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## ► To cite this version:

Olivier Lartillot. Integrating Pattern-Matching into an Analogy-Oriented Pattern Discovery Framework.. ISMIR: 3rd International Conference on Music Information Retrieval, Oct 2002, Paris, France. pp.269-270. hal-01161117

HAL Id: hal-01161117

<https://hal.science/hal-01161117>

Submitted on 8 Jun 2015

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# Integrating Pattern Matching into an Analogy-Oriented Pattern Discovery Framework

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## ABSTRACT

We claim that the core mechanism of a sufficiently general MIR system should be expressed in symbolic terms. We defend the idea that music database should be pre-analyzed before being scanned for MIR queries. We suggest a new vision of automated pattern analysis that generalizes the multiple viewpoint approach by adding a new paradigm based on analogy and temporal approach of musical scores. Through a chronological scanning of the score, analogies are inferred between local relationships — namely, notes and intervals — and global structures — namely, patterns — whose paradigms are stored inside an abstract pattern trie (APT). Basic mechanisms for inference of new patterns are described. The same pattern-matching algorithm used for pattern discovery during pre-analysis of musical works is reused during MIR applications. Such an elastic vision of music enables a generalized understanding of its plastic expression. This project, in an early stage, introduces a broader paradigm of automated music analysis.

## 1. INTRODUCTION

Musical shaping, stemming from a multitude of elementary constructive rules, may be transformed in numerous ways without altering its basic structure. If a dialog has to be established between a human user and a machine in musical terms, it has to take into account the specificity of music as a symbolic system. That is why it seems that the heart of a mature MIR system should be expressed in symbolic terms. Of course, the signal reality of music may be taken into account as the basic material and the medium of musical phenomenon.

The general research domain of Information Retrieval (IR) accepts a specific discrimination between two types of approaches, where user query is compared either to the rough documents themselves, or to a synthetic representation of the documents, resulting from an analysis of them.

The second approach features several interesting properties, in particular: reduction of computational cost, pertinent answering of queries, cognitive modeling. The pre-analytical approach is even more relevant in the music domain, since the elementary articulations of the discourse are much more hidden in musical surface than in natural language.

A general approach of musical pattern detection would have to be able to detect approximate repetitions of sets of notes inside the score multidimensional space. Each elementary similarity that defines the whole approximate repetition may be expressed along different musical parameters. And the pertinence of such a repetition has to be carefully formalized and justified in order to obtain musically pertinent patterns

and also in order to avoid computationally excessive complexity.

Generally, musical pattern discovery methods directly consider whole patterns. Such a global point of view enables a fast detection of patterns, as long as they are similar enough. As soon as musical plasticity is taken into consideration, this traditional approach is no more adequate.

## 2. *kanthume* APPROACH

### 2.1 Analogy

We suggest another method [2], highly developed in contemporary cognitive sciences and of high interest here, based on analogy. Indeed, “analogy-making lies at the heart of pattern perception and extrapolation” [1]. Analogy means that the similarity of two entities is hypothesized as soon as one or several resemblances of particular relevant aspects of them are detected. Human understanding heavily relies on such a mechanism since it progressively constructs a representation of phenomenon. The cognitive system has to take some risks, to *induce*, that is, to infer knowledge that is not directly present in the phenomenon, and, then, to check the good fulfillment of this hypothesis.

An analogy-based vision of understanding is even more accurate in a musical context. Indeed, music cannot be apprehended as a single object: at each step of music hearing, only a local aspect is presented. Thus the analogy hypothesis of music understanding means that the global music structure is inferred through induction of hypotheses from partial — in particular timely local — point of view. The temporal characteristic of music implies another important aspect: namely, a chronological order [3].

*kanthume* project aims at building a musical pattern discovery system based on cognitive-oriented modeling of induction of analogies and of temporal perception of music. In a first approximation, we limit our scope to pitches, durations, and time onsets. The score is scanned in a temporal order and, for a same time onset, in a growing order of pitch.

### 2.2 Musical representations

As we limit music as a score, that is a set of notes, at each instant of music listening, this local viewpoint consists in fact of elementary *notes n*, and relations (concerning time and pitch) between notes, that is: *intervals*. As we define interval within a local framework, temporal constraints are applied: intervals cannot exceed a certain temporal extension.

Pattern has been defined as a set of notes that is repeated (exactly or varied) in the score. All these repetitions, including the original first pattern, are considered as occurrences — or *actual patterns* — of a single *abstract pattern*.

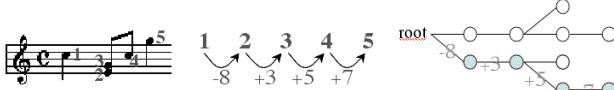
By existence of relation order in each dimension of the score space (namely pitch and time onset), notes inside a set of notes may be ordered through an induced relation order, that would consist of a main temporal relation order — which possesses

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actual cognitive significance —, composed with a secondary (arbitrary) pitch order. In this way, set of notes may be displayed as strings.

As pattern may be transposed, it is preferable to consider relative than absolute dispositions: notes should be consider not only along their absolute coordinates, but also along their reciprocal relations. As we showed that relations between notes could be decomposed into relations between couples, or intervals, then sets of notes (figure 1a) may be displayed as string of intervals between each successive note (figure 1b). This is called the *minimal interval representation*.

Collection of patterns may be represented as a trie (figure 1c), where each node is a note and where, for each branch, the ordered set of notes from the root to the leaf, is a pattern. Thanks to this kind of representation, two patterns that have a same prefix will share a same part of branch. This has cognitive ground since patterns cannot be discriminated when only their common prefix is heard. That is why the collection of abstract patterns — in *minimal interval representation* — related to a score will be represented inside such a trie called *abstract pattern trie* (APT).



**Figure 1(a-c).** Polyphonic pattern, its corresponding minimal interval representation, and its corresponding branch (with grey nodes) in an APT.

For each node of the APT is associated a value, which indicates the number of actual observed occurrences of the pattern represented by the branch from the root to this node. Each local viewpoint note, in the score, that terminates one or several actual patterns is linked to its corresponding abstract patterns in the APT. And reversely, to each node of APT is associated its corresponding actual patterns in the score.

### 2.3 Pattern discovery

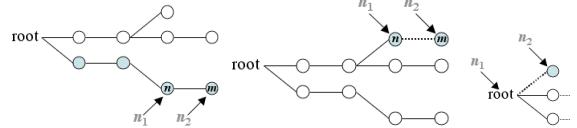
Each parameter of each element of local viewpoints — pitch, duration and onset of current notes and intervals — may be a characteristic property that, if retrieved later, will recall the considered element. Such a remembering mechanism will be possible only if there exist associative memory that links all elements sharing a same characteristic. In our framework, this may be formalized by considering parallel partitions of the set of notes of the score. Here memorizing a local viewpoint would simply mean adding current notes and interval in the equivalence class corresponding to each current value of pitch, duration, onset, etc.

We will now describe how similarity between current interval or note and memorized intervals and notes triggers analogy of motives. Let  $(n_1, n_2)$  be one of current intervals. Several cases are considered in this order of preference:

1. If the left element  $n_1$  of current interval is linked to an abstract pattern of the APT, and if its corresponding node  $n$  is not a leaf of the APT, current interval  $(n_1, n_2)$  is compared to all intervals between  $n$  and its children  $m$ . If one link is considered as similar to  $(n_1, n_2)$ , then the number of occurrences relative to the abstract motive from the root of the APT to  $m$  is incremented (see figure 2a).

2. In a second step,  $(n_1, n_2)$  is compared to all possible memorized intervals, from the last element of each associated actual patterns of current abstract pattern, that are stored in interval partitions. If similitude is found between one of these intervals and current interval  $(n_1, n_2)$ , a new child is added to  $n$ , its link featuring this new interval (see figure 2b).

3. In a last step, current interval is compared to every possible similar interval in the score, through a simple look at their equivalence classes in interval partitions, and also neighbor equivalence classes — that is, classes whose parameter value is similar to the value of current interval. If  $(n_1, n_2)$  is considered as similar to one or several previous intervals, a new node is added to the root of the APT (see figure 2c), initiating a new pattern.



**Figure 2(a-c).** The three main methods for growing the APT.

Pertinent candidates have to be selected with the help of some heuristics: similitude between current and abstract (or past) intervals; length of the pattern and number of occurrences (dissimilitude between intervals may be more easily tolerated if these intervals belong to bigger or recurrent structures), etc.

Now, patterns may be considered themselves as elementary objects, and patterns of patterns may be researched in a recursive way. General heuristics, analogous to those developed in the realm of semantic networks, are necessary for this recursive mechanism to offer pertinent results [2]. Contrary to notes, patterns cannot be directly compared one with each other, since the concept of interval of patterns is undefined. However, such a comparison may be envisaged by comparing all the information stemming from each pattern and selecting the relevant part.

Harmonic progression is implicitly taken into account in this framework, since chords may be considered as a degenerated case of pattern. Moreover, a transformed pattern may itself be considered as a new pattern if its new structure appears several times in the score. In this way, motivic transformation is made explicit.

### 3. *kanthume* APPLIED TO MIR

For each musical piece in the database, *kanthume* generates an APT following the *pattern discovery* framework showed in previous part. The MIR application will consist of a *pattern matching* between the query and all the APTs. The *pattern discovery* mechanism of *kanthume*, based itself on a *pattern matching* idea, will thus be directly applied to MIR.

The method that has been formalized in the last paragraph is now in process of implementation as a library of *Open Music* software. Such a project, still in a very embryonic aspect, suggests an ambitious utopia, where not only pattern but also any musical structure such as harmony or form, may be analyzed and taken into account for MIR.

### 4. ACKNOWLEDGMENTS

This project is carried out in the context of my PhD, directed by Emmanuel Saint-James (LIP6, Paris VI) and Gérard Assayag (Musical Representations, Ircam). Some ideas arise from discussions with Benoit Meudic and Carlos Agon.

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