COMPOzE — Intention-based Music Composition through Constraint Programming

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Abstract

The goal of this work is to derive four-voice music pieces from given musical plans, which describe the harmonic flow and the intentions of a desired composition. We developed the experimentation platform COMPOzE for intention-based composition. COMPOzE is based on constraint programming over finite domains of integers. We argue that constraint programming provides a suitable technology for this task and that the libraries and tools available for the constraint programming system Oz effectively support the implementation of COMPOzE.

This work links the research areas of automatic music composition on one hand and finite domain constraint programming on the other, and contributes the tool COMPOzE, which practically demonstrates the potential of constraint programming to open up new areas of application for automatic music composition.

1 Introduction

The aim of this project is to build a system for the automatic composition of music. Music experts are often skeptical about music which is autonomously composed by computers. We share this skepticism and therefore chose—instead of completely autonomous composition—the task of composition to accompany multimedia presentations as our application domain. In this context, music serves as acoustic background, and supports the intentions of the presentation using the appropriate musical effects.

The system developed in the project consists of two main modules: the arrangement system AARON [12] and the composition system COMPOzE. AARON derives a musical plan from the intentional and metric structure of a given presentation by proceeding in two steps. In the first step, it generates a vector of musical parameters describing in musical terms how the given intentions ought to be realized. In the second step, it generates from these musical parameters an harmonic progression. The harmonic progression fixes the metric, rhythmic and harmonic structure, but leaves open the harmonic elaboration and the melody.

COMPOzE derives concrete audible music (i.e. MIDI data) from a musical plan and an harmonic progression. In this presentation, we focus on the COMPOzE subsystem. COMPOzE produces a progression of four voice chords (soprano, alto, tenor, bass), which implements the musical plan generated by AARON and is in accordance with standard musical laws. To accommodate different musical tastes and to allow for easy tuning of the system, we want to open up the composition process to the user by giving her maximal flexibility in the choice of the musical laws. COMPOzE’s graphical user interface allows the user to choose musical laws by direct manipulation. The composition process is visualized including its solutions. The user can listen to and compare the solutions by mouse click.

It turns out that this task of open intention-based composition can be elegantly described as a constraint satisfaction problem and efficiently implemented using the constraint programming (CP) system Oz. The main contribution of COMPOzE is to demonstrate that CP in general and Oz in particular provide an adequate computational framework for open intention-based music composition.

2 Musical Plan

The given musical plan consists on the one hand of an harmonic progression. An harmonic progression is a sequence of harmonic functions. As an example, consider:
An interesting approach to the simulation of Jazz improvisations is described in [5]. The system takes as input a chord progression to which a melody is automatically improvised. Besides aesthetic criteria, there are no restrictions such as intentions given. The algorithm generates in the first step a certain contour. This contour represents the main shape of the melody and is derived by a regular grammar. In the second step the concrete pitches are chosen using constraints.

The expert system CHORAL [2] is a system for harmonizing chorals in the style of J.S. Bach. The input is a fixed soprano (melody) voice of a certain choral. The system’s task is to generate a four voice score according to the harmonic rules of Bach’s epoch (17th and 18th century) in traditional musical notation. The system uses a rule-based heuristic search with backtracking. The knowledge base contains 350 rules, which may be absolute or heuristic. The absolute rules represent conditions which must be strictly obeyed. The heuristic rules do not have to be strictly satisfied, but they are necessary to support composition decisions based on knowledge about the aesthetic appearance of chorals.

In [7], a system is described that automatically derives a four voice score from a given melody, i.e. it composes the missing bass and middle voices. The basic musical knowledge needed for realizing the scores is represented in an object-oriented framework. The composition task is represented as a constraint system. The algorithm has two main steps. In the first step, constraints are applied which represent relations of intervals between notes of a single voice in neighboring chords. The second step concerns constraints which represent relations between notes of the four voices in each single chord. The search algorithm is based on backtracking.

5 The Composition Task as a Constraint Satisfaction Problem

The most suitable framework in which to formalize the composition task is provided by the theory of constraint satisfaction [11]. Cast into a constraint satisfaction problem (CSP), the problem looks as follows:

- In general, there are $n \times v$ variables where $n$ is the number of chords in the sequence and $v$ the number of tones in each chord. In our case, we have 4 voices in each chord, namely bass, tenor, alto and soprano. We name the variables as follows: $B_i$, $T_i$, $A_i$, $S_i$, where $i \in \{1 \ldots n\}$.
- The domain for these variables is given by a range of playable pitches.
• The harmonic functions and the composition rules can be formulated as constraints ruling between one or several variables. For example, the crossing prohibition in Section 3 can be expressed by the following constraint:

\[ \forall i \in \{1, \ldots, n\} (B_i \leq T_i \leq A_i \leq S_i) \]

To solve this CSP it turned out that approaches from Operations Research are not able to account for the variety of present constraints. Thus, we used the framework of CP [3]. Recent developments in CP culminated, among others, in the system Oz [10] that we use as implementation platform.

6 Constraint Programming

The goal of CP is to progressively restrict the set of possible values for variables using the given constraints, until finally, a unique value has been found for each variable.

The set of possible values is kept in the constraint store. For example, the fact that the base pitch of the first chord must be taken from the first 25 pitches of the scale is expressed by the constraint \( B_1 \in \{0 \ldots 24\} \) in the constraint store. More complex constraints are expressed by propagators that observe the constraint store and amplify it if possible as depicted below.

![constraint store propagator](image)

7 Composition Rules as Propagators

A propagator inspects the store with respect to a fixed set of variables. When values are ruled out from the domain of one of these variables, it may add more information on others to the store, i.e., it may amplify the store by adding constraints to it. As an example consider the crossing prohibition in Section 3. It can be expressed for the first chord by installing the following three propagators:

\( B_1 =<: T_1 T_1 =<: A_1 A_1 =<: S_1 \)

To explain how they can amplify the constraint store, let us assume that \( A_1 \) is constrained to \( \{30 \ldots 45\} \), and \( S_1 \) to \( \{25 \ldots 60\} \). Then the third propagator will exclude the values 25, \ldots, 29 from the domain of \( S_1 \), reducing its domain to \( \{30 \ldots 60\} \). Vice versa, if later on it becomes known that \( S_1 \in \{30 \ldots 40\} \), then \( A_1 \) will also be constrained by \( \{30 \ldots 40\} \). Note that this propagator remains active, waiting for more information on either \( A_1 \) or \( S_1 \) to arrive. It only ceases to exist, when it becomes clear that it will never amplify the store again. Since it is not known in advance when the propagators will be able to perform their computation, they should be viewed as concurrent entities that observe the constraint store and amplify it whenever possible.

Similarly, we implement the Jump Law in Section 3 by a propagator that observes the distance between two neighboring tones of a voice. For example, the Jump Law is enforced on the bass voices of the first three chords by the following Oz program:

```oz
thread
  if (FD.distance B1 B2 '>: JumpDistance)
    then (FD.distance B2 B3 '=<' 2)
      if B1 >: B2
        then B2 <: B3
          else B2 >: B3 end
      else true end end
```

The conditional is moved to a concurrent thread of computation. As soon as the condition between \( \text{if} \) and \( \text{then} \) becomes logically implied by the constraint store, the conditional will reduce to the \( \text{then} \) part, which will emit a propagator for \( \text{FD.distance} \) and another conditional. If the negation of the condition becomes logically implied, the conditional just disappears, as indicated by \( \text{true} \) in the \( \text{else} \) part.

8 Search

Constraint propagation typically does not suffice to determine the values for all variables of the CSP. Thus, after exhaustive propagation, a non-determined variable is speculatively constrained to one of its remaining values. This decision typically enables some propagators to exclude values for other variables. Thus the search space is continuously pruned while it is being explored. For a more detailed treatment of search and finite domain programming in Oz consider [9].

9 The Experimentation Platform COMPOZoE

COMPOZoE takes as input a musical plan, as given by the user or generated by AARON. The output of COMPOZoE is one or several compositions that implement the given musical plan and fulfill user defined criteria. Figure 1 shows a snapshot of the current COMPOZoE interface after configuration by a user. COMPOZoE allows a user to decide for each musical law, if it should be be ignored (\textit{off}), strictly obeyed (\textit{hard}), or preferably obeyed (\textit{soft}) with a user given weight from 0 through 100. The implementation uses a branch-and-bound technique to minimize the violation of the soft laws. If there is more than one soft law, their weight is used to determine their relative importance. The Oz Explorer [8] is used to visualize the search tree as shown in Figure 2. The user can interactively listen to a solution (realized by generating MIDI output) by clicking on the so-
The current performance results are encouraging; with most user parameters and harmonic progressions of length 20 to 30, the system either shows that there is no solution or finds a first solution within one second of computation using a PC (Pentium 133Mhz). If there are soft constraints and the first solution was not optimal, the system usually finds several better solutions within another second. The resulting compositions are simplistic in style due to the rigid dynamic structure, but very pleasing from an harmonic and melodic point of view. Dynamics, instrumentation and percussion are subjects for further research.

References