MvS|C - A Constraint-Based Approach to Musical Knowledge Representation

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1. Abstract

Considering applications of constraint-based techniques to musical problems, it seems that additional research-work is required to evaluate the special advantages and disadvantages of the constraint-oriented approach within the context of musical knowledge representation.

M v S|C* is a study on these problems that arise when trying to model 4-part-harmonization in a specific style: the problem is how to reach a 4-part-version which meets certain stylistic criteria.

2. Introduction

The following paper aims at an investigation on the applicability of advanced knowledge representation formalisms within *computational musicology*. There is a twofold interest. First, theoretical AI research needs critical feedback from elaborated applications to check and improve its general tools. Secondly, computational musicology is mostly interested in powerful representation schemes to solve various modeling tasks in musical cognition. In particular, this paper reports current research on the application of a constraint satisfaction system to a specific problem within *musical thinking*, namely the harmonic interpretation of a choral melody. The central question is: where do constraint satisfaction systems match musical problem solving strategies (or processes of musical thinking) as close as possible?

The research described in this paper is in progress. Implementation of the whole system (which synthesizes Bach Chorals) will be done in BABYLON, a hybrid knowledge representation formalism and programming environment [Forschungsgruppe Expertensysteme 1985] and will run on Symbolics 36xx.

* *If* there is a System with Constraints *then* there is a Musical application

3. Background

The main objectives of *computational musicology* are the computational modeling of both *musical thinking* and the *interaction between musical thinking and other cognitive processes* (such as language, vision etc.). By musical thinking we understand the processes of recognizing, storing, remembering and manipulating *internal auditive representations* of audio patterns [LISCHKA 1986]. That means that we distinguish *auditive* representations (which are in a sense analog representations) from conceptual encodings and the like. The intuition behind this is the metaphor of *internal listening* as it is reported by professional musicians; Hugo Riemann made this to the core of his music theory [RIEMANN 1916].

According to the underlying methodological paradigm the basic strategy of computational musicology is to build working models of certain processes of musical thinking in order to get more detailed insight into these complex cognitive areas. Now, it seems a proper strategy to start modeling with some auditive *toy world* instead of simulating advanced and complex musical competence. So, for the present, we concentrate on a restricted version of the world of Bach Chorals.

4. A Case Study: Harmonization of Bach Chorals

When we explicate the basic problem solving strategies of professionals in the field of choral harmonization the following steps can be abstracted:

(1) The melody is separated into melodic "phrases"

(2) For each phrase, preliminary high level constraints are posted with respect to formal and thematic structures; in particular, a decision is made on the structure of the "cadences".

(3) Each phrase is "played" internally ("imagined")

(4) It is analyzed in terms of melodic "figures"

(5) From a dictionary, harmonic hypotheses are formed until a "stable" and consistent configuration is reached

(6) This "rough" design is now more detailed and finally we get a 4-part harmonization

Clearly, the flow of control is not as linear as in this idealization; there is much communication between the different levels. But it seems possible to make some "snapshots" of the whole design process where we can suppose a quasi-linear flow of control. One of the most interesting steps is the internal "playing" and "listening" and the auditory interpretation of the choral phrases in harmonic terms; according to *Riemann*, the latter essentially means interpreting tones as *representing harmonic functions*. The reason is that there are different levels of detail with respect to the representation of such functions; the most detailed interpretation is given in the case of a 4-part harmonization, but 3-, 2- and 1-part representations are possible as well. So harmonizing a melody can be grasped as making explicit the harmonic structure of this melody within a 4-part harmonization. (Obviously, there is more than one solution, in general.) Or, to put it another way, harmonizing can be seen as first labeling a melody with harmonic functions and then realizing a 4-part representation. The former is very similiar to the 3D-interpretations of the visual system [WALTZ 1972].

5. Some Details

Now, in order to formulate our analysis on a more implementational level we use BABYLON, a hybrid knowledge representation environment developed at our site. BABYLON is an *integrated* set of software tools for developing, implementing and supporting expert systems. It provides different knowledge representation formalisms: objects, rules, logic and constraints.

The object-oriented formalism is an extension of the Zeta-Lisp Flavor System and combines frame-like data-structuring with message-passing control structures.

The constraint formalism is realized by CONSAT, a processor for constraint-satisfaction [GÜSGEN 1986]; activating constraints produces filtered sets of variable-values. In particular, there is an abstraction mechanism which allows the definition of higher order constraints, i.e., we can handle constraint-*nets*. Local propagation is the standard control strategy; maximal, local consistency can be reached by passing value sets from one constraint to its neighbors.

In the following, we will sketch a constraint-oriented model of the harmonic labeling process. According to our informal intuitions we have at least two stages of the problem solving process:

(1) *Constraint Posting*. Given a choral phrase and a dictionary of melodic figures which associate note patterns with harmonic constraints, the first stage yields a mapping of matching figures into the choral melody. This mapping constitutes a constraint *net*.

(2) *Constraint Satisfaction*. Given this net, the constraint processor filters out the maximal local consistent labelings.

5.1. Constraint Posting

On the lowest level we represent Chorals as objects combining a note-structure and an analysis; note-structures are instances of a generic object:

```
(Defframe note-structure
    (slots (list-of-notes nil
          :doc "notes of the melody")
        (reference-note nil)
        (melodic-structure nil
          :doc "intervals relative to
                reference-note")
        (reference-duration nil)
        (rhythmic-structure nil
          :doc "proportions relative to
                reference-duration")
        (metric-structure nil
          :doc "metric weights")))
```

So a choral phrase is given by

```
(Defframe choral-phrase
    (supers note-structure)
    (slots (structural-analysis nil
            :doc "correspondences between figures
                  and notes of the phrase")))
```

The harmonic knowledge is given by the above mentioned melodic figures. Therefore, we first have a knowledge-base of primitive constraints analoguos to the following one:

```
(Defconstraint
    (:type primitive)
    (:name constraint-1)
    (:variables note-1 note-2 note-3)
    (:relation
      (:tupel (D S D3) )
      (:tupel (D S3 D) )
      (:tupel (T S3 D))))
```

These constraints are then used in a dictionary which associates them with note-patterns:

```
(make-figure figure-3
        3
        '(Prim SecondMajDown Prim)
        '(4 2 4)
        '(0 1 0.5)
        'constraint-1)
```

Now the constraint posting process runs as follows. Each figure is matched against the choral phrase. If the match is successful it yields a mapping of the variables of the associated constraint on the choral notes, e.g.,

'(constraint-1 second third fourth).

Because each choral note may correspond to more than one figure the set of these posted constraints defines a constraint net.

5.2. Constraint satisfaction

This net is now interpreted by the constraint processor. The CONSAT control strategy, which is based on a local propagation technique, filters the harmonic functions used in the constraints. The result of the propagation process are sets of harmonic functions corresponding to the notes. In general, the sets contain more than one function, what is to say, that the constraints don't specify an unambiguous choice of harmonic functions for the notes. So the system must refine the solution. This can either be done by posting new constraints and starting the filtering process again, or by applying heuristic search algorithms to the result of the propagation process.

6. Results and Further Considerations

In essence, there are two points which should be emphasized.

(1) Constraint formalisms are well suited to reduce the problem complexity by pruning the problem space, thus, bringing many problems into an addressable form at all.

(2) Beyond this, there is suggestive evidence that this pruning effect is modeled by the constraint formalism in a cognitive adequate manner. Indicative for this is, that the described strategy matches the problem solving behavior surprisingly well.

But in order to make the whole system more natural and complete the strict linear control flow should be replaced by a more flexible design strategy; for this reason the constraint posting and refining process will be embedded into a general top-down-refine strategy being best illustrated by the metaphor of a society of communicating experts/specialists.

7. Acknowledgements

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