Knowledge representation suitable for music analysis.

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1 Introduction

When trying to develop some work for the assignment of Cognitive Sciences in the Applied Artificial Intelligence MSc I started to survey work done in the music and AI field. Expecting that the subject was much more developed than what it is, I proposed some work which I later found very hard to accomplish. Those proposals appear now in the section 6 (future work) of this document

As I'm specially interested in music analysis from an historical point of view (actually I'm particularly interested in music history), I'd like to have support for the study of western tonal music which analysis theory is a very well developed (not formally) science.

I've found that no systematic studies have been done that address the problem of knowledge representation (KR) of music.

My approach will be to the area where we focused during the MSc course that is the employment of logic programming to reasoning.

Sections 2 and 3 are presented to get some insight to the subject. Section 4 is to discuss some traditional KR techniques as it's applicability. Section 5 is where the applications are presented and refined.

2 Musical cognition

Lots of work has been done in the music representation field. However it has been mostly concerned on the topics of reproduction (through hardware), transmission, accuracy, recording, printing. It's impossible to imagine a cognitive system in which a representation does not play a central role [Anderson 83; Fodor 83; Johnson-Laird 83]. In the psychology of music, alongside research in music production and comprehension, the majority of work has consisted of describing the nature of musical knowledge and its representation. Elaborate studies have been done in the domains of pitch (Krumhansl 79; Shepard 82), rhythm (Povel & Essens 81; Longuet-Higgins & Lee 84; Desain & Honing 89) and timbre (Grey 77; Wessel 79). There is, however, no general agreement on the assumption that mental activity is mediated by internal or mental representations, and when there is, there is still some discord on the precise nature of these representations. [Honing 93].

3 Musical analysis

Analysis - The resolution of a musical structure into relatively simpler constituent elements, and the investigation of the functions of those elements within that structure.

[Grove, 80]

The phrase 'musical analysis', taken in a general sense, embraces a large number of diverse activities. Some of these are mutually exclusive: they represent fundamentally different views of the nature of music, music's role in human life, and the role of the human intellect with regard to music. These differences of view render the field of analysis difficult to define within its own boundaries. More difficult still, in some ways, is to define where precisely analysis lies within the study of music. Underlying all aspects of analysis as an activity is the fundamental point of contact between mind and musical sound, namely musical perception.

3.1 How does a music analyst works ?

The analyst wants to reveal some salient feature from a given piece. The analyst is concerned with the nature, effects and it's relevance to the audition. The ultimate concern is the place of a musical structure within the totality of musical structures.

There is more in music then what is written in the score. Is a piece of music fully described in the notation ? It depends on a particular performance or interpreter ? It's on the audience mind's ?

The score "precedes" the realisation or interpretation [Nattiez 75]. Analytical procedures can be applied to styles of performance and interpretation as well as to those of composition

The analysis takes its starting point in the music itself, the score in Western analysis, but it has to be accompanied by a aesthetics and historical ground knowledge such as biographical facts, political events, social conditions, educational methods and all the other factors that make up the event of that phenomenon. No such knowledge can be easily formulated computationally and sure it's not the aim of this work. Instead it's concerned about what aid tools can be provided by the AI framework to the musical analysis job.

The music analysis starts by resolve the structures into simpler constituents and label those constituents and the relations in between. Then the central activity is comparison. Comparison of unit with unit within a single work, or between two works, or between the work and a model such as sonata form. The test for identity or degree of similarity is the base for the form building processes: recurrence, contrast and variation.

Some constituents have to be searched for a priori. One should look for the traditional basic units used in analysis. However these are not clearly defined, they heavily depend on which analysis theory we are dealing with. I considered several up-to-date theories (20th Century) both stylistic and formal ones such as the Fundamental structure [Schenker 32], Thematic Process [Réti 67], Functional Analysis [Keller 57], Formal Analysis, Phrase structure analysis [Riemman 895], Category and feature analysis [Larue 70], Distributional Analysis [Ruwet 66],Generative Theory [Lerdahl & Jackendoff's 83].

For this paper I will chose an abstract representation similar to Jackendoff's notion of "musical surface" [Jackendoff's 87] and originally proposed in [Wiggins et al. 89].

I will extend the proposed constituents to better address the music analysis tasks that I would like to see implemented, those of historical analysis.

To the historian, analysis may appear as a tool for historical inquiry. He uses it to detect relationships between 'styles', and thus to establish chains of causality which operate along the dimension of time and are anchored in time by verifiable factual information.[Grove 80].

4 Issues in music representation

Being the score the source tool for the music analyst what we have to define is an appropriate representation for it. There is an evidence that neutral file formats are most appropriate for information interchange and such a format should be standardised by an official standards body like ANSI, ISO or IEEE. However these organisations, namely ISO, has been concerned since 1989 in a format not suitable for knowledge [ISO 96] but mostly concerned with publishing or business purposes.. The next 4 sub-sections will describe the architecture of [Harris et al. 89] in a more understandable manner to initiated musicians and especially more treatable by prolog than the proposed one.

4.1 The basic entities

4.1.1 Events

The basic representation consists of a set of tuples, each of which we call an event that corresponds to a note of the music. Each tuple has five elements, a unique identifier, a pitch element (corresponding to the pitch of the note), a time element corresponding to the time of the start of the note, a duration element corresponding to the length of the note, and a timbre element that will describe timbre and intensity information. Such a description of musical notes is very natural;
we emphasise again that the pitch , time and duration elements are taken from the appropriate abstract data types.
So the general form of event statement will have the form:

event(id , Pitch , Time , Duration , Timbre, Intensity).

Now, for a given musical structure, by describing the structure as a set of events over which functions and relations may be applied we obtain a uniform way of making available most of the information needed to analyse, manipulate and create musical structures. To profit from this, we need some higher-level descriptions; this is the role of constituents.

I included an intensity argument to be used ahead. Two approaches a more exact numeric approach or a more traditional symbolic one ranging from *ppp* to *fff*.

4.1.2 Constituents

Music is best described at higher levels in terms of some sort of hierarchical structure. It's provided the framework in which such hierarchical structures can be specified, without committing the user to any particular hierarchy.

We call constituents the higher-level groupings of which a hierarchy may be composed.
For example, we might wish to represent rhythmic groupings, or a cadence, or both at the same time, or larger groups such as a recapitulation. These are all potential constituents.

There will thus be a hierarchy where an event may appear inside a constituent, which may appear inside another constituent, and so on. We will call the events and/or constituents from which a given constituent is directly formed the particles of that constituent. A constituent is described by its set of particles, together with a label of its type (in the above, this could be rhythmic unit or cadence), and a unique identifier.
It may be possible and useful to assign time information to a constituent directly, rather than have this information retrieved from the particles, and its allowed this possibility. The generic constituent type would then be:

constituent(id, musical_type, set_of_particles) [Wiggins et al. 89]

4.2 Time representation

Time is represented in terms of number of units of some underlying pulse, say quavers, and durations in numbers of quavers.

4.3 Structure representation

As it is intended to be implemented using a declarative language as prolog, the structure of the notated representation is then simply the constituents themselves associated with their respective label.

The structures represented so far are those presented in [Wiggins et al. 89] suited for simple cases as the one presented:

Figure 1: Mozart, Variations on "Unser dummer Pöbel meint" (bars 1-2)

with:

% event(id, pitch, start, duration, timbre).

% pitch = [note,accidental,octave], start = # quavers from start

```
% duration = length in quavers, timbre as yet undefined
event( ev00,[g,natural,4], 0, 2, [ ] ). event( ev01, [g,natural,3], 0, 2, [ ] ).
event( ev02,[g,natural,2], 0, 2, [ ] ). event( ev03, [g,natural,4], 2, 2, [ ] ).
event( ev04,[g,natural,3], 2, 2, [ ] ). event( ev05, [g,natural,2], 2, 2, [ ] ).
event( ev06,[f,sharp,4], 4, 2, [ ] ).   event( ev07, [f,sharp,3], 4, 2, [ ] ).
                                        ... event( ev26, [d,natural,2], 12, 4, [ ] ).
```

As seen my event is richer in that it incorporates the intensity information that is essential for the rest and dynamic structures. Also note that timbre is always an empty set for it is yet undefined. Structures used are:

% constituent(id, musical type, set of particles)

% time-labelling of stream (stream(t,d)) omitted for readability

```
constituent( st15, melody, [ev00,ev03,ev06,ev09,ev12,ev15,ev18,ev21,ev24] ).
% rhythmic units
constituent( st00, dactyl, [ev06,ev09,ev12] ).
constituent( st01, dactyl, [ev15,ev18,ev21] ).
constituent( st02, dactyl, [ev39,ev43,ev46] ).
constituent( st03, single, [ev00] ). constituent( st04, single, [ev03] ).
constituent( st05, single, [ev24] ). constituent( st06, single, [ev27] ).
constituent( st07, single, [ev30] ). constituent( st08, single, [ev33] ).
constituent( st09, single, [ev36] ). constituent( st10, single, [ev37] ).
constituent( st11, single, [ev38] ). constituent( st12, single, [ev47] ).
constituent( st13, single, [ev51] ).
% metric chunks
constituent( st50, metric chunk, [st03,st04] ).
constituent( st51, metric chunk, [st00] ).
constituent( st52, metric chunk, [st01] ).
constituent( st53, metric chunk, [st05] ).
constituent( st54, metric order, [st50,st51,st52,st53] ).
```

4.4 The relations

Relations operate over the defined sets (events and constituents) and produce interesting, for the purpose of analysis, ordering or classification on the members of these sets.

4.4.1 Temporal

The objects of interest are points in time, and durations. we expect to be able to describe a duration as the time interval between two points in time and to compare the durations of notes (hence we need an order ≤), and indeed to be able to add two durations together to get a third (hence an addition operation).

One concrete example would measure time in terms of number of units of some underlying pulse, say quavers, and durations in numbers of quavers.

So for example the duration from beat t1 to beat t2 is

dur(t1; t2) = t2.

More formally, this consists of a set of times *time* and a set of durations *duration*, together with a mapping dur that measures the duration dur(a; b) between two times a and b. To compare the durations of notes we need an order ≤, and to be able to add two durations together to get a third an addition operation written + (not necessarily the usual addition). We take the convention that if time b precedes time a then the duration dur(a; b) is negative.

dur is compatible with the duration structure, in that
dur(x; y) = 0 ⇔ x = y, that
dur(x; y)+dur(y; z) = dur(x; z), and that
dur(x; y) = -dur(y; x)

4.4.2 Melodic (Horizontal)

Here the interesting sets are the corresponding pitch (⇔time) and intervals (⇔duration) there is a similar order relation ≤ and the same overloading of operators applies.

4.4.3 Harmonic (Vertical)

These relations would operate over the sub-class of vertical constituents that are not yet defined but will be suggested in the next section. I will then suggest the appropriate similar relations.

As stated before, the events and constituents presented so far, which are at the core of [Harris et al. 89], lack some essential features for completeness to represent the subjects of this work and are thus appropriate to do only some very simple analytical procedures as suggested in [Wiggins et al. 89] (similarity analysis). Some more elaborated structures that could be suggested are the following:

4.5 Extensions

The use of a single constituent term does not appear to aid the usability and performance of pieces of a considerable size as real subjects of analysis are. I propose new terms that set apart from the generic type and labelling proposed. These will provide a much better framework for logic programming.

4.5.1 Vertical constituents

4.5.1.1 Triads/Chords

These are the main structures from which an harmonic structure is built since the French composer and theorist Jean Philippe Rameau stated that it should be considered the fundamental musical element in his famous Traité de l'harmonie. [Grout,D.J. 88]. Being absolutely fundamental for several tasks of analysis like the key determination, some additional information is fundamental for the representation of triads. Two structures are proposed to be used the more appropriate:

a) Chord(id, chord_type, position, set_of_particles)

Where chord_type should describe the number of sounds in the chord 3, 4 (seventh chord), 5 (ninth) , position one of fundamental F, inversion I, sixth II, fourth and sixth III [Candé 89]. Care should be given in that the fundamental of the chord should be the first event in the set of particles to automatically define the nature of the chord.

b) Chord(id, chord_type, position, nature, set_of_particles)

Here nature must be explicit because in the set of particles the first event is to be the lowest note. This variant is presented because of its usefulness when dealing with continuo.

4.5.2 Expression constituents

4.5.2.1 Dynamics

A kind of structure that relates two events within the same melodic line. It must have a type of modulation (crescendo, deminuendo). Different sorts of progression[1] can be stated although it is generally assumed to be the interpreters musical choice how to perform so it doesn't lie in the scope of this work. Such structure is

dynamic(id, type, initial, final)

4.5.2.2 Rests

A rest could be nothing but a particular event that is a note with null intensity. However there can be special needs when rests are very important for the piece studied. For instance in XXth century classical music, Jazz or XIVth century **Hoquetus**.

4.5.2.3 Expression Ligatures

To represent tied events in prolongation ligatures nothing further is needed for it simply suffices to add the duration of the notes. but for expression ligatures a new constituent of type ligature is used:
The information needed is so:

ligature(id, set_of_particles)

In regular pieces of Western Music the particles of the set must be adjacent in time.

4.5.2.4 Articulation

Articulation is fundamental to achieve stylistic analysis very used in historical reasoning. Until the very beginning of the XXth articulation was very discrete (no strange mingles) and thus must be considered in this framework. I propose then a constituent that addresses the several traditional articulations.

Articulation(id, type, set_of_particles)

In type one can have the usual symbols . ∧ ∨ < > ‾

4.5.2.5 Motif

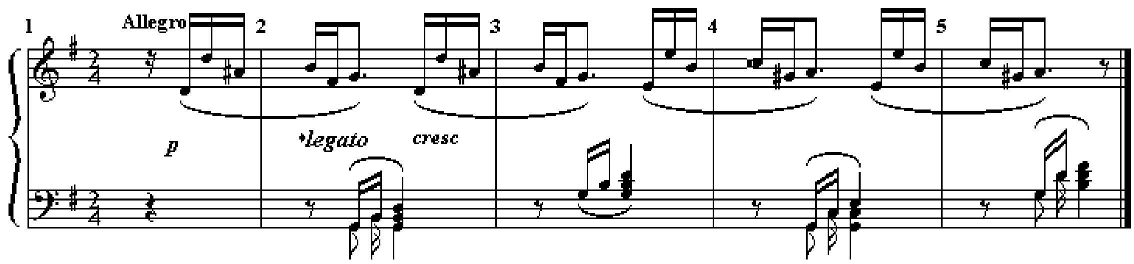
Motivic construction of phrases is a very current methodology. For many pieces in tonal music are built in such way, it is convenient to use a particular constituent for motif where its basic constitution is represented. The motif is usually recognised by due to it's characteristic rhythm. So a motif can be

Motif(id, set_of_durations).

4.6 Illustration

[1] Linear, quadratic, ...

A more elaborated short part of a classical piece is used to illustrate the power of the proposed framework:



Enhancing the work presented in section 4.3 we have now the following example:

% event(id , Pitch , Time , Duration , Timbre, Intensity).
% Pitch [note, accidental] with the usual notation.
% length in demiquavers is the underlying pulse.
%Intensity from 0 to 127 corresponding to MIDI

event(ev00,_,4,1,[],0).
event(ev01,_,4,4,[],0).
event(ev02,[re,natural],6,1,[],10).
event(ev03,[re',natural],7,1,[],10).
event(ev04,[la,sharp],8,1,[],10).
event(ev05,[si,natural],9,1,[],10).

event(ev06,_,9,2,[],0). % rest

event(ev07,[fa,sharp],10,1,[],10).
event(ev08,[sol,natural],11,3,[],11). % linear progression with crescendo
event (ev09,[_Sol,natural] 11,1,[],20).

...

ligature(l01,[ev02, ev03, ev04, ev05, ev07, ev08]).

...

chord(c01, 3, F, [ev13, ev14, ev15]).

...

dynamic(d1, crescendo, ev16, ev52)

5 Reasoning techniques

Music analysis, as previously told, is reasoning about it's representation. Logic Programming (LP) brought to computer science the important notion of declarative programming [Alferes,J.J. 97] and it rapidly became a tool for KR. The definition of a semantic meaning for a program as been one of the most important problems in LP. A nonmonotonic reasoning method goes beyond classical logic by supporting more conclusions , so it is necessary to start with the basic knowledge. In Logic Programming nonmonotonic reasoning has been developing making use of several techniques like Completion [Clark 78], Circumscription [McCarthy 80], Default Reasoning [Reiter 80], Situation Calculus [McCarthy 69] or Event Calculus [Kowalski 86]. The framework proposed constitutes a Knowledge Base (KB) that any of these techniques can explore. The point in this work is to show how some techniques are suitable for reasoning within musical analysis.

The work of analysis as seen is a conjecture based one. After a conjecture is proposed by the analyst he is to proceed by one of the methods introduced in section 3.1 and so the representation of the piece in study with the conjecture added to the KB should be consistent to prove the point. Inconsistency may arise and then a contradiction removal semantics has to be chosen.

The forms of commonsense reasoning forms proposed could be ordered on how sceptical or "brave" they can be considered. For this is to work upon artistic works a brave reasoning formality ought to be considered first, although the formalities presented namely Defeasible Reasoning, Hierarchical taxonomies, Hypothetical reasoning and Reasoning about actions with situation calculus are all possibilities, the "braver" is picked: Hypothetical reasoning.

I followed the application of logic programming extended with the concept of undefinedness and a suitable form of explicit negation proposed in [Alferes,J.J. 96] to some forms of classical common sense reasoning to illustrate the suitability to this work purpose.

Throughout the example presented the same representation is used and I shall give here a brief summary although for a deeper overview the reader should consult [Alferes,J.J. 96].

Definite rules

if A then B.	**B ← A.**

Definite facts

A is true	**A.**
A is false	**¬A.**

Defeasible rules

Normally if A then B	**B ← A, not ab(A).**

Exceptions to defeasible rules

Under certain conditions COND there are exceptions to the defeasible rule H ← B, not ab	**ab ← COND.**

Preference rules

Under conditions COND prefer to apply the defeasible rule $H_1 \leftarrow B_1$, not ab_1 instead of rule $H_2 \leftarrow B_2$, not ab_2	**$ab_1 \leftarrow$ COND, not ab_2.**

Unknown possible fact

F might be true or not	**F ← not ¬ F.** **¬F ← not F.**

Hypothetical rules (possibly applicable)

If A then B may or may not apply	**B ← A , hyp.** **hyp ← not ¬ hyp.** **¬ hyp ← not hyp.**

5.1 Hypothetical reasoning

In defeasible reasoning we want to express what could normally hold and the contradiction removal suggestion is a sceptical one by expressing exceptions and preferences. This is not our interest since no such rules are in the basic KB. Note that for some analysis it could easily be included but that is a further matter (perhaps in the proposals in the next section).

Hierarchical taxonomies also introduces preferences among defeasible rules using the notion of more specific information [Nute 86]. No choice is possible between because everything is defined as seen in the hierarchy.

Hypothetical reasoning considers the alternative hypothetical possibilities with no preference rule present. Several models correspond to the alternatives. The analysts conjecture is a rule hypothetically applicable or a hypothetical fact. An example could be searching if the excerpt in our example is motif oriented being the constituent

constituent(st1, melody, [ev02, ev03, ev05, ev07, ev08]).

Its hypothetical motif. Then the hypothetical rule in the form depicted above should be automatically inserted into the KB.

motif(m1, duration(st1))← constituent(st1, melody, [ev02, ev03, ev05, ev07, ev08]), motif(m1, duration(X)).
motif(m1, duration(X)) ← not ¬ motif(m1, duration(X)).
¬ motif(m1, duration(X))← not motif(m1, duration(X)).

Being duration a predicate that collects the duration of the events in the parameter melodic structure.

X can traverse all melodic constituents and care must be taken not to use the constituent used to build the hypothesis. In our example it should traverse all the constituents in the same melodic line initiated by each event different from ev02.

6 Future work to be developed

6.1 Component parser

6.1.1 knowledge extraction from unstructured representation (MIDI, SMDL)

The key here is the appropriate translation from the unstructured representations to ours. Then our reasoning machines could be applied. This work is perhaps the most important because it will provide automatically basis material to manipulate. Standard Music Description Language (SMDL) ISO/IEC DIS 10743 is currently only a draft standard. The aim of SMDL is primarily to permit the application neutral interchange of all such music as can reasonably be expressed in common practice music notation, i.e. the written notation commonly used for Western-style art music, dance music, and commercial music. It's designed for the transmission and storage of music and hypermedia information. However, music represented in SMDL need not actually have ever been expressed in common Western music notation, or in any other particular notation. The use of SMDL as an abstract music representation does not preclude the rendition of special symbols or other particular notational or performance practices, in either visually or aurally perceivable source or formatted output materials. One of the domains in which the draft proposal is divided into, the analytical domain is completely in the province of the music theorist(s), musicologist, or music critic who create(s) it. Such an author can use the full power of the HyTime addressing and linking facilities to make extremely precise observations and comparisons regarding all of the information in cantuses, performances, and scores (the other 3 domains). The analysis architectural form itself is derived from the HyTime [ISO 95] ilink architectural form, and it specifies in its *linkends* attribute the cantus element(s) to which the analysis as a whole corresponds.

The need is then for an abstract representation to be worked for the analytical domain and the proposed structure with the appropriate extensions will do.

6.1.2 Cadence

Perhaps the easiest structural unit that can be extracted from a piece represented is a system like the proposed. The identification is fairly straightforward using the chord constituent. e. g. the perfect cadence identified by the tonic chord normally related to the conclusion. Similar constraints can be applied to the different cadences (and cadence strength) whose analysis are peaceful in western tonal music namely authentic , plagal, full, half or even elided [Green 81, pp 9-17].

6.1.3 Phrase

The only thing that writers on music seem to agree about phrases is that the phrase (1) exhibits some degree of completeness and (2) comes to a point of a relative repose [Green 81]. The keywords here are 'some degree' and 'relative repose'. There is not a absolute referential but only measured contextually are phrases defined (and it depends of style). Only those points of repose that reach the completion of a musical thought should be considered so a definition would be:

A phrase is the shortest passage of music which, having reached a point of relative repose, has expressed a more or less complete musical thought.

Phrase recognition is then dependable of harmonic action that is responsible for the impression that a musical event as taken place and the relationship between dissonance and consonance. Some of the vertical constituents presented above play a central role in recognising phrase structures by their harmonic structure namely the chords that identify the cadence that brings a phrase to its close.

6.1.4 Motif

Several motivic variation can be searched: repetition, sequence comprise, transposing, addition of apogiatura, interval reversion, ornamentation, inversion, retrogression. From a motif representation that can be explicitly stated the machinery to recognise such variations can be easily included in.

6.2 Key and modulation analyser

An extensive analysis can be now formulated for a non-naive key analysis. The chord as told in section 4.5.1.1 is the fundamental structure for the definition of the key of some excerpt. However several disguisable features have been developed over the time. Mainly it's the tonic cord usually in the end that determines the key but it can be the first, melodic chords, and/or modulation chords that are those that regulate tonalities to modulate [Zamacois 92]. In the extreme case only the complete harmonisation of the piece can determine the key and such harmonisation is now representable.

6.3 Figured bass realisation generator

The baroque technique of realisation of the "basso continuo" is nowadays a task only for the well formed interpreter. Only highly trained musicians are able to realise at sight. However there are established common principles that can be incorporated [Candé 88] to automatically generate a appropriate figured bass score. I don't intend that it could be artistically viable or accurate results but with the structure proposed in 4.5.1.1 b) is fairly straightforward to implement.

7 Conclusion

Theoretical proposals using declarative language constructs are easy to accomplish. Sound theoretical approaches which span over a multidisciplinary field are somewhat more difficult. My work is a tiny humble contribution to show the applicability of a very recent interesting development in LP, nonmonotonic reasoning, to a traditional work from the real world where a large amount of in-depth knowledge is necessary and a huge amount of labour is customarily needed to accomplish simple demonstrable work as the Music Analysis is.

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