Structural analysis and Cognitive activity

TOWARDS REAL-TIME METHODS IN MUSICAL ANALYSIS

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Abstract

Structuralism and cognitivism have been confronted in their attempt to provide a method to musical analysis. The aim of musical analysis appears to be the description and explanation of the relations between the events constitutive of a work (internal analysis) and between those events and other fields (external analysis). Similarity and grouping appears to be the main kind of relations for internal analysis. This capacity of joining up events has to be related to the cognitive processes involved in the act of listening. A real-time procedure allowing to give account of those relations is proposed and illustrated with an example taken from Mozart's last Piano Sonatas. The way this analysis is performed provides a description of the cognitive activity suggested by the score according to "cognitive phases" specified at each level of the structure. It allows to give a global conceptual frame for the analysis of any kind of music, but also a model for listening able to take into account different kind of listeners.

1. Introduction

Our civilisation has a marked tendency to conceptual separation. This is of course very useful when we think in terms of categorisation. However, it can also lead to misunderstandings and deprive us of a true comprehension of phenomena. Today, Musical Analysis is confronted with such a difficulty. There would be on the one hand the score, on the other the act of listening, on one side a "structural" analysis, on the other a "cognitive" activity, and once more, on one side static, on the other, dynamics, object vs. subject, space vs. time… Music is neither a puzzle, nor a perceptive stimulus, and with respect to its specificity as a work of time and emotion, we ought to try to understand it in a different manner.

The concept of event, which involves together space and time, provides a clue for the description of musical phenomenon. A "score" can then be defined as *a sequence of events* and furthermore: *a* *sequence of events ordered for listening*. Hence, the distinction between structural and cognitive analysis already begins to become more blurred. Analysing music as an autonomous phenomenon is also a way of understanding the sounds according to their own purpose (and not as the mere illustration of some theory).

This article proposes an efficient method that allow to imagine the continuity between structural analysis and cognitive activity. This does not mean that we should listen in a structuralist way… but perhaps that we should “structure” in a more “cognitive” way. Representing temporal behaviours and dynamic systems also means giving an account of the way a music stimulate our perception with a specific solicitation of our attention and memory.

2. The three questions of analysis

Ian Bent (1987) begins his famous book on musical analysis with this definition :

> Musical analysis is the resolution of a musical structure into relatively simpler constituent elements, and the investigation of the functions of those elements within that structure.[1]

This is reflecting the classical top-down and out-of-time conception of analysis. Commonly, the purpose of Musical Analysis can be summarised into three questions: *What? How?* and *Why?* (that is to say: *What for?*). *What* and *how*, as long as you do not intend to explain its origins but rather to undertake a mere description of the factual evidence, concern what we should call the system's “internality”. Those two questions meet with what Bent calls “constitutive elements” (*what*) and “functions” (*how*). They are related to the distinction made by semiologists between “paradigms” (*what*) and “syntagms” (*how*). But the “aesthetics” question (*why*) can not be set aside from musical analysis. Taking into account the “external” factors is certainly essential for analytic investigation even if it is difficult to formalise. In the field of semiology, expressions such as “external paradigmatic”, “connotation”, and of course “semantics”, underline the involvement of parallel worlds

[1] Ian Bent, *Analysis*, The Macmillan Press Ltd, Houndmills, 1987, p. 7.

within the understanding of any kind of message. The meaning itself is related to those parallel worlds, but there is also a specific meaning of the elements and of the functions, apart from the "linguistic-like" semantic.

The value of an analysis often lies in the articulation of a description and an interpretation. Therefore, the knowledge about an object whose purpose is to be understood (perceived or received emotionally) by a subject, can inform us about understanding (perception, emotion) itself. In other words, the object "music" gives us information about the subject "musician" or "music lover", and this probably to a much greater and better extent than the delayed (explanations given afterwards) or reductive (information captured in time, but therefore very elementary) testimonies experimental psychology can work on[2]. Then we are bound to find those questions in the field of cognitive sciences. *What?* is the question of recognition, it deals with *identity* or *similarity*, *How?* is the question of temporal articulation or structuration, it deals with *inclusion* or *grouping*, *Why?* is the question of meaning attribution.

Historically this also corresponds to three main way of representing music that are not exclusive but never really managed to complement one another. The first one, not so different from traditional thematic analysis, was principally illustrated by Ruwet (1972) and Nattiez (1975) from a semiological point of view, and emphasises the "paradigmatic" axis of the relations. The second one, following the ideas of Schenker (1935) and that of Chomsky, proposes a hierarchical conception of the relationship between the elements. Meeus (1994) called those kinds of paradigmatic relations "internal", as opposed to "external paradigmatic relations", that is to say external associations as they were defined by Saussure. This third point of view has been illustrated by works like those of Ujfalussy (1961) or Tarasti (1971). It intends to relate musical events to a global topology of human representations. Little has been made to sum up those conceptions and at the same time give them a cognitive consistency.

3. Cognitivism and neural networks as a metaphor of analysis

[2] Of course we also need this kind of studies to understand musical behaviour better…

Philosophers, and especially phenomenologists like Husserl (1905) gave all its importance to the question of time and consciousness. Otto E. Laske (1977) proposed the terms of « psychomusicology » or « cognitive musicology » to emphasise the close relations music, memory and thought were led to share. A lot of books and papers have been published about music and cognitive sciences (MacAdams and Deliège 1989), computer representations and models in music (Marsden & Pople 1992), understanding music with Artificial Intelligence (Smoliar 1992), theory, analysis and meaning (Pople 1994) not to speak about more recent works (e.g. Lartillot 2003). In the attempt of musicologists to understand the emotional and intellectual expressive power of music, there has always been a problematic point whether to consider as the objet of their study the actual acoustical facts (often reduced to its transcription in a score), or the mental phenomenon induced by those facts. The answer to this question seems to change the objet of the study itself. This debate had already been summed up by Meyer (1956) as one between absolute and referential meaning. It of course runs right through Nattiez's discussion (1975) of “Molino's tripartition”. According to Meyer those two conceptions were not mutually exclusive, and he intended to relate analytic observations to psychological evidence. His definition of shape deserves to be quoted here: “The apprehension of a series of physically discrete stimuli as constituting a pattern or shape results from the ability of the human mind to relate the constituent parts of the stimulus or stimulus series to one another in an intelligible and meaningful way”. This ability of the human mind to relate constituent parts of music is definitively to be considered as the central nexus of any aim to understand how music works. But concerning the nature of the relations involved there still remains a lot of uncertainty and discrepancy.

The purpose of this chapter is to present another perspective about the neural network metaphor and its consequences for analysis. The first thing to be learned from neuro-sciences is perhaps the human variability, besides the apparent stability of brain functions. “Genes can only predetermine statistical order, and original chaos must reign over nets that learn, for learning builds new order according to a law of use” (Pitts & McCulloch 1947). This has some influence on our perception of music. For instance, the learning of a specific musical culture through the multiple repetition of the same occurrences builds exclusive and restricted circuits adapted to this culture's expectations. If this learning is too restricted or "narrow-minded", it can produce an incapacity to hear anything that is not related to it. This is of course a much broader problem than the musician/non-musician categorisation often used by experimental psychology.

Whatever the specificity of the neural cards, the adjacent links that allow them to communicate with each other (the re-entry) is also very important and emphasises the limits of a strictly mechanical and hierarchical behaviour of the brain. This "science of links", that neurones illustrate marvellously, is a nice *metaphor* of what we expect from analysis: highlighting the relations that are involved in musical experience.

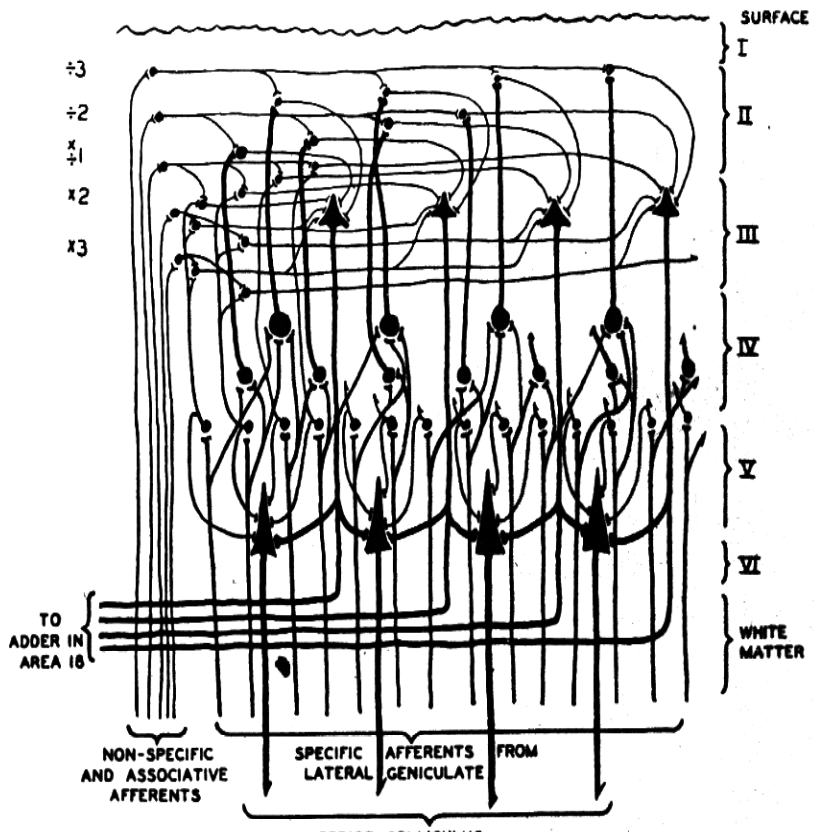

Fig. 1.: scheme of neural networks involved in perception (here visual) (after Pitts & McCulloch, op. cit. pp. 134 & 135)·

The above drawing has little to do with music analysis, but provides a good suggestion of what should be a description which could take into account at the same time both the formal / paradigmatic links throughout the time, and the structural / syntagmatic links. This is only a *metaphor*, mainly because the space axes of the former drawing does not fit the time and structural level axes of the diagram that follows (Fig. 2). The analytical description of a temporal object (a flux of events) involves the time indexation of the different kind of associations (or relations) analysis performs as a specific event, and this might be constitutive of the consciousness of what is happening.

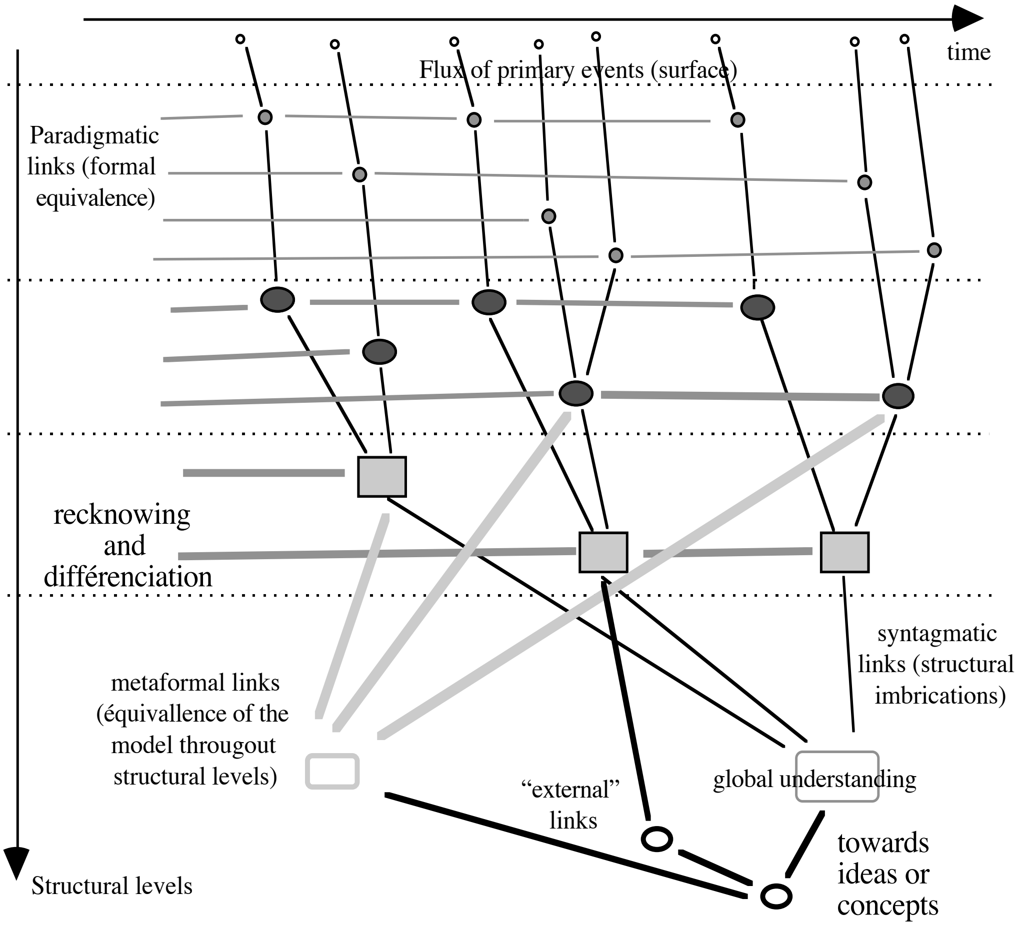

Fig. 2.: Schematic representation of the analysis of a flux of events that would account at the same time for all different kinds of relations between events. Events are represented at different levels and are all indexed by the same time axis.

Musical scores or recordings provide us with far more easy-to-grasp objects than the real stream of consciousness we may suppose they intend to stimulate. The precise study of those objects can help us to keep at a distance two fictions of cognitive psychology: the "ideal" and the "mean" subject. When you reveal, by means of analysis, a link, whether internal or external, hierarchical or of similarity, this absolutely does not implies that you have revealed a perceptual evidence. Even more, this revelation can change the evidence of your perception of the work. The main hypothesis that can be inducted from this discussion is that explicitation of the analytic procedures allows a better understanding of the way the spirit constructs objects to satisfy its own requirements and desires.

4. Cognitive analysis: definitions and hypothesis.

The project of cognitive analysis, as it is conceived here, can be summed up as follows:

- Show, dynamically, the work's constitution. Therefore, cognitive analysis can lead to “real time” analysis. This implies reintegrating certain concepts, especially structuration, formerly described as “out of time”, in a temporal logic.
- Report the way thinking is to work with temporal objects. This does not mean imitating the brain, but giving to understand what thinking is about. This has to do, of course, with some aspects of phenomenology, but is formulated perhaps in a more heuristic, operational and immediately applicative way.
- give a better understanding of the musical works, providing us with results directly concerning æsthetics and history of ideas, through the hypothesis that it is possible to obtain some evidence of the people who made and received the works through the works themselves.

Practically, cognitive analysis must allow to:

- report all the “links”, as defined formerly, present in a given work.
- preserve the integrity of the data (memorisation). In other words: it should be possible to reconstruct the work from the elements of the analysis, of course not as a mere recording (the “there is..., there is...” litany of a “level zero” description) but with the idea of optimising the memory task.

That's why the inherent contradiction between integral conservation of the information and minimal memory occupation is a major goal for cognitive analysis. This necessity of compacting also implies a kind of understanding, *with or without a code*. One must be aware that such constraints, as they can be optimised in a computer-oriented way, have little to do with what happens in an æsthetic context where the hedonistic purpose has little to do with learning tasks.

However, one can make the hypothesis that our mnesic performances owe something to this kind of cognitive mechanism, and cognitive analysis should lead to a precise description of the possible processes suggested by a given work.

5. Proposition for a cognitive model of analysis

Among the attempts to formalise analytic procedures (not related to Shenkerian-oriented analysis or rule-based and grammatical methods) those proposed by Ruwet (1972) and by Riotte (1988) and Mesnage (1991) were “out of time” procedures, giving very little consideration to the coherence between structural results and the temporal description of the method itself. Time is the main constraint in the realisation of a cognitively coherent methodology: all the links must be described as the result of an “in time” process. Further on, we will not specify the nature of the “events”, and shall assume that whatever this nature and whatever the phenomenological level, the processes involved are possible.

As we have seen (cf. chapter 2), in the constitution of streams of events, two kinds of internal relations must be described: *identity* (or *similarity*), and *inclusion* (or *grouping*). The problem is to do that *at the same time*. Inclusion supposes that there is an elementary level (i.e. a level for which it is not relevant to divide an event), and a hierarchical or structural construction that comes to an end with the global event constituting the “work”. The “atomic” events can be the “notes”, if the kind of music investigated allows this simplification[3], or a window on the acoustic signal, very like that used in Fourier analysis for example, if the music uses more complex features (as in electroacoustic music)... But any other objet corresponding to the former definition (chords, characters...) can be considered. An event, and then an object, can be a multi-parameter entity. A list of preferential grouping rules has been proposed by Lerdhahl and Jackendoff (1983) concerning tonal

[3] As long as music can be described as a set of events, e.g. playable on a sampler, Midi encoding is a good approximation of what “events” can be on the acoustical level. A “quasi-linear” relation between acoustical and perceptual level is not absolutely irrelevant, as long as the important limitations revealed by psycho-acoustics are assumed. A strictly causal hypothesis is clearly not relevant between perceptual and mental levels (e.g. a specific event can reach major importance and then mask other objects).

music. In the spirit of “gestalt theory”, those rules follow a principle of spatio-temporal proximity, and, more generally, a principle of economy. Whatever their presumed universality those kind of rules can be suspected to be rather external than internal. Composers and performers very often give precise indications, signals that work as a clue to the very way they consider the structuration has to be understood. Deciding that a group of events is a unity of its own is a rather complex task, and criteria can often be conflicting. It is important to understand that the act of grouping has no inner limitation. Nevertheless, all groups of events do not constitute a correct cognitive *object*. This might well be the definition of what is an “object” : a set of events properly grouped. Whatever the criterion for this “correctness”, it may be useful to imagine a possible algorithm for structural construction. This is roughly what the following lines intend to do. A similar recursive process has been presented by M. Baker in a quite different context (see McAdams & Deliège 1989, p. 450).

```
level := 0; ...                                  (initialisations)
for all the successive elementary-events (i from 1 to n):              (temporal motor)
        object[level,i] := elementary-event[i];       (acquisition of the event(s) in progress)
        structuration[level, object[level,i]];
                {hypothetical-object[level+1,i] :=
                        hypothetical-object[level+1,i] "U" object[level,i];      (integration)
                        if hypothetical-object[level+1,i] reaches formal statute for
completeness :                           (formal completeness and correctness is established)
                                {object[level+1,i] := hypothetical-object[level+1,i];
                                        (memorisation of the structural definition of the object)
                                level := level + 1;
                                structuration[level, object[level,i]];
                                level := level - 1;}                 (recursive mechanism)
                }                                (definition of the structuration function)
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Of course this is only a basic presentation, yet it gives a framework for further reflection. Taking into account a more complex reality, an optimisation is probably to be obtained between the realisation of the integration operation and the results of the formal completeness test. Nevertheless, the mechanism described above leads to a complete description of the structure, that is to say all the objects at all the levels, according to the criterion given by the test. This criterion is intentionally not defined here, for the purpose is to modify the algorithm, at every level, according to the precise intentions of the analyst (or the listener as a real-time analyst) and then to be able to modelise his subjectivity or his adaptation (or not) to the specific context of a given musical work.

Despite of its capacity of describing the structure, the former algorithm fails to acknowledge the relations of identity, or similarity, what semiologist call the “paradigmatic” relations. This relation is the main tool in the definition of musical form. Form means precisely here, the way a defined material (*e.g.* a set of “objects”, but the concept of material can be enlarged), at a specific level of the structure, is deployed within the duration of a work. The real-time cognitive process involved in the definition of musical form has been described in a former article (Chouvel 1993a). The schematic algorithm was the following:

level := ?; *(definition of the structural level)*
for all the successive object[level,i]: *(temporal motor)*
    if object[level,i] is not similar to objects present in the material-memory: *(similarity test)*
        {write object[level,i] in material-memory}; *(constitution of material memory)*
    keep a trace of the position of object[level,i] in form-memory; *(constitution of form memory)*

The similarity test can be forced to a binary option, i.e. identity or difference; but the degree of variation can also be taken into account in the formal diagrams. One of the basic hypotheses in the definition of the similarity relation is that it is possible to compare objects: this seems realistic only if they belong to the same structural level. As shown in figure 2, metaformal links are possible throughout the levels: they concern form's *model*, and not directly the objects. What is called here “material-memory” can be either specific to the analysed work, and the algorithm describes “internal” links, or related to former experience and “external” knowledge.

Form and structure need one each other to be effective. Structure needs form to define the models of its objects and ensure the correctness of its groupings; form needs structure to make possible on a coherent level its associations and give a meaning to similarity. Furthermore, there are certainly not two separate cognitive processes, one for the structure and one for the form, and we will see now what their interactions can look like.

Memory is a central point throughout this study as formal and structural mechanism must be “memory efficient”, i.e. allow the major possible memorisation using the minimum information retention. We have seen that structure and form do not apparently involve memory in the same way. Structure needs first temporary memory for the current object and what we call "hypothetical-objet". Form needs constant memory, to memorise the elementary sound events (what we call "material memory"). But in fact, form and structure coincide in the fact that an object of a certain level is defined by its relations to its directly inferior components. This means that an ideal process involving both mechanisms will only have to memorise elementary events and those relations, in the discovery part of the process and, of course, at all the levels involved. This is illustrated in the following figure, based on the last movement of Mozart's Piano Sonata K. 545 as described in Chouvel (1993a and 1998).


RONDO.
Allegretto.
a
b
a
c
d
legato
e
a
b
f
g
a
b
a
c
h
i
J
k
l

Ex. 1. W. A. Mozart, Rondo (Allegretto) of the Sonata K. 545.

Mozart and cognitive activity have already been analysed in Marsden (1987). To make the understanding of next figures easier, elementary events are taken at an approximate two-bar segmentation level. This is obviously not a limitation of the method but a didactic simplification. The whole piece is reduced to the following basic sequence:

aba'caba'cdea"b'fgaba'chijklmh'i'nopqaba'crsrs'ttu

Structure is represented in figure 3 with usual grouping conventions taken from the set theory. The *discovery front* is the part of the diagram that, at each level, shows new material: it is represented by dark boxes. The objects similar to those pointed in the discovery front are represented on the same level by dashes or grey levels. Variations have been pointed out with the traditional ' and " conventions but are not taken into consideration in this diagram. A little circle indicates the paradigmatic *allusions*, when objects that have been considered as different partially refer to former presented material. A representation of this kind was proposed by Leman (in McAdams & Deliège 1989, pp. 503-522), that was more specifically designed for short-term memory.

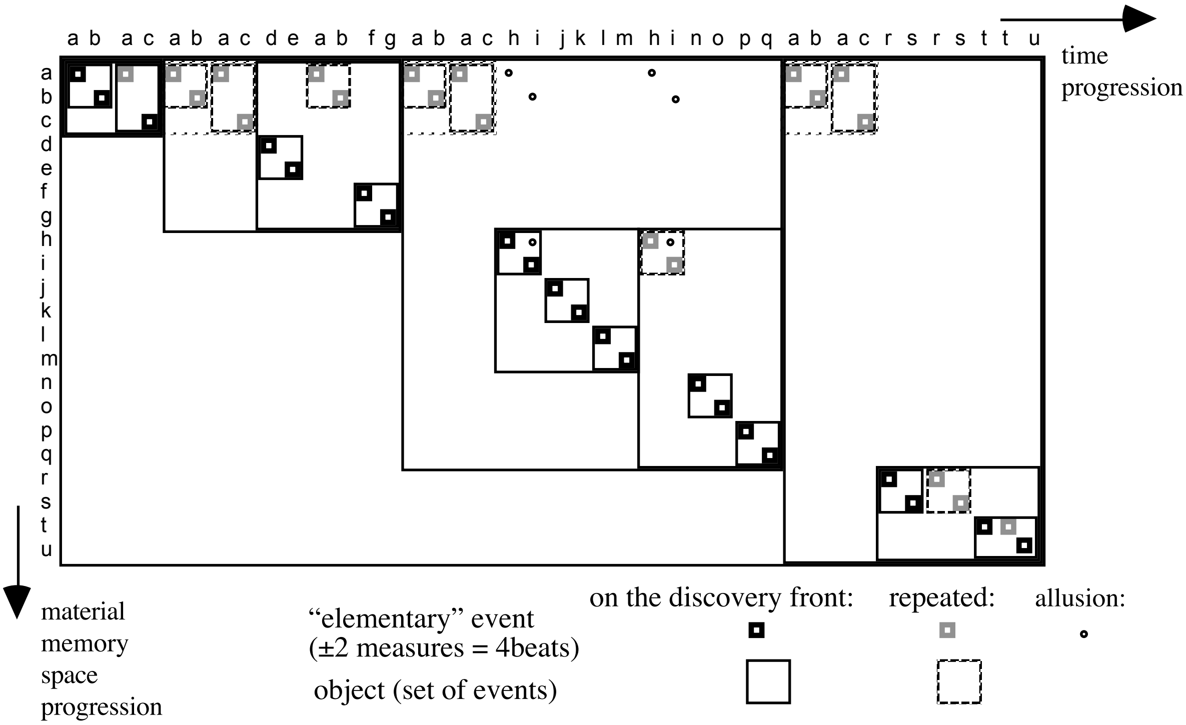


Fig. 3: Formal and structural representation of Mozart's Allegretto of the sonata K. 545.

The traditional representation for structure is not usually related to time apart from the linear initial level. Yet, the structural link can be related to the moment when appends the grouping decision. This is what is intented in figure 4..

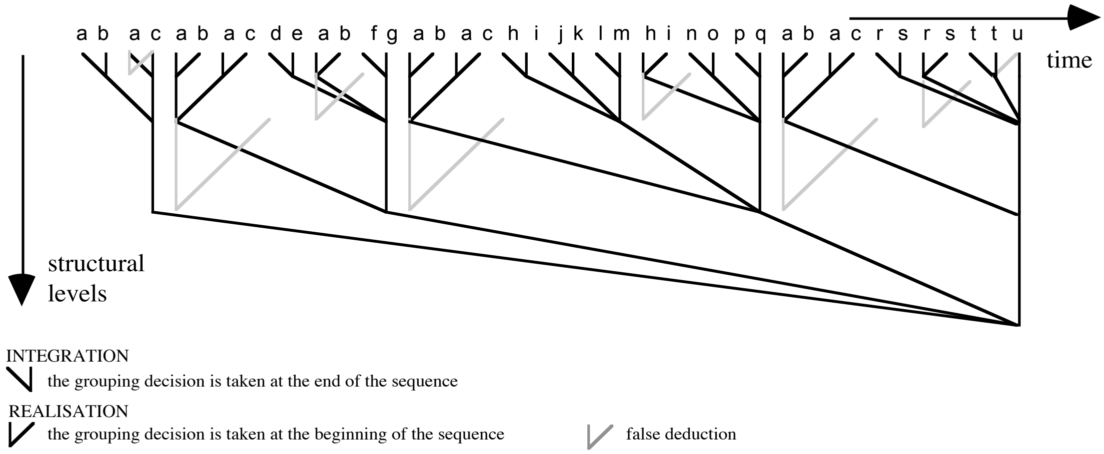


Fig. 4: Representation of structure giving a temporal meaning to the grouping links.

When the decision is taken at the end of the sequence, that is to say when no hypothesis is possible and when the material is “discovered”, an *integration* is performed. When an object has been recognised at a lower level an inference can be made on the future according to what already occurred after this recognised object, and a grouping decision occurs at the beginning of the sequence. If this expectancy is confirmed by the facts, there is what we will call a *realisation*. Otherwise, the inference is contradicted by the facts: it was a *false deduction*. In more complex context and description, several hypothesis could be in competition.

The different operations necessary to realise the former diagrams do not involve the same cognitive circuits. The integration-realisation mechanism is certainly of major importance in the course of musical audition. It is related to the predictability of the music and could be schematised at each level with a phase diagram. For semioticians, the former considerations would be pointed out as “esthesic” or “inductive esthesic”, in Nattiez's last categorisations. as they concern the reception of musical information. But in the course of this reception, the mind is engaged either in a discovery process, or in the confirmation of what is already known. This reminds strongly Meyer's implication-realisation model. The difference is only a question of what system is being considered: here, the work itself, as an autonomous whole; in Meyer, the global intellectual system. But it is easier (and epistemologically more correct...) to extend what has been clearly established on a basic information level to specific cultural norms than to derive cognitive considerations from a normative aesthetic.

Figure 5 sums up all the former reflections as a general model. This procedure allows the realisation of figures 2 and 3. It is represented with the algorithmic conventions, and structured in a recursive way, around the two main tests corresponding to recognition and completeness as we have already described them.

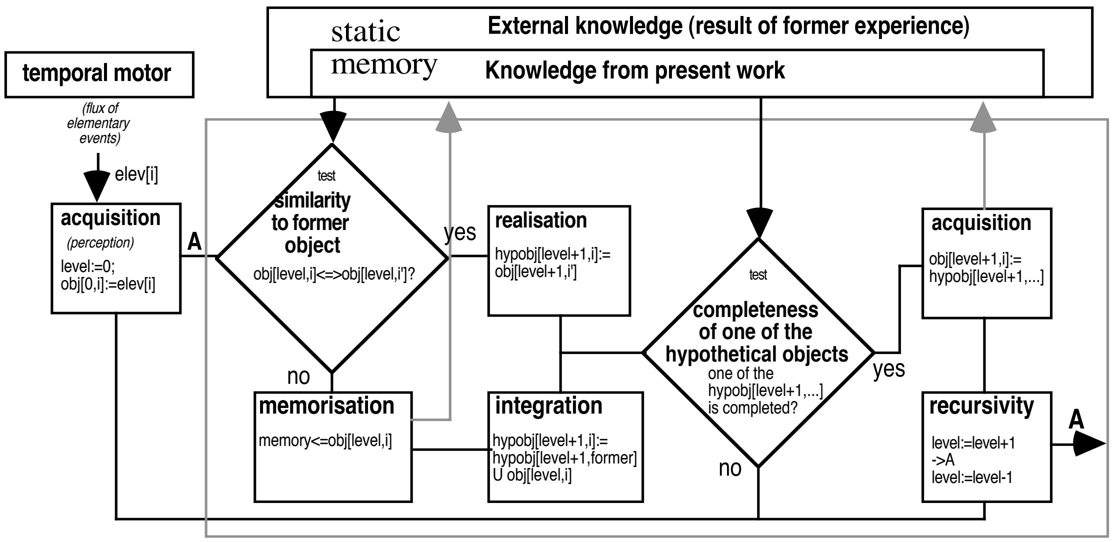
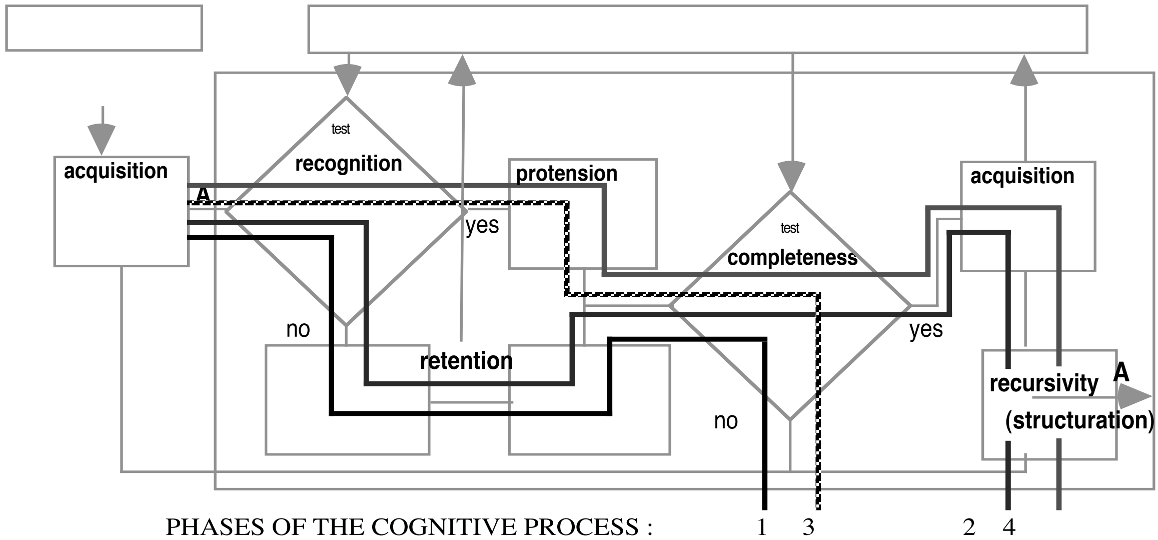


Fig. 5: Cognitive basic process for optimised memorisation of flux of events.

Even if it looks like a mechanist procedure[4], this model is to be understood as a conceptual framework for a global understanding of the cognitive actions possibly involved in musical experience. “Similarity to former events” and “completeness status” are very complex cognitive decisions, involving, especially if knowledge external to the work is introduced, tremendous data bases, with super-efficient access, or a kind of global solution for which neurone networks probably give a good approximation. Because of its being an in-time process, we can also imagine that the relation between the complexity of the information and the listener's performance is an important factor too.

We can now carry through the idea that musical analysis can be done in terms of *cognitive phases*, that is to say parts of the cognitive process implied at each level by the time progression of the piece. Cognitive phases are determined by answering the two main questions (test) of the process. In a binary world, this makes 4 possibilities at each level. Figure 6, through figure 5, gives those four phases, when figure 7, through figure 4, illustrates Mozart's Rondo understood with this tool.

[4] Which indeed it could easily be if similarity were reduced to identity and completeness were decided whenever a new identity as been detected on the inferior level, both rules being nearly sufficient with the example of figure 3.



1:	**no similitude** **no completeness**	memorisation/integration (= retention)	*waiting unknown*
2:	**no similitude** **completeness**	retention acquisition/recursivity	*waiting unknown*
3:	**similitude** **no completeness**	realisation (= protension)	*waiting for something already known*
4:	**similitude** **completeness**	realisation (= protension) acquisition/recursivity	*waiting for something already known*

Fig. 6: description of the 4 cognitive phases.

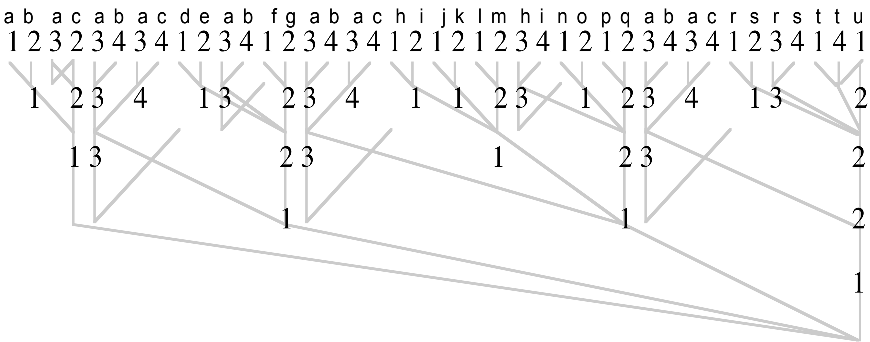


Fig. 7: Mozart's rondo described with cognitive phases.

Figure 7 gives an idea of the way Mozart's rondo goes through the 4 different phases of the cognitive analytical process. All the phases are exploited (excepted of course in the higher levels where those considerations are not very meaningful) and there use is quite homogeneous. In other words, this figure shows what's happening while analysing/listening, and when the related mental events happens.

6. directions for future research

There is a long way to go from this representation to a realistic model of listening, and perhaps it is not the goal. Further research should emphasise the importance of this kind of analysis as a great comparative tool giving precise information about temporal strategies of different kinds of music. Here, with this anodyne example of Mozart's music, we have a wonderful illustration of the very structured and balanced way of composing of the first Viennese school. We understand better how variety is distilled within the apparent evidence of this music to make it a perfect solicitation of our cognitive possibilities.

Many further improvements will be possible when a computer implementation will replace this simple hand-made example. Anyway, the main theoretical result is that it is possible to analyse music with two basic functions: recognition and grouping. The analysis is sensitive to the way and the level those functions are defined and this can explain major discrepancies that can provide future explanation for some effects of subjectivity.

This result is also important on an æsthetic point of view, as it demonstrates the possibility for an interpretation of musical works to bypass codes, rules or grammar and access directly to the temporal framework that is music's major expressive tool. This is of great interest for contemporary music, where analysis is often reduced to poïetic *mimesis*.

Conclusion

The performance of memorisation is certainly not an aesthetic goal, nor systematic recognition a criterion for pleasure. Considering the cognitive processes as autonomous from specific reference systems allows to integrate all the aspects of musical understanding in a comprehensive framework where internal and external relations are made more explicit. Its adaptability is important to respect the plurality of the possible analyses, that is to say the composer's and the listener's diversity. Moreover, it is possible to interpret this diversity as a consequence of cognitive choices and conditions.

Confronting itself to the “mystery” of time, musical analysis provides us here with a tool that can begin to suggest this unknown “time geometry” presupposed by the common expression “musical form”. Cognitive analysis is therefore a prolongation of structural analysis in a field where many researches are now to be undertaken.

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