kinesis, resolving and further accentuation [5:1] – the end of the sequence.

From a compositional point of view, this sequence shows an intention of conveying a clear quaternary metre while at the same time moulding some kinetic qualities derived from it. Measures 1, 2, and 3, contain clear saliences on the first beat which stabilises any motion (i.e. instability) that may occur inside the measures. These instabilities are the different ways in which this sequence conveys kinesis. As shown above in detail, at a macro perspective one can also observe that there is an increase of motion from measure 1, to the high kinetic bursts at the end and beginning of measures 3 and 4 respectively. At the point of the high peak in kinesis (i.e. highest instability), the sequence started to prepare the return to stability, which finally ended on a clear salience on [5:1].

In short, the rhythmic structure of the sequence makes some pulses more salient or kinetic than others, and hence more prominent to the listener. In this way, the qualities resulting from a rhythmic construct can be measured against that resulting from other musical parametres. By providing a means to assess rhythmic pulse salience, the proposed rhythmic model becomes a specialised tool within an overall analytical approach.

The above rhythm and metre model has also applications across a range of musical activities. It can complement existing methods of musical analysis in order to provide new insights into the durational parametres of music – both in terms of purely durational structure, and in terms of the interaction between durational and other parametres (e.g. melody, harmony). The formulation present in *Just in Time* may help the composer in shaping and predicting the effects of silence and kinesis resulting from particular rhythmic constructs – and perhaps the improviser too. Similarly, the rhythm and metre model may contribute to an understanding of the role of the performer in realising the inherent potential of a particular rhythmic construct. Although the qualitative and open stance of the *Just in Time* rhythmic analysis is able to successfully play a significant role in the mainstream music theory, in which one is not necessarily looking for exact quantitative measures of salience and kinesis, we felt the need and potential to develop the model and attempting a formalisation. In this manner, we build on it in such a way as to develop a quantitative measure of rhythmic salience and kinesis, and implementing it as analytical software.

4. THE STABILITY AND INSTABILITY QUANTIFICATION METHOD

SALIENCE QUANTIFICATION

Based on the qualitative construct in *Just in Time* and research presented in Cruz et al. (2007), we propose a way to quantify the salience of each note in a particular measure. Considering then that in accordance to *Just in Time* the salience value of a pulse depends on three factors:

- The pulse metric position;
- The pulse duration (i.e. agogic accentuation);
- The rhythm cell accentuation concept (i.e. the number of small pulses that precede a larger pulse).

The following mathematical functions were devised:

Metric Position Value:

$$O(\omega) = BU - M(\omega - 1)$$

Agogic Accentuation Value:

$$P(\eta) = \eta$$

Rhythm Cell Accentuation Value:

$$Q(\eta) = \sum_{(\zeta,\sigma)\in C} \left(\left\lceil R\left(\frac{\eta}{\zeta}\right) M\sigma \right\rceil \right)$$

From which it was derived the Pulse Salience general formula:

$$S(\eta,\omega) = BU - M(\omega - 1) + \eta + \sum_{(\zeta,\sigma)\in C} \left(\left\lceil R\left(\frac{\eta}{\zeta}\right) M\sigma \right\rceil \right)$$

Where:

η is the pulse's type
ω is the pulse's metric position
B the number of beats in each measure
U the value filling a beat
M the value of the shortest pulse present in the rhythmic sequence.

C a set of tuples (ζ, σ) representing the preceding rhythm cell - that can be in fact a group of equal homogeneous cells. For each tuple, ζ is the value of a pulse type and σ the number of pulses of that type in the rhythm cell.

R a function given by:

$$R(x) = \begin{cases} x & \text{if } x > 1 \\ 0 & \text{if } x \leq 1 \end{cases}$$

Fig. 11 represents all the possible metric positions of a pulse in a measure, while on Fig. 12 it is represented the different pulse durations used in our system, and their possible values.

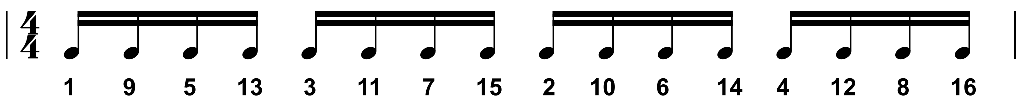


Fig. 11: The Sixteenth Metric Positions in a Quaternary Metre

Pulse	Notation	Value
Quarter Note	♩	1000
Dotted Eighth Note	♪.	750
Eighth Note	♪	500
Sixteenth Note	𝅘𝅥𝅯	250
Sixteenth Rest	𝄿	0

Fig. 12: Pulse Types and their Values

As an example, follows the pulse salience values of the different pulses in the rhythm sequence shown in Fig. 13.

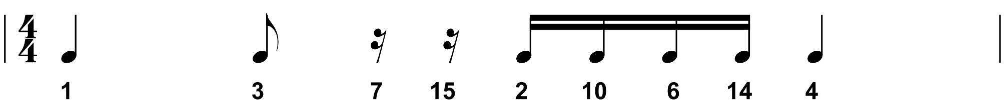


Figure 13: Pulse Salience Values for a Random Rhythm

$$S(1000,1) = 4 \times 1000 - 250 \times (1-1) + 1000 + 0 = 5000$$

$$S(500,3) = 4 \times 1000 - 250 \times (3-1) + 500 + 0 = 4000$$

$$S(0,7) = 0$$

$$S(0,15) = 0$$

$$S(250,2) = 4 \times 1000 - 250 \times (2-1) + 250 + 0 = 4000$$

$$S(250,10) = 4 \times 1000 - 250 \times (10-1) + 250 + 0 = 2000$$

$$S(250,6) = 4 \times 1000 - 250 \times (6-1) + 250 + 0 = 3000$$

$$S(250,13) = 4 \times 1000 - 250 \times (14-1) + 250 + 0 = 1000$$

$$S(1000,4) = 4 \times 1000 - 250 \times (4-1) + 1000 + 4000 = 8250$$

As one can see, the quarter note in metric position 4 has a salience value of 8250 especially because it is located straightly after a rhythm cell comprising four sixteenth notes.

INSTABILITY QUANTIFICATION

This model divides rhythm instability into two mathematical measurements: Pulse Instability and Rhythm Sequence Instability. Rhythm Sequence Instability may only be calculated if Pulse Instability was calculated previously for all the notes in the sequence. Let us start with Pulse Instability. We propose that the instability of a pulse is related to its high salience value, and its position on a weak metrical point (such as position 10 or 16 in a quaternary measure, as shown above). We therefore defined Pulse Instability as:

$$instability_{pulse}(\eta,\omega) = S(\eta,\omega) \times \omega$$

This will cause the Pulse Instability value to increase proportionally in accordance with its metrical position value. There is however one special case; which relates to rests. Obviously we did not assign a salience value to rests, but the fact is that their presence has to be acknowledged since they can be part of a rhythm sequence. For this purpose, we have contemplated rests in our formula the following way:

$$instability_{pulse}(0,\omega) = \frac{\sum_{\omega \in s} O(\omega)}{n_s^2} = \frac{\sum_{\omega \in s} BU - M(\omega - 1)}{n_s^2}$$

Where:
s is the group of rests
ns is the number of rests

The division by n_s^2 works as a weighting device to reduce the importance of instability of a great amount of rests next to each other, and with this spreading the value throughout the rests that belong to the group.

The general formula for Pulse Instability is then given by:

$$instability_{pulse}(\eta,\omega) = \begin{cases} \dfrac{\sum_{\omega \in s} BU - M(\omega - 1)}{n_s^2} & \text{if } \eta = 0 \\ S(\eta,\omega) \times \omega & \text{if } \eta > 0 \end{cases}$$

The Pulse Instability formulas are able to associate an instability value to each pulse in a quaternary metre, but there is still a problem concerning the quantification of the overall sequence instability. This is why we developed the Rhythm Sequence Instability. We cannot just sum the Pulse Instability for each pulse in a rhythm sequence, since this would result in a higher Rhythm Sequence Instability value for sequences consisting of more pulses, and a lower one for sequences with a few pulses. The solution was to weight the overall Rhythm Sequence Instability value by the number of pulses in a rhythm sequence:

$$instability_{rhythm} = \frac{\sum_{\omega=1}^{16} instability_{pulse}(\eta,\omega)}{n_{pulses}}$$

For a more efficient readability we decided that we should also present the Rhythm Sequence Instability as a percentage value. We did so by finding a possible highest and lowest numerical value and divide this numerical spectrum into 10 intervals. For the definition of the interval endpoints we carried out some empirical experiments where we generated large quantities of rhythms and found that the Rhythm Sequence Instability values oscillated in between 6000 and 32600 (most of them between 11320 and 21960). As a result, we defined the Instability intervals as such:

$$0\% \text{ to } 10\% : [6000, 11320[$$

$$10\% \text{ to } 20\% : [11320, 12650[$$

$$20\% \text{ to } 30\% : [12650, 13980[$$

$$30\% \text{ to } 40\% : [13980, 15310[$$

$$40\% \text{ to } 50\% : [15310, 16640[$$

$$50\% \text{ to } 60\% : [16640, 17970[$$

$$60\% \text{ to } 70\% : [17970, 19300[$$

$$70\% \text{ to } 80\% : [19300, 20630[$$

$$80\% \text{ to } 90\% : [20630, 21960[$$

$$90\% \text{ to } 100\% : [21960, 32600[$$

Here is the detailed calculation of the Rhythm Sequence Instability for the rhythm sequence present in Fig. 13:

$$instability_{pulse}(1000{,}1) = (4 \times 1000 - 250 \times (1-1) + 1000 + 0) \times 1 = 5000$$

$$instability_{pulse}(500{,}3) = (4000 - 250 \times 2 + 500) \times 3 = 4000 \times 3 = 12000$$

$$instability_{pulse}(0{,}7) = \frac{(4000 - 250 \times 6) + (4000 - 250 \times 14)}{2^2} = \frac{3000}{4} = 750$$

$$instability_{pulse}(0{,}15) = instability_{pulse}(0{,}7) = 750$$

$$instability_{pulse}(250{,}2) = (4000 - 250 + 250) \times 2 = 8000$$

$$instability_{pulse}(250{,}10) = (4000 - 250 \times 9 + 250) \times 10 = 20000$$

$$instability_{pulse}(250{,}6) = (4000 - 250 \times 5 + 250) \times 6 = 18000$$

$$instability_{pulse}(250{,}14) = (4000 - 250 \times 13 + 250) \times 14 = 14000$$

$$instability_{pulse}(1000{,}4) = (4000 - 250 \times 3 + 1000 + 4000) \times 4 = 330000$$

$$instability_{rhythm} = \frac{instability_{pulse}(1000{,}1) + \ldots + instability_{pulse}(1000{,}4)}{7} = \frac{111500}{7} = 15928{,}57$$

5. SALIENCE AND INSTABILITY STUDY WEB-BASED TOOL

The empirical experiments which led us to the preceding Pulse and Rhythm Sequence Instability formulas, were made with the help of a script created with the intent of helping us to understand the behavior of Pulse Salience and Kinesis proposed in Lopes (2003). We created a system embedded in a HTML page where we could calculate the Pulse Salience and Pulse Instability for every pulse, and additionally calculate the Rhythm Sequence Instability. The script is located at http://home.uevora.pt/~el/Rhythm/saliencia_calculo/saliencia_calculo/, and a screenshot can be seen in Fig. 14. As an effect of the overall theoretical construct presented in this article, this tool turned out illustrating the theoretical principles quite clearly.

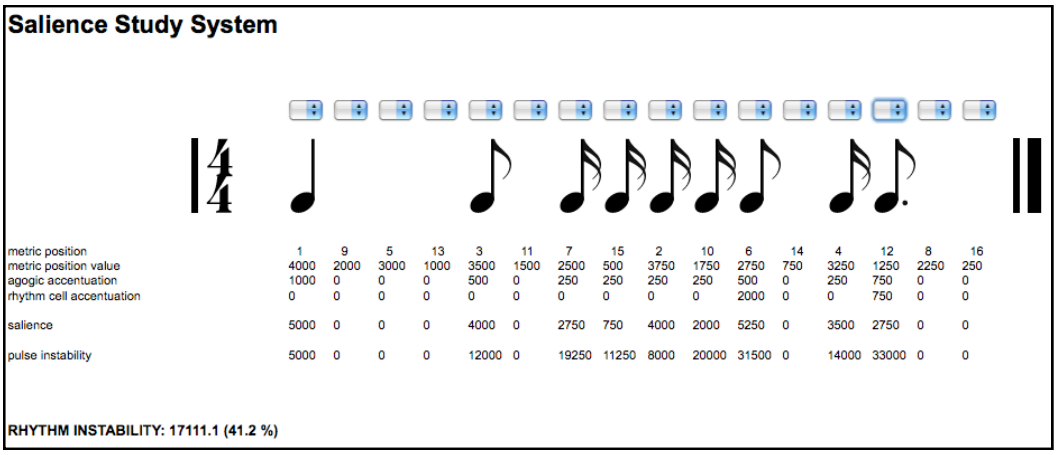


Fig. 14: A Screenshot of the "Salience Study System" Script

6. CONTRIBUTION

As an implementation of the rhythm analytical model Just in Time, and because it promotes a systematic understanding of the means to produce, underline, or contradict pulse salience and kinesis, we believe this web tool has something to offer the composer, performer, improviser, and music teacher. It can complement existing methods of musical analysis, as well as performance practise concepts, by providing new insights into the durational parametres of music – both in terms of purely durational structure, and in terms of the interaction between durational and other parametres. The systematisation of the operation of rhythm and metre may help the user (e.g. composer, performer, student) to shape and predict the effects of silence and kinesis resulting from particular rhythmic constructs. Also, and as an analytical software highly rooted in music perception, it may help to bridge the gap between music notation and effect.

7. FUTURE WORK

Future work in this quantification method of the basic rhythm qualities of salience and kinesis and corresponding web study system will apply it to research that its objective is to generate rhythmic music following an art painting. More specifically, it is being developed a computer system that generates audio musical rhythms in accordance to the shapes present in a particular painting. We will use instability as the common conceptual feature between music rhythms and shapes (Hubbard, 2003) - in which instability values are assigned to geometrical shapes according to their angles (Melford, 1999). Summarising, we plan to insert a picture in the system, and it calculates the instability for the shapes of the picture, and generates - using a method which combines randomness and probabilities - rhythms with the same instability value as the ones previously calculated for each shape. The overall result is an aural and visual consistent perception of instability or stability sensations.

The model presented here was studied and developed using some constraints. One of them was the number of measures and its corresponding metric positions. As we mentioned before, due to the high complexity of the parametres involved, we decided that the studies would be limited to one measure – that for musical proposes would repeat in a loop fashion. In order to integrate the developed model in a wider musical context, we intend to develop it so that it would extend its context to at least 4 measures. Concerning possible applications further on the road and in other fields, the model can also be developed so that it can be applied in other intermedia projects, especially for dance/music. In this context, we envision a quite useful application in which a dancer would perform a gesture considered more-or-less unstable (i.e. kinetic) and the system would trigger rhythmic music in accordance to the level of kinesis of the gesture. To finalise, and returning to the first context of music/paintings, there is also the possibility of using the present method as a tool within a computational system that could generate pictures or shapes following the rhythm kinesis of a musical piece or live performance. ■

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