SEMIOTIC STRUCTURE LABELING OF MUSIC PIECES : CONCEPTS, METHODS AND ANNOTATION CONVENTIONS

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ABSTRACT

Music structure description, i.e. the task of representing the high-level organization of music pieces in a concise, generic and reproducible way, is currently a scientific challenge both algorithmically and conceptually. In this paper, we focus on *semiotic structure*, i.e. the description of similarities and internal relationships within a music piece, as a low-rate stream of arbitrary symbols from a limited alphabet and we address methodological questions related to annotation.

We formulate the labeling task as a blind demodulation problem, whose goal is to identify a minimal set of semiotic *codewords*, whose realizations within the music piece are subject to a number of *connotative variations* viewed as *modulations*. The determination of labels is achieved by combining morphological, paradigmatic and syntagmatic considerations relying respectively on (i) a morphological model of semiotic blocks in order to define their individual properties, (ii) the support of prototypical structural patterns to guide the comparison between blocks and (iii) a methodology for the determination of distinctive features across semiotic classes.

Specific notations are introduced to account for unresolvable semiotic ambiguities, which are occasional but must be considered as inherent to the music matter itself. A set of 500 music pieces labeled in accordance with the proposed concepts and annotation conventions is being released with this article.

1. INTRODUCTION

Music can be defined as "the art, process and result of deliberately arranging sound items with the purpose of reflecting and affecting senses, emotions and intellect" [1]. From a more operative viewpoint, music can be approached as a set of sounds organized by human composers for human listeners. From these definitions, the role of structure in the musical process appears as rather essential, as it is both a constituent and a support of the musical discourse.

In the domain of MIR, music structure is frequently considered as a central element to music description and modeling, but also as a scientific challenge, both algorithmically and conceptually [2]. This situation has triggered significant effort in the MIR community, towards the production of annotated resources [3][4] and the organization of evaluation campaigns [5].

At the scale of an entire piece, music structure is a concept which can be approached in several ways :

a. **The acoustic structure** which consists in describing the course and turns of active sources and/or timbral textures within the piece : singer(s), lead entries, instrumentation, etc…
b. **The functional structure** which is based on usual designations of the different parts in terms of their role in the music piece, for instance : intro – verse – chorus – bridge – etc… (cf. [6], for instance),
c. **The semiotic structure** which aims at representing, by a limited set of arbitrary symbols (called labels), the similarities (and interrelations) of structural segments within the piece.

These various views of music structure have influenced the design of methods and algorithms for the automatic analysis of audio data, for instance [7][8][9].

However, in spite of a need and an interest for methodological and operational concepts [10][11], there is no well-established principles for the structural annotation of music pieces, either in terms of problem statement, procedure, or annotation conventions, even in "simple" cases like pop songs.

In this context, some of our former work [12][13] has been focused on the definition of structural block boundaries. In this article, we address the labeling task, i.e. the determination of equivalence classes between structural segments so as to obtain a symbolic transcription of the piece's structure. Our methodology is primarily designed for audio data but can also be applied to written music.

By approaching a music piece as a "communication system", we formulate (section 2) the labeling task as the resolution of an ill-posed problem, for which the solution is seeked by assuming that recurring properties and systematic differences across structural blocks are more prone to be semiotically relevant than irregular and occasional variations.

Within this scope, semiotic analysis aims at ensuring a trade-off between :

- coverage : i.e. to encompass the largest possible number of musical properties in the semiotic description
- regularity : i.e. to obtain a transcription as regular as possible and relating to a simple prototypical pattern.
- accuracy : i.e. to account as faithfully as possible for the distinctive properties across semiotic elements.
- compactness : i.e. to limit the semiotic alphabet to a reasonable number (and distribution) of elements.

This trade-off is obtained by combining methodological criteria based on morphologic, syntagmatic and paradigmatic considerations (section 3).

In section 4, we introduce annotation conventions which cover the most typical situations but which also handle occasional semiotic ambiguities, i.e. segments undecidedly belonging to two classes at the same time.

We release, with this article, a set of approximately 500 music pieces, annotated with the proposed conventions, and accompanied with additional documentation.

2. CONCEPTUAL APPROACH

The semiotic annotation of a music piece consists in summarizing its high-level structure as a short sequence of arbitrary symbols drawn from a limited alphabet, for instance :

A B C D A B C D E C D C D D

In the scope of this work, we suppose that the elements thus indexed are structural segments (or *blocks*) of comparable size and at a typical timescale between 10 and 25 seconds.

2.1 A music piece viewed as a communication system

Assuming the existence of a semiotic description of music structure is intimately linked to the hypothesis of an underlying communication scheme which governs, at the structural scale, the global narrative organization of the piece.

It is rather commonplace to consider music in general as a means of communication, based on a set of rules and conventions (which clearly depend on the type of music under consideration). Here, we consider that *each music piece* can itself be viewed as the output of a particular communication system, with its own constituents : a *sender* (the composer), one (or several) *receiver(s)* (i.e. listeners), a transmission *channel* (which can take various forms), a message (the musical *narration*) and a *code*, namely the alphabet of *semiotic elements* (or *codewords*) with which is built and developed the narration.

From this viewpoint, the codewords are fundamentally piece-specific and they are discovered (and inferred) gradually by the listener while the piece unfolds, i.e. while the musical narration develops. Describing the semiotic structure of a music piece can thus be viewed as a deciphering task based on the observation of the output of a communication system (possibly with the help of more or less conscious knowledge of composition conventions).

2.2 Semiotic structure : an ill-posed inverse problem

Semiotic structure description falls in the category of *ill-posed inverse problems*, and therefore cannot be solved unequivocally unless additional constraints are incorporated to condition the solution.

One option could be to try to formulate the conditioning constraints in terms of particular properties of the music substance, more or less specific to the genre of the piece. However, this approach would require sharp expertise, general concordance and a stable status of the compositional rules for all genres, which is difficult to imagine and which would certainly raise major problems of comparability and compatibility of the result across pieces (and annotators).

Our objective is to formulate the properties of semiotic elements (i.e. the conditioning constraints) as generically as possible. This is why, we propose that the structural description of the piece should be approached as some sort of *blind information demodulation problem*, i.e. the separation of a *carrier* (the sequence of codewords) and a *modulation* (the variations in the realization of the codewords), solely based on the *behavior and relationships* of musical properties, but not on their actual substance.

2.3 Inferring a semiotic code : an intuitive example

Let's consider the following sequence :

A careful study of this sequence reveals that :

- Almost all items are directional.
- Only 4 distinct orientations are observed (say N, E, SE and NW).
- Gray level varies but does not show any regular pattern, nor does the tail of the objects, nor their size.
- Orientation is driven by a strong syntax (for instance, SE is always followed by NW, NW never by E, etc…)
- The shape of item #9 is singular (could be interpreted as pointing SE *or* NW, though)

Let's now consider this second sequence :

Here, we observe that :

- Almost all items are (also) directional but
- Direction is taking all sort of random, unquantizable values
- Gray level takes only 4 different values (say 20, 40, 60 or 80 %)
- The tail of the objects (still) does not show any regular pattern, nor their size.
- Gray level is driven by a strong syntax (for instance 20 % is always followed by 80 %)
- The gray-level of item #9 is singular / undecided

The successive values or states taken by the various properties constitute *information layers* and, in both cases, a particular layer exhibits some systematic and organized behavior : "orientation" in the first sequence, "gray-level" in the second one. The knowledge of their behavior conveys, at a low explicative cost, significant information on the overall sequence. At the same time, the other properties appear mostly as creating different variants (or connotations) in the realization of these properties.

In both cases, the symbolic representation of the most organized information layer is :

A B C D A B C D E C D C D D

and in fact, considering any other property (or combination of properties) would create rather uninformative, much less regular or almost trivial descriptions, such as **ABCDE…KLMN, AABCBCDAEBADAA**, or **AAA…ABAAAAA**.

2.4 The carrier-modulation model

In the proposed approach, we assume that the sequence of structural elements can be decomposed into :

- **A carrier component** which is built on information layers whose behavior, is periodic, cyclic, regular, recurrent, repeated, correlated, quantized, organized…
- **A modulation component** which corresponds to information layers which appear as aperiodic, acyclic, irregular, occasional, erratic, sporadic, uncorrelated, isolated, continuous-valued, scattered, etc…

The sequence of semiotic labels describes the succession of *property values* taken by the carrier component. The modulation component represents circumstantial or incidental *variations* of the semiotic elements

2.5 Application to music

At the level of a short musical passage, successions of notes belonging to a given musical scale form an acoustic melody whose properties (amplitude, duration, attack, …) are modulated over time to convey expressivity.

Similarly, at the level of the whole piece, the succession of structural blocks forms some sort of *semiotic tune*, build on the "scale" of semiotic elements and whose modulation constitute *connotative variants* across different stages of the musical narration. However, as opposed to conventional music units, those "macro-notes" are piece-dependent and they are primarily inferred by detecting and comparing structural elements over the whole piece.

At this point, it is very important to note that the particular status of a property as being either semiotic (carrier) or connotative (modulation) cannot be *a priori* decided on the single basis of its nature.

Indeed, in a number of pieces, structural blocks are built on a few distinct harmonic progressions which recur throughout the piece together with a strong variability of the melodic line, whereas other pieces may be built on a unique harmonic cycle from the beginning to the end, the melodic line being the only distinctive feature between blocks. Some techno or electro pieces rather use the timbre or the texture to create structural patterns over a constant melodic-harmonic loop. In percussive pieces, the structural organization usually stems from rhythmic properties, etc…

Therefore, the analysis of semiotic structure primarily requires to identify, for each music piece, which are the *musical information layers* (melody, harmony, rhythm, etc…) taking part to the semiotic component.

2.6 Semiotic features

Let us now consider a third toy example, which we suppose to be an other realization of **ABCDABCDECDCDD** :

Here we have a slightly more complex situation than in section 2.3, in the sense that the structure of the sequence is based on a *switch* of the semiotic property on which the carrier component is built, as summarized in the table below :

Symbol	Orientation	Gray-level	Tail-shape	Size
A	**North**	*any*	*any*	*any*
B	**East**	*any*	*any*	*any*
C	*any*	**20 %**	*any*	*any*
D	*any*	**80 %**	*any*	*any*
E	**Indistinct**	**Multiple**	*any*	*any*

Such a situation is very common in music : for instance in a song, verses 1 and 2 may consist of two distinct melodies based on a same harmonic progression while choruses 1 and 2 may be based on two distinct chord loops (while the melodic line would be identical or almost). Indeed, in the case of music, semiotic structure relies on musical properties whose nature varies *across* pieces but which may also vary *within* a given piece.

Semiotic annotation therefore requires the determination of what we call *semiotic features*, i.e. not only the semiotic properties but also the particular values taken by these properties to form the carrier component describing the sequence of structural blocks. In the case above, the semiotic properties are *orientation* and *gray-level*, while the semiotic features are *North orientation*, *East orientation*, *20 % gray-level* and *80 % gray-level* (the other values of orientation and gray-level being irrelevant to the carrier component).

It is also worth noting that, in this example, the syntagmatic organization of the sequence plays an essential role in guiding the determination of the relevant semiotic features. Indeed, East is always followed by 20 %, itself always followed by 80 %, and more globally, the pattern N-E-20-80 is observed twice.

2.7 The three ingredients of semiotic structure

To sum up the underlying process at work behind semiotic analysis, we can distinguish 3 levels of reasoning which jointly participate to the determination of the semiotic description :

- Morphological analysis : *intrinsic features* of the structural elements composing the sequence (i.e, the properties and the values of these properties).
- Syntagmatic analysis : *local relations* that elements exhibit *with their neighbors* within the piece
- Paradigmatic analysis : *similarities* and *differences* which they exhibit *with other elements.*

The following sections investigate in details these three facets of semiotic structure analysis and how they interact with one another.

3. METHODOLOGICAL AXES

3.1 Morphological analysis

The morphological analysis of structural blocks is based on the *System & Contrast* (S&C) model [14].

Under this approach, each structural block is assumed to be built around 4 *morphological elements* (of typically 2 bars each) forming a *square carrier system.* These elements relate through a (usually 2x2) matrix of simple relationships. Structural blocks can be more complex, but they usually can be reduced to a square stem.

In general, on some musical information layers, the 4th element departs from the logical sequence formed by the first three (thus creating some sort of punctuation).

The morphology of a square S&C can be written as :

$$a\ f(a)\ g(a)\ \gamma(g(f(a)))$$

where a is the "seed" morphological element, f and g are the internal relations between the elements forming the carrier system and γ a *contrast* function that represents the (relative) disparity of the 4th element. S&Cs exist on several musical layers in different forms and at different timescales simultaneously. Their synchronization contributes to the musical consistency of the segment and to its autonomy [12]. Identifying S&Cs is thus very useful to locate, at the chosen timescale, the boundaries of the structural blocks.

A S&C can be summarized as a quadruplet : a, f, g, γ, which can be viewed as the "genetic code" of the structural block. Moreover, in many situations, either f or g (or both) are "identity" (*id*), resulting in well-identifiable morphological patterns such as *aaaa, abab, aabb* (for $\gamma = id$) or *aaab, abac, aabc* (for $\gamma \neq id$). These patterns can straightforwardly be extended to *"close-to-id"* or *"begins-like"* functions : *aaa'b, aba'c, aa'bc, …*

The morphology of structural blocks can therefore be primarily characterized by the various systems followed by its (say p) active musical layers, i.e. as a multi-dimensional quadruplet $\{(a, f, g, \gamma)_i\}_{1 \leq i \leq p}$. In many cases, this quadruplet can be represented more simply as the morphological pattern governing each layer : for instance, $a_1 b_1 a_1 b_1$ for the melodic line, $a_2 b_2 a_2' c_2$ for the harmony, $a_3 a_3 a_3 b_3$ for the drum loop, etc…

3.2 Syntagmatic analysis

Moving back now to the timescale of the entire piece, we discuss how the position and context of structural blocks within the piece can be taken into account in order to guide semiotic labeling.

Indeed two structural blocks will be considered to be *a priori* more likely to belong to the same equivalence class if they appear in similar contexts in the piece, i.e. if they are located beside similar left and/or right segments within the piece. For instance, in the sequence **ABxDAByDECDCDD**, **x** and **y** are more likely to belong to the same semiotic class than in **ABxDyBCDECDCDD.** This criterion partly relates to commutability, often used in semiotic analysis.

A second syntagmatic factor to take into account is that differences between two blocks should not be appreciated in the same way if the two blocks are immediately next to each other or if they appear at some distance in the piece : a slight difference observed between two successive similar blocks may be distinctive (especially if this opposition is recurrent in the piece) whereas a stronger difference at a long distance may just be a connotative variation, especially if the two blocks occur in similar contexts.

The guidance of a *prototypical structural pattern* (see Table I) is also an essential element of syntagmatic analysis, for weighing similarities and differences between and across blocks and interpreting them with respect to the global organization of the piece.

However, while the semiotic structure of music tends to be based on recurrent patterns, the actual *realization* of a structural pattern in a music piece generally shows irregularities (which are bound to increase when getting towards the end of the piece). For instance the structural description **ABCDABCDECDCDD** can be viewed as a realization of 4 cycles of an **(ABCD)** structural pattern with growing irregularities towards the end of the piece.

In practice, structural patterns can prove to be very efficient to guide the annotation for some musical genres, but they can also turn out to be totally useless for others.

3.3 Paradigmatic analysis

The goal of paradigmatic analysis is to determine the set of semiotic features within the population of structural blocks, i.e. what are the semiotic properties (and the values taken by these properties) which characterize the equivalence classes (cf. subsection 2.6).

A key concept of this process is that, rather than comparing the surface properties of the structural segments, the semiotic comparison of blocks is based primarily on the comparison of their *carrier system*, i.e. the triplet a, f, g (as defined in subsection 3.1) resulting from their morphological analysis. Note that the contrast function γ is treated separately, as a special form of modulation (see 4.1).

For a given music information layer, the carrier systems of two structural blocks **x** and **y** are considered as homologous, if there exist a *property* of that layer for which the triplets (a_x, f_x, g_x) and (a_y, f_y, g_y) are similar. For instance, if the musical layer is the melody, the property can be the melody itself, the support notes of the melody, the shape of the melodic line, etc…

This comparison is carried out for all musical layers which show some morphological organization and the subset of common properties that emerges from the comparison provides the characteristics of a potential class encompassing **x** and **y**. In particular, if the similarity of the systems holds for *all* music information layers active in **x** and **y**, it is considered that these segments should be grouped into a single semiotic class.

Semiotic features can thus be hypothesized as conjunctions of properties (*together with* their particular values) occurring in similar S&Cs and these features can be ordered (at least partly) according to their coverage of the various musical information layers.

A global solution is then searched (empirically) as a partition of the population of structural segments grouping those with *equivalent* carrier systems *in the subspace of* *their semiotic features*. In case of several possible solutions, the one yielding the most regular sequence of labels is chosen.

Finally, the set of *distinctive features* is established as the minimal subset of properties (and their particular values) which is necessary and sufficient to distinguish each semiotic element from all the others.

Of course, the trade-off between accuracy of the description and compactness of the semiotic set is an essential stopping condition. It is conjectured that a "good" *a posteriori* distribution of labels should follow some sort of Zipf law, or at least should not depart too much from it.

4. ANNOTATION CONVENTIONS

4.1 Primary notation of semiotic labels

Quite naturally, two blocks with non-equivalent carrier systems are denoted by 2 distinct alphabetic capital letters : **A** vs **B**.

When two blocks show equivalent carrier systems but different contrasts (γ), this difference is noted as a subscript : $\mathbf{A_1}$ vs $\mathbf{A_2}$. Blocks showing no (or extremely weak) contrasts are denoted $\mathbf{A_0}$ and conversely, blocks showing exceptional contrasts are denoted $\mathbf{A_*}$ (they usually tend to occur at the end of the piece).

When two blocks have equivalent carrier systems, but they significantly differ in their (surface) realizations (connotative variants), they are denoted with distinct superscripts, for instance : **A'** vs **A''**. Optionally, the superscript may be chosen specifically to indicate the nature of the variant. For instance, the notations $\mathbf{A^+}$ and $\mathbf{A^-}$ are used to indicate more or less rich occurrences, and $\mathbf{A^\sim}$ can be used to denote exceptional variants of **A**.

When a property evolves gradually within a block, this is denoted as a fade-in or a fade-out. This is denoted as **<A**, **A>** and it may apply to surface properties such as the intensity, the instrumentation support, or to strengthening or vanishing properties of the carrier system.

If a block is realized only in a half-form, specific notations are used : **A/2** for a half-size block, **|A** and **A|** for left (resp. right) truncated half block, more general cases of incomplete blocks being denoted as **…A** or **A…**.

Table II summarizes these annotation conventions.

4.2 Composite labels for handling ambiguities

Inevitably, semiotic labeling leads to some situations which exhibit ambiguities, resulting from the *combination* or the *mutation* of semiotic items to create new hybrid ones, namely some sort of chord, at the level of the semiotic structure. This is indeed a natural process in music at many time-scales

Therefore, a set of additional notations were designed to render these ambiguities through *composite labels* (whose configurations are schematized on figure 1).

AB (*vertical hybrid*) : block showing undecided prevalence of properties of **A** and **B**, for instance, superposition.

A&B (*intrication*) : block showing intertwined portions of **A** and **B**. The size of block **A&B** is the total of that of **A** and **B**.

B|A (*horizontal hybrid*) : a specific system (**B**) is present in the first half of the block but the second half recalls the system of **A** (sometimes with a different contrast).

B<A (*kinship*) : block **B** is acceptable as autonomous at the current timescale but it exhibits strong cohesion with the previous block **A** via some common property or super-system. The sequence **[A][B<A]** could be described as a single morphological system at the immediately upper timescale.

B/A (*mutation*) : morphological system partly similar to **A** (*rooted* in **A**) but with a subset of properties whose system strongly departs from that of the other elements of class **A**. This is typically the case in some types of solos, where the harmony is common to some former block but the melody of the lead becomes freestyle. This situation also includes cases when the subset of properties is simply void, for example a passage (in particular, an intro) where the instrumental background is played alone, without any main lead.

A?B (*indetermination*) : ambiguous segment which cannot be annotated unequivocally. A typical situation like this is $\mathbf{B?A^\sim}$, when it is impossible for the annotator to conclude whether the segment is a specific semiotic element **B** or a very particular connotative variant of item **A**.

We also introduce notations for short segments that occasionally intervene in between regular ones :

A_B (*overlap*) : i.e. tiling segment corresponding to a partial superposition between **A** and **B**.

_AB_ (*connexion*) : *short segment* located between **A** and **B** which cannot decidedly be related primarily to **A** or **B**.

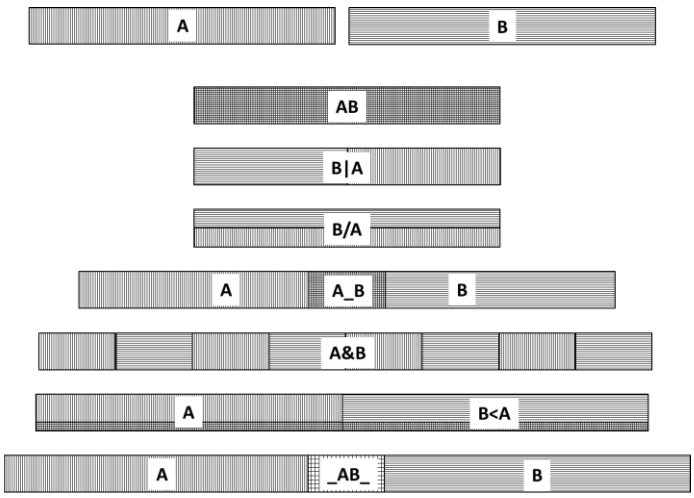

Figure 1 : composite labels (schematic configurations)

4.3 Proto-functional symbols

Even though semiotic structure description is distinct from functional structure description, we consider that it can be informative to choose the semiotic labels in such a way that they somehow reflect the *proto-functional* status of the block within the piece. We therefore propose to use, *as much as possible*, the alphabetic letters with the correspondence given in Table III.

4.4 Transcription example

Semiotic symbols can be put into brackets to facilitate visual parsing, especially when they are composite. Due to a lack of space, we leave it to the reader to "decode" the semiotic transcription represented below :

[I/A] [A_1] [A_2] [B] [C] [J/2] [A'_1] [|A'_2] [B'] [C] [X/C] [Y/2] [C*]

4.5 Concluding remark

We want to underline that a primary objective of these notations is to provide a consistent *communication language* for describing the most obvious aspects of the semiotic structure of music, while also being able to reflect some of its subtle ambiguities.

5. ANNOTATION EFFORT AND FUTURE WORK

The set of approximately 500 music pieces, for which annotations in terms of structural boundaries have been released in 2011 [13], has been updated and complemented with semiotic labels obtained with the present methodology and is accessible at [15]. These annotations have been produced manually. They come with additional documentation and with the analysis of some difficulties met during the annotation process.

Future work will be turned towards the formalization of the concepts and methodology presented in this article in terms of information theory criteria, and their investigation for the design of models and algorithm for the automatic inference of music structure.

Prototype	Illustration	Codification
Trivial	AAAAAAAA…	(A)
Binary	ABABABABAB…	(AB)
Ternary	ABCABCABC…	(ABC)
Quaternary	ABCDABCDABCD…	(ABCD)
Alternate	AABCCDAABCCD…	(2A,B,2C,D)
Cyclic	ABBCDDDABBCDDD…	(A,2B,C,3D)
Acyclic	ABBCDDDEEF…	A,2B,C,3D,2E,…
Ergodic	ABCDBADAAACBCC…	{ABCD}

Table I : Most common prototypical structural patterns

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<table>
<tr><th></th><th>Regular</th><th>Specific</th></tr>
<tr><td>Semiotic variants</td><td>A_1, A_2, A_3, …, A_i, A_j</td><td>A_0, A_*</td></tr>
<tr><td>Connotative variants</td><td>A', A'', …, $A^{(i)}$, $A^{(j)}$</td><td>A^+, A^-, $A^\sim$</td></tr>
</table>

<table>
<tr><th>Fade-in / out</th><th>Non-square</th><th>Incomplete</th></tr>
<tr><td><A
A></td><td>A/2 or (1/2)A
(3/4)A, (5/4)A</td><td>|A, A|
…A, A…</td></tr>
</table>

Table II : Main set of semiotic labels

	Intro	Pre-central	Central	Post-central	Relay	Other (recurrent)	Other (sporadic)	Outro
Primary set	I, J	A,B	C,D	E,F	J,K	M,N	X,Y,Z	K, L
Secondary set	G,H	P,Q	R,S	T,U	G,H	V,W		G,H

Table III : Proto-functional semiotic symbols