Categories and Representation in Cognitive Musical Analysis

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Music figures among the most complex phenomena with which human beings are confronted. This observation brings to mind Augustine's famous sentence about time: "If no one ask of me, I know; if I wish to explain to him who asks, I know not."[1] Music, as an art form that is strongly related to time, involves the same type of difficulty. Musical analysis consists in an explanatory attempt that often remains removed from the actual experience of listening to music.

The approach to musical analysis that I tried to initiate with my doctoral dissertation in 1990 rests on the idea that the analytical process must follow as closely as possible the behavior of the musical one.[2] This means that we have to be aware of the cognitive processes at play *when one is listening*.[3] Despite the increasing accuracy of experimental psychology and of the neurosciences, it seems that these processes will remain out of reach for a long time. Moreover, we can easily expect the complexity of musical experience to be far greater than that of a musical score. This does not imply that such an idea is purely utopian. With a score, or a recording, the analyst may imagine that he possesses a transcription or a testimony of what can occur during listening. When said this way, this supposition is of course false. But it would not be absurd to consider that it has some truth to it, and that some coherence holds between music and its intent to affect us.

1. About cognitive analysis

I call "cognitive analysis" the theoretical research associated with this aim.[4] Cognitive analysis lies within the field of immanent musical analysis, that is to say, it deals with an objective description of the musical phenomenon in close relation with its materiality, be it that of the symbols of a score, or of the sound fields of a recording. The basic idea behind cognitive analysis is that it can be performed in *real time*, and that the way it occurs gives us impor-

tant information on the temporal configuration of the work. Many proposals for a cognitive model of hearing have been made since the precursory work of Émile Leipp and Otto Laske in a field that, since then (1977), has been known as "cognitive musicology."[5]

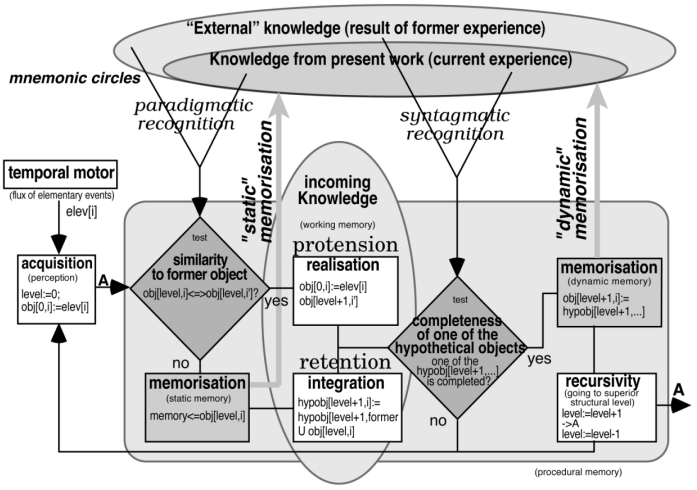
My own original purpose was to solve the problem of analytical methods in musicology as Nicolas Ruwet had initially formulated it.[6] Ruwet wrote: "The main issue here is about discovery procedures, that is to say, analytical criteria."[7] He was quite successful in his attempt to formalize a generic method (since then known as "paradigmatic analysis"), but Ruwet himself was very much aware of the fact that beyond this apparent efficiency something remained unclear as to the interactions between form and structure. Structural levels must be determined before we are able to proceed with a paradigmatic comparison. As for Ruwet the determination of structure remained linked to the ability to divide a whole into parts, the entire piece had to be known before it could be broken up and a comparison of paradigms performed. This difficulty, which often goes unnoticed by analysts, obviously does not allow this analytical method to qualify as a "real-time" discovery procedure.

The basic procedure and the algorithm that permit an understanding of how structure and form can be processed in real time have played an important part in my research and have lead to publications in French and also in English.[8] In particular, I was able to design an algorithmic diagram that synthesized a problem perfectly described by Ruwet, but also by the philosophy of time, especially within the scope of phenomenology (but also in the work of Deleuze).[9] This diagram is reproduced in example 1.

Even if the reader only intends to skim through this essay, it may be worth spending some time examining this figure, which provides the framework of cognitive analysis. The purpose of the algorithm is to demonstrate how knowledge is constituted through the processing of basic temporal information, that is to say, a flux of elementary events ("elev"). This can be the MIDI data transmitted by a keyboard player, but at a lower level it can also be understood as a "granular" sound sample. Whatever the basic level considered as that of entry to the process, it must be understood that

the main frame (with the rounded edges) represents the process at one given level, and that the process uses recursivity to jump from this level to the next highest one. From this premise it stands to reason that the model presented here is not meant to offer any similarity to real human cognition.

Ex. 1. The framework of cognitive analysis.



The purpose of this model is to convert an indeterminate flux of "events" into a collection of structured "objects." Two abilities are necessary, here labeled after the vocabulary of linguistics as *paradigmatic* and *syntagmatic* recognition, represented by a *similarity* test and a *completeness* test. According to how these tests are performed the whole analysis can be completely different. This does not suggest a deficiency in the model, but on the contrary it is indicative of its strength. Searching for universal rules and "ideal" descriptions is not much relevant here: one needs to render explicit the categories that are used for investigation.[10] Another point is that, due to its recursivity, the framework is given for "any" one layer, while it is mostly probable that each structural layer has its own specificities. From the point of view human cognition, it means that each layer might be addressed by adequate neuronal circuitry.

A description depends on specific criteria, which does not mean that it stands in complete relativity. According to the algorithm, descriptions have to acknowledge each specific piece of information delivered by the flux of events. This is a very important point, meaning that "objects" are not predetermined by the theory but constructed by the reality of what is happening. Analysis is not looking *for* something; it is really looking *at* things, and paying attention to every detail. Once again, there is no evidence that human listeners behave that way, either because of distraction, or the expectation of such or such convention. Often there is some confusion between esthetic availability and code sharing. This can be modeled by the introduction of "former knowledge" as additional referential information. One of the interesting points is that this is not necessary: the algorithm is able to constitute "knowledge" on its own, thus displaying the relationship between listening and *learning*. One does not already need to know in order to learn. As a matter of fact, learning has nothing to do with knowledge accumulation, or else a magnetic tape would learn: *learning requires structuring*.

Hence, the elaboration of relevant categories is the main point here. This process—let us qualify it as the "structuring process"—takes place between the "similarity" test and the "completeness" test.[11] It follows a different path according to whether some similarity has been detected or not. If no similarity is detected, then we are dealing with new material, which requires specific memorization. When some similarity is detected, another mechanism is involved that deals with the possibility of anticipation, meaning that the events that follow can be deduced from former experience. Expectation is not about the unknown but about confirmation, or (perhaps) surprise. This resembles the notions of "retention" and "protension" inherited from Husserl's phenomenology of time, yet with the considerable difference introduced by the presence of structural layers.[12]

Structure is what allows segmentation to be performed in a continuing process and segmentation is what makes it possible to extract manageable objects from what would otherwise constitute an indiscriminate flow.[13] The elaboration of a complete object at a

higher level takes place somewhere similar to what psychologists used to call the "working memory." Its span is related to the "present moment" and its relation to consciousness will no doubt represent an important topic in future research.[14]

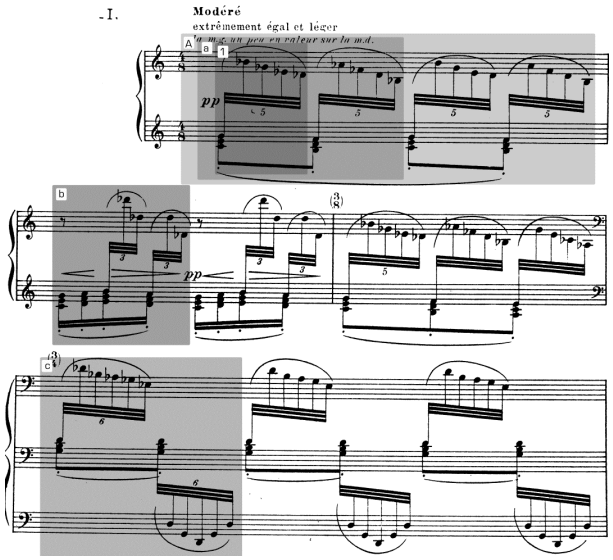
We will go no further here, as our concern is restricted to the methodology of musical analysis. Cognitive analysis makes it clear what form and structure in music are (as well as in every kind of temporal expression), and how they are integrated within a temporal process. It offers a very powerful tool for the exhaustive description of music, regardless of its style, or medium. The reader may find several illustrations of the notions I have just presented in my former writings. Most of them could almost seem too well-fitted to the concepts under discussion, but they were intended to be pedagogically useful. I will now present a slightly more complex example, which is the first piece of Debussy's *Second Book of Preludes*, "… Brouillards."

2. Some reflections on representation

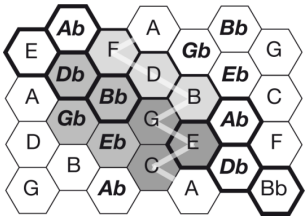
The binary structural scheme of the piece is presented from the outset, but it is disturbed by the introduction of odd metric elements such as the quintuplets of the first measure, the triplets of the second measure, and the meter changes from the initial 4/8 to 3/8 and 3/4 in the third and fourth measures. This may introduce a difficulty for the definition of structural levels, but whenever this kind of ambiguity appears, the analyst must know that it means something specific. (See example 2.)

Therefore, although a standard binary structure is suggested, it is purposely shaded off in many ways. This is the case with the harmonic structure as well. While the left hand alternates between what seem to be the first and fifth degrees of C major, the arpeggios in the right hand complete the harmony in a way that evokes the color of the octatonic scale. The underlying progressions of thirds allow all twelve tones (minus the A) to be heard in the space of a single bar without communicating any feeling of dissonance. (See example 3.)

Ex. 2. Claude Debussy, "…Brouillards," from *Second Book of Preludes,* 1st ed. (Paris: Durand & Cie, 1913), p. 3, beginning of the piece.



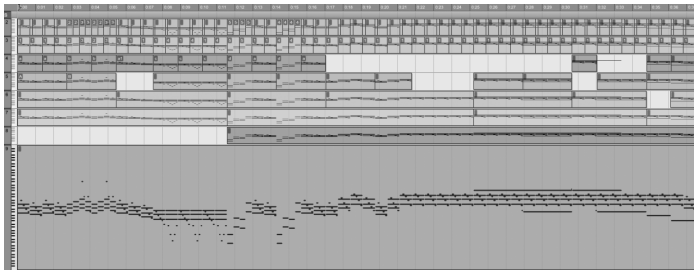
Ex. 3. Representation of harmony in the first bar of Debussy's "…Brouillards" by means of a hexagonal Eulerian lattice.



A structural representation has been created in a sequencer (Pro-Tools) from a MIDI file of the piece.[15] This representation shows the successive inclusion of the material of the piece in progressively broader excerpts. At about 0′17″ [measure 7], there begins a sequence that leads to an ostinato (0′22″ [measure 9]). Above this ostinato, a much slower musical element is introduced, which sounds temporally disconnected from the accompanying agitation.

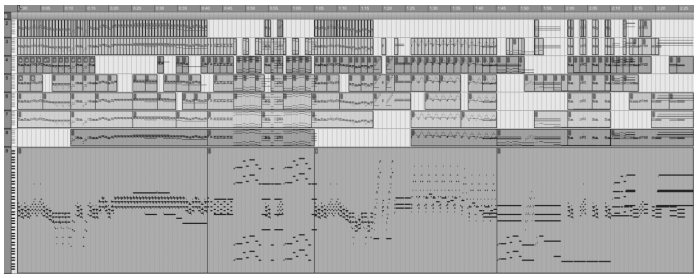
The lack of intermediate structure is very important for the appreciation of this moment. (See example 4.)

Ex. 4. Piano roll representation (created in ProTools) of the structure of the beginning of Debussy's "… Brouillards."



If some structural levels are easy to identify, the idea of a perturbation of standard structural patterns is visible along the whole piece, as the entire representation suggests (example 5):

Ex. 5. Representation (created in ProTools) of the structure of Debussy's "… Brouillards."

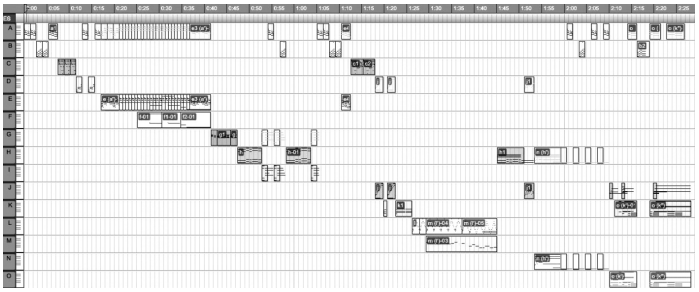


Structural discontinuity in Debussy has been evidenced by Michel Imberty in his study of "… La Puerta del Vino."[16] But what about form? We have shown before that form could afford different shapes according to the structural level involved.[17] This is due to the fact that the determination of form depends on the similarity question and it is not appropriate to compare musical excerpts that belong to different structural layers—even though they may sometimes share the same "model," that is, display the same shape regardless of the structural level to which they belong. Form is the

expression of similarities, yet on the other hand it also expresses differences. Form cannot be constructed where there is no possibility of discrimination. And the process is probably more efficient when discrimination is maximal. This often occurs at a specific level where musical ideas reveal themselves as what Messiaen called "characters" ("*personnages*"), which is a way of pointing to some underlying narrativity in the course of the piece. The beginning of "…Brouillards" displays no ambiguity about the "characters" involved since they correspond to the bars and the repetition of precise motives.

The representation of the form of the piece (see example 6), also achieved in ProTools, shows the deployment of the successive musical ideas and how they recur in the temporal unfolding of the piece. When played in a real time sequencer,[18] it is possible, by using the scrolling playhead, to obtain an at-will time-reading (and hearing) of this diagram.

Ex. 6. Representation (created in ProTools) of the form of Debussy's "…Brouillards."

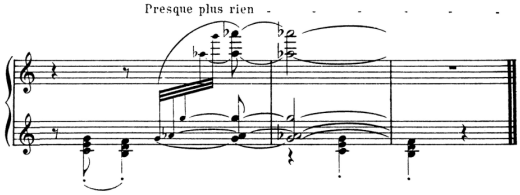


It is always difficult to get an idea of the meaning of such a diagram when one is not aware of its clues. But anyone familiar with musical sequencers can intuit that it provides a kind of "decomposition" of the piece, showing the progressive apparition of the musical material in an orderly way. Whenever something is repeated, it is placed in the same line as where it first appeared. Conversely, whenever something new is sounded, the diagram conventionally extends down the vertical axis. The way in which it extends pro-

vides essential clues about the formal strategy at play: I call this the "discovery front."

Traditional paradigmatic analysis is not efficient when it comes to dealing with polyphony. In the above representation, on the opposite, polyphony is quite easily accounted for (see example 6). For instance, the ostinato figure appears in layer E (5th line down) while the leading voice is represented in layer F.[19] Here, it has been decided to attribute a new layer to the ostinato as constituting a new musical idea even though its material is clearly derived from the initial motive. This is why its relation to layer A is rendered with a "muted" block. The same goes for the end of the piece (example 7):

Ex. 7. Claude Debussy, "…Brouillards," from *Second Book of Preludes,* 1st ed. (Paris: Durand & Cie, 1913), p. 6, end of the piece.



The left-hand chords are those already present in the first measure. However, they return without the complementary E-flat minor seventh arpeggio. This would not have been a problem had we designed the formal diagram to address a lower level of the structure where the chords would not have been grouped (as in level 2 of example 4). But the material labeled "A" embeds both elements. This points to the entanglement between form and structure, but also to the limits of the yes or no answer to the similarity test in the cognitive model, especially when it comes to higher structural levels. Most of the time, understanding variations requires looking at the lower structural levels.

3. Changing categories

Many further comments would be in order but my purpose here is not to analyze Debussy's piece, nor is it to discuss specific philological problems. I would like at this point to examine the plasticity

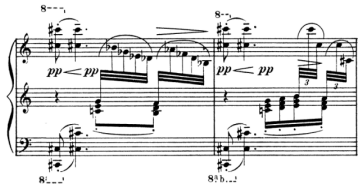
of the representations with which we are now more or less familiar and focus on the opportunity to change the categories with which we have been dealing so far. For instance, let us try to reduce to a minimum the number of musical ideas taken into account in the construction of the formal diagram. The result may resemble the following (example 8):

Ex. 8. Another representation (created in ProTools) of the form of Debussy's "… Brouillards."

All the elements distributed among 15 tracks in example 6 are now condensed into 3 tracks thus labeled: (i) "Undulations," (ii) "Gesture toward the high register," and (iii) "Slow, low and deep 'melodies'." If we try to listen to the piece this way, as if through an aural mist, the result is by no means absurd. It may even seem clearer than without the help of these categories. The interruptions of the musical flow, with their dramatic resonances, are made clearly apparent and the global evolution toward the low register in the third track becomes particularly legible. It may also be worth mentioning that while the whole piece seems to be built around a confrontation of the three basic shapes, the section from 1′25″ to 1′45″ attempts a kind of synthesis where the undulations emphasize the high register with the presence of a slow melody. The section ends brutally despite the fact that a 6-tone chord is left to resonate and is followed by an immediate reminiscence.

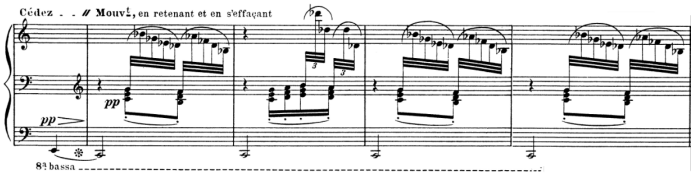
The beginning of the piece (measures 1–24, 0′00″–1′05″) and the recapitulation (measures 24–52, 1′05″–2′30″) are based on the same model, the recapitulation being essentially a magnification of the first part.[20] The purpose there is to draw the listener's perception to a specific experience that involves the deception of its expectations. In the first part, this takes place in measures 20–21, where the formula of the first bars returns as a distant echo (example 9):

Ex. 9. Claude Debussy, "… Brouillards," from *Second Book of Preludes,* 1st ed. (Paris: Durand & Cie, 1913), p. 3, measures 20–21 (±54″).



In the second part, the measures concerned are 43–46. The C□ formerly projected over several octaves has now become a single, dramatic low C□. Although this tone should function as a harmonic resolution, it sounds in fact like a cleaver, mainly because it comes straight after the triplets, thus undermining the perception of a recapitulation (example 10):

Ex. 10. Claude Debussy, "… Brouillards," from *Second Book of Preludes,* 1st ed. (Paris: Durand & Cie, 1913), p. 6, measures 43–46 (±2′).



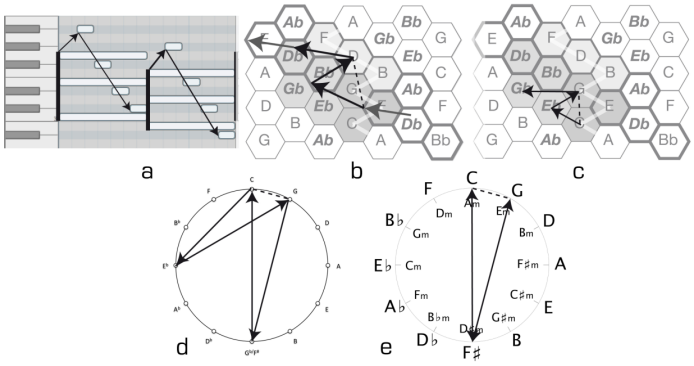
It is not only the elements of the "material" itself that are important for the understanding of the musical thought at work, but also the way these elements are strung, *and the way they were strung before*. This is true on the scale of a single piece, but also on an even larger scale, against the entire cultural background. For instance, it is no mere chance if "… Brouillards" concludes with the reversal of the classic tonal cadence (I–V instead of V–I, see example 7), cancelling the realization of one of the strongest "implications" of tonal music.

A great number of representations have been developed in musical analysis, but there is little synthetic research on what is actually meant by the fact of representing, especially with respect to real-time cognition. While categories are usually assimilated to "material," it might be pertinent to investigate their derivatives, i.e. the

categories related to changes of "material." This amounts to emphasizing the dynamic aspect of movement, to giving prominence to transitions rather than to positions. As a matter of fact, whenever there exists a space to allow the representation of positions, it is possible to derive from it a space to represent the transitions between these positions. This latter space might be defined as a "vector space." If x and y are two positions, a transition can be understood as (x,y). This means that, for a cardinality of the position space n, the cardinality of the transition space is n^2, regardless of possible equivalences. This combinatorial fact may explain why dynamics aspects are less studied. Nevertheless, they convey a potentially important image of the trajectory of a piece.

Let's take the example of the motive at the very beginning of Debussy's Prelude. In example 11a, the position space is that of the keyboard, which becomes a "piano roll" when a time axis is added. Transitions are dynamic intervals allowing the vectors to draw a melodic "profile." The descending shape of this profile might present a significant contrasting element to the ascending gesture mentioned in the discussion of example 8.

Ex. 11. Some representations of the initial chords of Debussy's "…Brouillards" from a dynamic point of view.



In example 11b–c, the position space is that of a minor- and major-third hexagonal Eulerian lattice, with the succession of fifths on the vertical axis and that of minor seconds on the horizontal one. This type of representation may possess two meanings according

to whether the pitch labels are to be understood as actual tones (C would then be spelled as C_4 or C_5) or as "pitch classes," regardless of the octave. In the first case the representation resembles a cylinder, in the second case a torus. Example 11b shows the evolution of the centroid of the chords as it moves around the torus. Example 11c displays the progression of the fundamental bass (which remains "virtual" here for all the chords except the first). In this particular case, harmonic movement seems to consist in an exploration of the neighborhood and it does not seem to extend around the torus since the vector that would close the cycle is a diminished fifth (not represented here). Example 11d represents the same progression on the circle of fifths, providing another view of the "distances" implied, and example 11e uses another version of the circle of fifths with chords that takes into account the "relative" equivalence relation. The oscillation between opposite poles, with the neighbor motion of the two struck chords, is made perfectly clear on this figure.

This description merely accounts for the first half of the first bar of the piece. Moreover, it is difficult to ascertain what aspect would appear more important to the ear. All these partial representations probably blend into a global mental representation of which we are not aware, and which that may differ from one person to the other. It seems pointless, therefore, to find out whether one representation is superior to the others. Each of them helps to highlight some specific issues in relation to the categories on which they are based. The underlying idea is that a suitable category allows a signal to emerge while an inadequate one will remain within the noise range—but it might also be useful to know something about that noise.

4. Categorizing the representations

The aim of this essay is to attempt to provide a general framework for representation in the domain of musical analysis. As mentioned above, one of the principal difficulties raised by this attempt concerns the role of time. Historically, physicists have shown more interest in this issue than mathematicians. Representation of ordinary space is already a controversial problem, which has been

subjected to strong philosophical criticism, especially from phenomenology. But phenomenology was also much concerned with the specificity of the constitution of an interior reality by consciousness within the course of time.

Analyzing means bringing relations to light. For this, we must concentrate on the information at our disposal depending on the particular system chosen. Within that system, which is made up of a set of data, it is essential to distinguish between two main classes of relation. One relates to the ability to recognize objects (for that purpose mathematicians use symbols such as $=$, $\approx$, $\Leftrightarrow$, etc.), the other to the possibility of grouping these objects (mathematicians use symbols such as $\in$, $\subset$, etc.). These are the basic tools, also from a cognitive point of view (see example 1). The first class of relation (similarity relations) is suitable only for entities of a similar type (sharing the same structural level) while the second is suitable for entities of different types (belonging to adjacent structural levels). This makes nonsense of expressions such as $x \in x$, and allows us for instance to dispose of Russell's paradox.

To make a time-related representation possible, it is necessary to consider "events" that are characterized by spatial, energetic and temporal coordinates. (A musical tone, or more accurately the beginning of a tone, is thus described in terms of its frequency, its intensity—or in MIDI language its "velocity"—and its temporal position.) Continuous data can be sampled at a rate that exceeds the capacity of human perception so that it makes no difference to the latter. Waveform is a temporal representation for which the space is reduced to intensity. To build a sonogram, we need to extract categories for instance by using a fast Fourier transform (FFT), and change the structural layers and the time scale. Space can lead to its own representations, following its own inner order and the possibilities it affords for the structuring of higher-level categories. "Space," in fact, designates a set of categories that belong to the same structural level (e.g. in a sonogram frequencies can be structured into tones regrouping harmonic spectral components, tones can be structured into harmonic intervals which themselves can be structured into triads, etc.). This is the "static/out-of-

time" part of example 12, a diagram that aims to give an overview of the possibilities for representation in musical analysis.

Whatever the space, i.e. the set of categories, an event can be represented as a "trace" that reveals the presence of such or such a category along the time axis. Of course, this may only be true of categories that are relevant to a particular work, with respect to pertinence and exhaustiveness alike, hence becoming what should be termed *descriptors*. Whenever time is sampled, what can be called a "presence matrix" is implied, where *presence* relates to the energy coordinates. The order of the "categories" axis can conform to previously given or abstract spatial considerations (such as the order of frequencies for a piano roll) but may also follow the time order, enabling only the specific categories that qualify as *descriptors*. This is what happens in formal diagrams such as that presented in example 6. Time enables a structure of its own (specific to a certain work) that can be coherent or not with the structuring possibilities extant within the conceptual "out-of-time" frame. The "static/in-time" part of example 12 has been one of the most commonly used until now.

It is also possible to represent temporal behavior in multidimensional plots that take different categories for their reference axes (upper-side parts of example 12). This is the case of Eulerian lattices such as that shown in example 3, where the categories are the intervals. Even though the vertical vector is the interval of the fifth and the horizontal vector the minor second, the minor- and major-third vectors are better generators that are more apt at revealing the cycle of thirds of diatonicity (the white line in example 3). This takes us to topological considerations whereby a piece of music draws a kind of trajectory (e.g. example 11b–c), or to global statistics, depending on the axes and the categories chosen. This can be visualized temporally, especially by means of a motion picture.[21]

Everything we described so far can be duplicated from a dynamic point of view. This means that whenever categories are defined, a world of temporal transitions between those categories emerges simultaneously. If categories are parameters, this can consist of a simple derivation. An interesting example of such a situation is that provided by the differential sonogram.[22] Instead of showing

the presence of energy within a bandwidth, it allows representing the variation of energy inside this bandwidth. The information is similar but the viewpoint is different, thus emphasizing changes. This is perhaps even more consistent with our perceptive behavior, which is always eager to find out about changes happening around us.

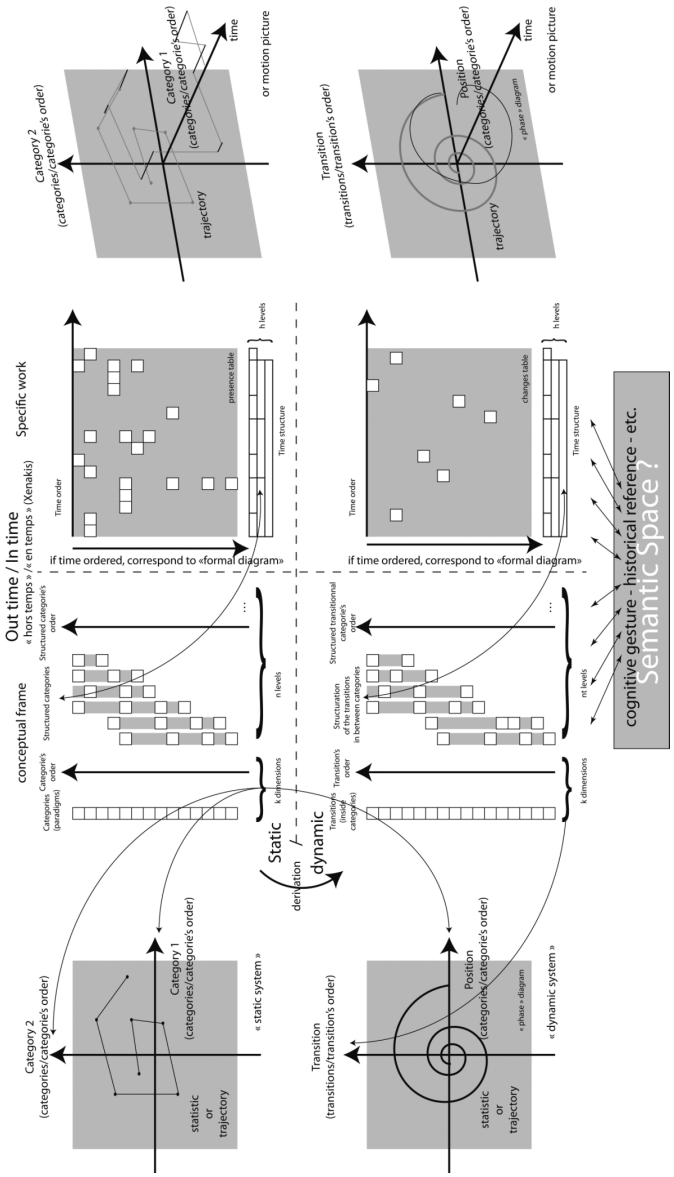
A special emphasis must be placed on a type of representation that blends categories of the static order with their transitional derivatives (bottom left side of example 12). This type of diagram, which was introduced by physicists in the late 19th century, is known for enabling the visualization of the determinism of a given dynamic system. In quite a different context, it has also been used by such composers as Henry Cowell and Iannis Xenakis.[23] But it can also allow a description of the logic of scale degrees in tonal music, or of the "behavior" of a mode…

Conclusion

Processing the data of a work in a systematic, cognitive way reveals another aspect of immanent analysis, which is less subjective and yet closer to the subject, and addresses critical aspects of musical behavior. When trying to understand music as a phenomenon, two different logics seem to be entangled: that of space, as a preestablished order independent of the work examined, and that of time, which more specific to the particular work and relates to the present moment.

This has led us to general considerations about the use of representations in the field of musical analysis. The main interest of a typology of musical representation is to broaden the possibilities of constructing images from musical data, and opening new possibilities for semantic interpretation. Finally, the exploration of multimedia possibilities that enable real time analysis constitutes a challenging opportunity for imagining new tools for systematic musicology.[24]

Ex. 12. Proposal for a typology of representation for musical analysis.



Notes

[1] Augustine of Hippo, *Confessions*, Book 9, chap. 14, trans. J.G. Pilkington (Edinburgh: T. & T. Clark, 1886), http://www.newadvent.org/fathers/110111.htm.

[2] Jean-Marc Chouvel, "Sur la théorie de la forme et son implication dans la création musicale contemporaine" (doctoral dissertation, Université de Lille-III, 1990).

[3] See Jean-Marc Chouvel, *Esquisses pour une pensée musicale* (Paris: L'Harmattan, 1998), and *Analyse musicale: sémiologie et cognition des formes temporelles* (Paris: L'Harmattan, 2006).

[4] Jean-Marc Chouvel, "L'analyse cognitive: décentrement méthodologique ou malentendu épistémologique?," in M. Ayari, J.-M. Bardez and X. Hascher (eds), *L'analyse musicale aujourd'hui/Music Analysis Today* (Le Vallier: Delatour-France, forthcoming in 2014).

[5] Émile Leipp, *La machine à écouter: essai de psycho-acoustique* (Paris: Masson, 1977); Otto Laske, *Music, Memory, and Thought* (Ann Arbor, MI: University Microfilms International (now Bell & Howell), 1977).

[6] Nicolas Ruwet, "Méthodes d'analyse en musicologie," *Revue belge de Musicologie/Belgisch Tijdschrift voor Muziekwetenschap* 20/1–4 (1966): 65–90.

[7] "Le problème crucial ici est celui des procédures de découverte, c'est-à-dire des critères d'analyse." (Ruwet, p. 65.)

[8] See Jean-Marc Chouvel, "Musical Form: From a Model of Hearing to an Analytic Procedure," *Interface* 22/2 (1993): 99–117, and "Structural Analysis and Cognitive Activity: Towards Real-Time Methods in Musical Analysis," *Journal of New Music Research* 33/1 (2004): 19–29. References to publications in French can be found in note 3.

[9] See Gilles Deleuze, *Différence et répétition* (Paris: PUF, 1969); trans. P. Patton as *Difference and Repetition* (New York, Columbia University Press, 1994).

[10] This is true of many analytical tools, although we tend to forget it. For instance, many people will consider sonographic analysis as a given fact, when it can be severely altered by the parameters of the underlying Fourier analysis.

[11] From a gestaltist point of view, it would be possible to perceive some equivalence between "completeness" and "similarity" at a higher structural level.

[12] Edmund Husserl, *On the Phenomenology of the Consciousness of Internal Time (1893–1917)*, trans. J.B. Brough (Dordrecht: Kluwer, 1991). Original work published 1928.

[13] The main criteria allowing the "completeness" decision can be a codified indication (often related to a dynamic shape, such as the silence between words) or the recognition of a previous element at a lower level.

[14] The "present moment" is a concept introduced by Daniel Stern in his book *The Present Moment in Psychotherapy and Everyday Life* (New York: Norton, 2004).

[15] The fact of performing the analysis with a standard computer tool allows one to listen to the piece simultaneously in a way that makes the concepts developed here easier to apprehend. There are more subtle ways of representing structure, especially in a case like this where the levels involved are not binary, but they cannot be achieved with a common sequencer.

[16] Michel Imberty, *Les écritures du temps: sémantique psychologique de la musique,* vol. 2 (Paris: Dunod, 1981).

[17] See notes 3 and 8 above.

[18] The video sequences may be downloaded from http://xxxxxxxxxx

[19] MIDI gives the possibility of sounding those layers separately, which is more difficult to achieve when analyzing from a sound support without having the initial mix.

[20] This would correspond to the 10th structural level which has been omitted from example 5.

[21] Attempts at such a form of visualization can be found here: http://www.musimediane.com/spip.php?article21. Also consult Louis Bigo's doctoral dissertation and conference presentations: http://www.lacl.fr/~lbigo/.

[22] See http://www.ems-network.org/spip.php?article294.

[23] See Henry Cowell, *Ritournelle* (1939), and Iannis Xenakis, "Musique stochastique markovienne," *Musiques formelles* (Paris: Stock, 1981), chap. 2, pp. 61–131. 1st edition 1963.

[24] See the online journal of the French Society for Musical Analysis (SFAM), *musimediane*, http://www.musimediane.com/.