

# GELISP: A LIBRARY TO REPRESENT MUSICAL CSPS AND SEARCH STRATEGIES

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## ABSTRACT

In this paper we present *Gelisp*, a new library to represent musical Constraint Satisfaction Problems and search strategies intuitively. *Gelisp* has two interfaces, a command-line one for Common Lisp and a graphical one for *OpenMusic*. Using *Gelisp*, we solved a problem of automatic music generation proposed by composer Michael Jarrell and we found solutions for the *All-interval series*.

## 1 INTRODUCTION

A *Constraint Satisfaction Problem* (CSP) is a formalism to represent combinatorial problems. To solve a CSP we need to find objects that satisfy a number of constraints (i.e., criteria over those variables). CSPs provide a declarative way to represent combinatorial problems, specifying constraints instead of a sequence of steps to find the solution (as used in imperative programming). Additionally, it is possible to specify strategies to choose between branches during search.

CSPs in computer music can be used to solve harmonic, rhythmic or melodic problems. In addition, they can be used for automatic generation of musical structures satisfying a set of rules. For instance, we can find solutions for the *All-interval series* [4], where we need to find a sequence of 12 different pitches with 12 different intervals.

In order to solve a CSP, we can use constraint programming languages such as Prolog or Mozart-Oz [10]. In order to solve a CSP, those languages use a *Constraint Solving Library (CSL)* such as Gecode [7]. CSLs are usually written in C++.

### 1.1 The problem

Using traditional CSL's or programming languages to solve CSPs is time-demanding and it is intended for specialized users because they usually require

deep knowledge on C++ or logic programming. This makes these tools often unpractical to specify musical CSPs. Furthermore, these tools do not provide a representation for musical data structures.

### 1.2 Our solution

*Gelisp*<sup>1</sup> is a wrapper for Gecode to Common Lisp. *Gelisp* was originally developed by Rueda in 2006 and we modified it to work with current version of Gecode. Furthermore, we added support to model CSPs and search strategies graphically on *OpenMusic (OM)* [1]. In addition, *Gelisp* can take advantage of the musical data structures and functions defined for OM.

The novelty of *Gelisp* is to provide a graphical representation for search strategies (e.g., Depth First Search) and global constraints (e.g., "all the intervals of a sequence must be different"), based on an efficient CSL.

### 1.3 Related Work

Several graphical CSLs for OM have been developed in the last decade. *Situation* [5] generates music based on constraints, *OmRc* [6] finds structures corresponding to rhythmical constraints, *OmClouds* [9] finds approximated solutions to a CSP, and *OMBacktrack* (<http://www.ircam.fr/equipes/repmus/>) is a wrapper for the CSL *Screamer* [8] (a CSL written on Lisp).

A graphical CSL to solve musical CSPs should be able to setup search strategies in a graphical way, post multiple kinds of constraints graphically without declaring explicitly loops and recursion, and solve the problem using state-of-art algorithms.

Unfortunately, *OmRC* and *OmSituation* are designed to solve specific problems. *OmBacktrack* is no longer available for current versions of OM. Finally, *OmClouds* does not guarantee a solution satisfying all the constraints (i.e., a complete solution).

<sup>1</sup> <http://gelisp.sourceforge.net/>

## 2 GECODE

Gecode is a Constraint Solving Library (CSL) written in C++. Gecode provides a *propagator* for each type of constraint. Propagators translate a constraint into basic constraints supplying the same information. Basic (finite domain) constraints have the form  $x \in [a..b]$ . For instance, in a store (i.e., a set with all the constraints asserted) containing  $pitch_1 \in [36..72]$  and  $pitch_2 \in [60..80]$ , a propagator for the constraint  $pitch_1 > pitch_2 + 2$  would add constraints  $pitch_1 \in [63..72]$  and  $pitch_2 \in [60..69]$ .

As described in the above example, the action of propagators ends up narrowing down the set of possible values for each variable. This, however, does not guarantee that it will eventually be inferred a single value for each variable. Gecode thus include *search engines*. The purpose of a search engine is to choose additional basic constraints to add into the store until all variables have reduced their domain to a single value. Using them we can find one, many, or all the solutions for a CSP.

Gecode works on different operating systems and it will be used as the CSL for Mozart-Oz, therefore it is very likely to be maintained for a long time. Furthermore, it provides an extensible API, allowing the user to create new propagators and user-defined search engines. For instance, we can extend Gecode to reason about trees and graphs, which are useful in musical CSPs.

## 3 GELISP

*Gelisp* provides an interface for Common Lisp and another for OM. In *Gelisp*, sequences of variables are represented by lists, as opposed to Gecode, where they are represented by arrays. This makes the power of list processing (provided by Lisp and OM) available for *Gelisp* users.

### 3.1 Interface for Common Lisp

To solve a problem using this interface, we need to write a script. A script is a function to define the problem variables and their domains (the possible values that a variable can take), post constraints over the variables, and setup a search strategy.

This interface allows the user to call most of Gecode propagators for both, Finite Domain (FD) and Finite Set (FS) constraints. Basic FD constraints deal with expressions of the form  $x \in R$ , where  $R$  is a range or a set of ranges of integers. On the other hand, FS constraints deal with expressions among sets of FD variables. In what

follows, we present some propagators that *Gelisp* provides for FD and FS.

*Gelisp* provides FD propagators for defining domains (e.g.,  $Domain(X) = [2, 5]$ ), equalities and inequalities (e.g.,  $X + Y < Z$ ), cardinality (e.g., 1 occurs two times in  $[XYZ]$ ), boolean constraints, regular expression constraints and the all-distinct constraint. The all-distinct constraint makes the elements of a sequence pairwise different.

On the other hand, for FS we provide constraints for defining domains (e.g.,  $V \subseteq \{1, 2, 3\}$ ) and set relations (e.g.,  $X \subset A \cup B$ ).

In addition, *Gelisp* includes two search engines, Depth Search First (DSF) and Branch-and-bound (BAB). The DFS engine works by choosing some variable, then a value for that variable, if this does not succeed (a constraint does not hold) then chooses another value. If the value succeed, then chooses another variable, then a value for it, etc.

The BAB engine works in a similar way, but solutions are computed in such a way that each subsequent solution increases or decreases the value of some user specified FD variable. Both engines can be used for both FS and FD. In addition, we can define search heuristics for value (i.e., the order to assign a value to a variable) and variable order (i.e., the order to choose a variable). These heuristics are parameters for the search engines.

### 3.2 Graphical Interface for OpenMusic

Instead of writing a script, in the graphical interface we represent a program with a special patch, called *CSP patch*. A patch is a visual algorithm, in which boxes represent functional calls, and connections are functional compositions. Inside a *CSP patch*, we can place special boxes to define a constraint in the CSP, variable and value heuristics, the variable to be optimized during the search, and a time limit in the search.

For instance, we provide a variety of boxes to represent simple constraints (e.g.,  $a = 2$ ) and global constraints (e.g., “all the intervals from a sequence must be different”).

Using the graphical interface we can express a variety of problems declaratively with global constraints. Global constraints have parameters. For instance, the graphical box to find the intervals of a list “ $x \rightarrow dx$ ” has a parameter to choose among absolute, non-absolute, or modulo  $n$  intervals (calculated as  $(V_{i+1} - V_i) \% n$ ). Additionally, it has a parameter to post an *all-distinct* constraint over the intervals.

Moreover, the output of a CSP patch can be connected to a box to find one solution or a box to find  $n$  the solutions

## 4 APPLICATIONS

In this section, we describe both, an intuitive and formal definition of two CSPs and we explain how to solve them with *Gelisp*. Formally, a CSP is triple  $\langle X, D, C \rangle$ , where  $X$  is a set of variables,  $D$  is the domain for each variable, and  $C$  is a set of constraints (read as conjunction) over the variables.

### 4.1 All-interval series

In this problem, we need to find a sequence of 12 different pitches with 12 different intervals (fig. 1). This problem can be generalized to find  $n$  different pitches with  $n$  different intervals equivalent under inversion<sup>2</sup>. For instance, a value of  $n = 24$  represents the *all-interval series* for microtones.



Figure 1. An all-interval serie for  $n = 12$

Therefore, a solution to this CSP is a sequence of  $n$  pairwise different variables with domain  $[1..n]$ , where all modulo  $n$  intervals of the sequence are pairwise different. We give bellow a formalization of this problem

**Variables:**  $V_1 \dots V_n$   
**Domains:**  $[1..n] \dots [1..n]$   
**Constraints:**

- $C_1$  alldiff( $V$ )
- $C_2$  alldiff( $(V_{i+1} - V_i) \% n, i \leq n$ )

There is not a constraint over the interval  $(V_n - V_0)$  because that interval is always six, according to the literature. Furthermore, it is enough to calculate the series where  $V_0 = 0$  because the other ones can be obtained from that one using transposition. In addition, we know that if  $V_1..V_n$  is an all-interval serie,  $V_n..V_1$  is also one. For those reasons, we include these two constraints to avoid symmetrical solutions:

- $C_3$   $V_0 = 0$
- $C_4$   $V_0 < V_n$

We represent graphically this CSP (fig. 2) with a box to create  $n$  all-different variables with domain  $[1..n]$ , an  $x \rightarrow dx$  box for  $C_2$  with an all-different parameter, an equality box for  $C_3$ , and an inequality box for  $C_4$ .

<sup>2</sup> For instance, an interval C-E is equivalent to E-C.

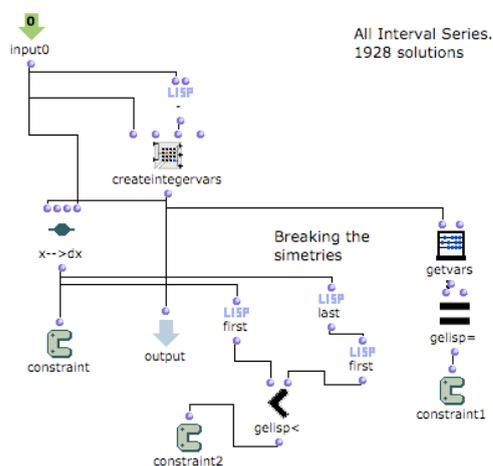


Figure 2. All-interval Series CSP on OM

### 4.2 Jarrell CSP

Composer Michael Jarrell proposed an idea for automatic music generation [2]. The goal is to generate a sequence of  $n$  notes. There is a fix number of occurrences  $OM_1 \dots OM_A$  for each sequences of intervals (called motives)  $M_1 \dots M_A$  over the sequence of non-absolute intervals of the output sequence. In addition, each note of the output sequence belongs to a Chord  $Ch$ . Moreover, the first  $L_1$  and the last note  $L_2$  of the output sequence are fixed. We give bellow a formalization of this problem

**Inputs:**

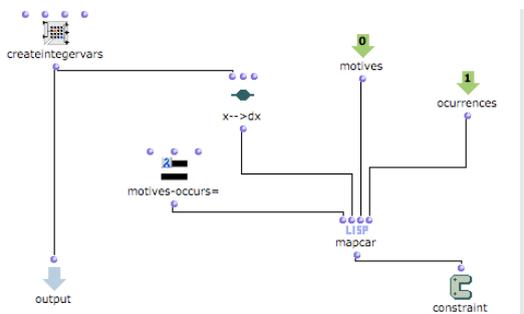
- Motives  $[M_1 \dots M_A]$ , Limits  $L_1$  and  $L_2$ , Occurrences  $[OM_1 \dots OM_A]$ , Chord  $Ch$

**Variables:**  $V_1 \dots V_n$   
**Domains:**  $[0..127] \dots [0..127]$   
**Constraints:**

- $C_1 \forall_{1 < i < A} |\{j, M_i \text{ is a subsequence of the variables' intervals that starts on } j\}| = OM_i$
- $C_2 \forall_{1 < i < n} V_i \in Ch$
- $C_3 V_1 = L_1 \wedge V_n = L_2$

We represent graphically (fig.3) the constraint  $C_1$ . We use the  $x \rightarrow dx$  and motives-occurs= boxes to fix the number of occurrences of each motive over the intervals of the output sequence.

Jarrell also proposes in [2] to consider absolute intervals and octavation for the chords, the limits and the motives. For instance, using absolute intervals, an interval  $V_{i+1} - V_i$  is equal to  $V_i - V_{i+1}$  and using octavation, a pitch G4 is equivalent to G1, G2, G5, etc. Finally, he also proposes to have



**Figure 3.** Constraint  $C_1$  for Jarrell's CSP on OM

specific motives and chords for each segment of the output sequence, according to a user-defined segmentation. For simplicity, we do not present those constraints in this paper. However, a complete model of this problem can be found at *Gelisp* website.

## 5 CONCLUDING REMARKS AND FUTURE WORK

We presented a library for Common Lisp and OM providing a variety of constraints and search engines. *Gelisp* provides graphical boxes to represent some constraints and search strategies. *Gelisp* abstracts minor details that are not necessary for musicians and mathematicians.

It would be pretentious to conclude that we can easily model any musical CSP using *Gelisp* graphical interface, or using the command-line interface. However, we can model a variety of problems using *Gelisp* in a simple way taking advantage of the state-of-the-art propagators and search engines provided by Gecode.

In future works, we will explore a bigger sample of musical CSPs and their representation using global constraints. In addition, the idea of representing CSPs and their search strategies with business rules from *Rules2Cp* [3] can be extended to generate a musical CSP based on musical rules.

## 6 ACKNOWLEDGMENTS

Thanks to Moreno Andreatta, Jean Bresson, Serge Lemouton, Killian Sprotte, and Guido Tack for their valuable comments when developing *Gelisp*.

Thanks to Carlos Toro and Jorge Pérez for their remarks on this paper.

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