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# The Music Representation Project at IRCAM

G rard Assayag, Camilo Rueda

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## Abstract

This paper describes the ongoing works in the Music Representation Group at IRCAM. The general aims are stated. Then some insights are given on some specific projects such as a new quantifier, a general musical constraint satisfaction environment, and application of combinatorial optimization to musical problems.

## 1. Music Representation

The Ircam Music Representation Group, a new project that has been set up in June, 1992, constitutes a pole of competence in computer science as applied to music. It is a privileged place for us for discussion among musicians, scientists and technicians to arise. The boundaries of that collaboration are those of music formalization directed towards composition and analysis. Outputs are academic works, general software tools for computer assisted composition, specific libraries that concentrate the knowledge and the musical philosophy of composers that have significantly contributed to the musical developments during the past 40 years inside and outside Europe. Although we define a methodology that keeps us as independent as possible from the technology of sound production and performance - which are treated by specialized teams at IRCAM - we are clearly committed to the process of creation in motion, thus we are not restricted to instrumental music - an area which has produced the most accurate music formalisms. As a consequence the Representation group also includes specialists of real and non real time sound synthesis and processing, whose work is to define models for a fine grain integration between abstract architectures as treated by CAC programs and known synthesis and dsp techniques.

The representation group puts a continuous development effort on **PatchWork** [LRD 93], a functional, common-lisp based visual programming environment which has been under design during the past three years and is now available through the new IRCAM User's Group. PatchWork has already been described in ICMC papers so we will just recall that it allows the user to go seamlessly back and forth between the Lisp programming level and the visual patch one, attention has been paid to genericity so different kind of musical objects may travel along the wires between modules, and the local states of modules can be viewed and edited through linked musical editors that offer a fairly good Common Music Notation interface.

A significant number of libraries have been designed this year including composer-specific formal systems - Bonnet, Boulez, Lindbergh, Malherbe, Messiaen, Murail, Riotte, Xenakis, among others - and music analysis ones such as an impressive model for a section of Ligeti's *Melodien* for orchestra by Marc Chemillier. The latter belongs to the field of *formalized analysis* pioneered by Riotte and Mesnage [Mesnage 88], where a computer model is build with the integral restitution of the analysed work in view when the model is submitted to simulation [Assayag 93].

PatchWork is a convenient platform for us to test new ideas and simulate prototypes of new systems, some of which will be briefly described here.

## 2. Kant

Kant is a project on rhythm quantification that has been raised by the attested failure of traditional approaches to that problem in the case we are confronted to at IRCAM : complex duration streams algorithmically generated submitted to transformation into a metrical structure in order to be integrated with other music materials prior to final instrumental writing - a different problem than quantifying an instrumental performance. Besides new formal tools such as neuronets [Desain 92] are still bounded to very simple sequences and fail to adress the higher levels of polyphony an metrics complexity.

The main ideas in our approach are :

- 1. the metrical structure should not be a-priori, but built from the salient reationships that arise from the materials (articulation points).
- 2. the polyphonic aspects should not be deffered to the end of the process but handled from the very beginning because they help to determine the salient aspects quoted previously.
- 3. the whole process should be interactive with the composer being able to correct the articulation points put by the computer and to add its own, that might be determined by other parameters than just durations.
- 4. we are in a creation process. Again the point is not to restitute a reality as in performance, but to analyse interactively a material and transform it or select part of it in order to smoothly warp it into the instrumental notation scheme.

Kant is at the very beginning, a prototype has been realized in PatchWork and promising results are already raising.

## 3. The TSP revisited.

This work is the generalization of a research done at IRCAM a few years ago by composer Claudy Malherbe and Gérard Assayag [Assayag 85]. The problem was to build from arbitrary material such as frequency analysis of complex sound objects a graph expressing harmonic relationships between objects. This graph would then be exploited when writing an instrumental score that would integrate those objects.

The idea is then to design a general tool that would help the composer to organize a database in order to build sequences optimized for any kind of relationship that he wants to reveal among objects. The underlying hypothesis is that to efficiently connect in time two musical structures whether it be such simple things as chords or more complex ones, maybe involving heterogenous materials (e.g. instruments and synthesis), one has to find a "perceptual interface", a common substructure that can be given a certain perceptual weight. This interface cans stay implicit (e.g. a common subfundamental betwenn two chords, or a sub. tactus between two rhythmic patterns) or be explicit (e.g. harmonic link between two chords). Once this is done, a graph can be built that expresses the weights of relationships between objects as well as data for later use. At this point, the idea of preferential pathes along this graph arises naturally. One would like for example to arrange a subset of the data base in order to gain a maximized expression of the relation ship (e.g. a sequence of chords that maximizes harmonic links, or joint motion between voices, etc.).

Unfortunately this is an instance of the *Traveling Salesman Problem* [Gilmore 92] (find a tour of a set of cities while minimizing the overall distance travelled through) which is the model for NP-complete problems (problems that no known reasonably fast algorithm can treat in general). We use an approximation of the TSP that is proved to yield a path that is no more than two times worst than the

hypothetical optimal path. It runs that way:

- 1. find a minimum spanning tree in the graph (a spanning tree that globally minimize the relationship considered), using for instance Prim's  $n \log n$  algorithm [Prim 57]. (see figure below).
- 2. build the sequence of nodes by a pre-order traversal of the tree.

A set of solutions can be built and compared, the freedom degrees being the choice of the tree root and the order of the children in the tree traversal.

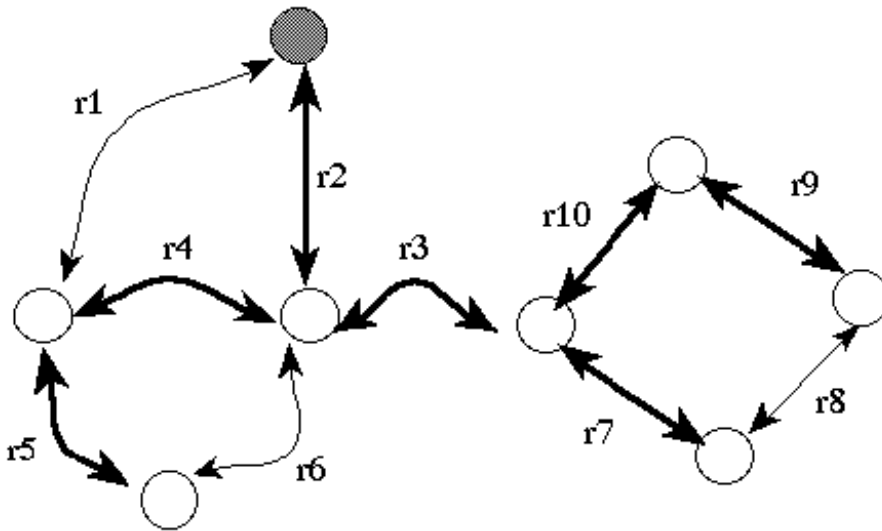


Figure 1.

The technique has been successfully tested in harmonic link optimization. An experience is being setup where the optimizing function is the joint motion between complex aggregate resulting from frequency and Terhardt analysis, the constructed data being sent to **Foo** (a synthesis control prototype by Gergardt Eckel) which will exploit this pre-structure in order to develop a continuous synthesis process where the voice motions will be emphasized by the effect of gain, vibrato, and any known technique of de-fusioning. Our aim there is to put the foundation for new tools that will help in the difficult problem of instruments-synthesis homogeneity.

## 4. Partially Instanciated Musical Structures

A fundamental activity in musical composition is that of constructing material obeying a certain number of relations. Elements in this material are grouped into structures by the relations they entail. Computer utilities helping defining and operating upon these structures thus constitute valuable tools for the composer. Two complementary approaches have recently emerged in this realm. Firstly, a functional approach aiming at providing higher level operators for easing the task of explicitly constructing musical structures. Systems such as the PatchWork [LRD 93] graphical environment, Common Music [Taube 91] and , in a somewhat different domain that in [Balaban 92], are of this type. Secondly, a declarative approach pursuing the automatic construction of the structures from a given set of precisely defined relations. Systems such as Echidna [Ovans 90] belong to this domain. The two approaches are complementary in the sense that for certain type of material one or the other proves to be more convenient. Our research concern has been to unify both ways of conceiving the process of constructing musical structures. The underlying notion sustaining this aim is that of a Partially Instantiated Musical Structure (PIMS). Loosely speaking a PIMS is a generalization of a structure in the functional sense whose elements are sets and augmented with a collection of relations called *Constraints* . In what follows we precise this notion and describe *Niobé*, a Common-Lisp-CLOS implementation of a system using PIMS for the specific case of generating musical sequences.

## 4.1 The Theory of PIMS

A PIMS is the basic building block for generating musical material. It is defined as the structure  $\langle D, R, C \rangle$  where  $D$  is a finite collection of finite sets (called *Domains*),  $R$  is binary relation on  $D$  and  $C$  is a set of constraints (relations) on  $D$ . Basically  $R$  is a *structuring* relation on  $D$  whereas elements in  $C$  are *filtering* relations on elements of  $D$ . Constraints in  $C$  define subsets of the cartesian product of the sets in some subset of  $D$ . Any element in the cartesian product of a constraint  $c$  is said to *satisfy*  $c$ . If all constraints in  $C$  define non empty sets the PIMS is said to be (locally) *consistent*. A PIMS in which  $D$  contains only singleton sets is called a PIMS *instance*. A PIMS *exemplary* is a consistent PIMS instance.

A partial order can be defined on PIMS's as follows: Let  $P = \langle D1, R, C \rangle$  and  $Q = \langle D2, R, C \rangle$  be PIMS. If any cartesian product on  $D1$  is contained in some cartesian product on  $D2$  then  $P \leq Q$ . Given a PIMS  $P$ , the PIMS *instanciation problem* consists in finding a PIMS exemplary  $E$  such that  $E \leq P$ . In this case  $E$  is said to be an exemplary of  $P$ . Seen from this perspective a PIMS is a structure scheme representing the set of its exemplary structures. The graph in the figure below represents a PIMS for the set of all three note chords beginning in any one of the notes in the set *base* (in MIDI), having consecutive intervals taken from the sets *int1*, *int2* (in semitones), not containing octaves and positioned within the register from 60 to 79 in MIDI.

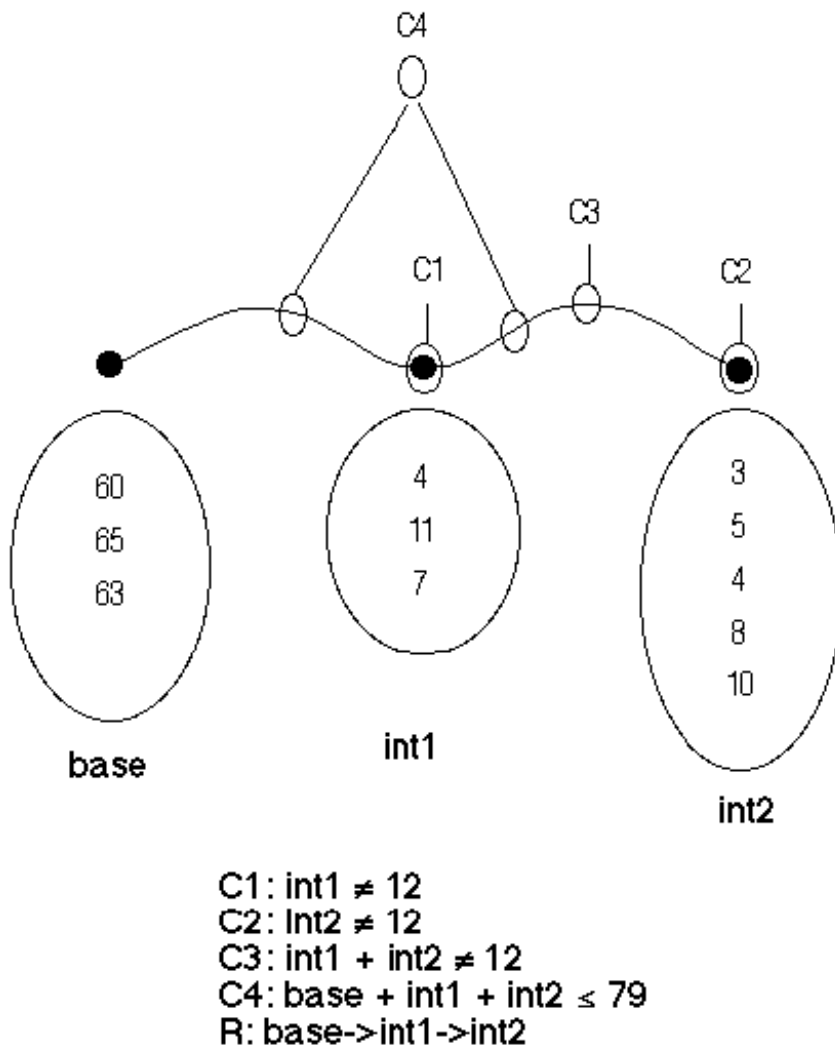


Figure 2.

### 4.1.1 Structure Instanciation by Arc Consistency.

Building musical material can thus very generally be seen as a two step process: First constructing a

suitable PIMS and then solving the PIMS instantiation problem on it. For the latter we use in Niobé arc consistency techniques. These are well known procedures in the constraint satisfaction field aiming at improving efficiency of solution calculation by reducing the given domains. Domains are reduced by insuring that constraints are locally consistent. A constraint can be represented in a graph having domains as nodes by an arc linking those domains it constrains. An arc in this graph is said to be consistent if, for any element in any of the linked domains, there can always be found elements in the other linked domains such that all taken together satisfy the constraint. Values in the linked domains not obeying this property can be eliminated, thus reducing domain sizes. Algorithms for achieving arc consistency were originally described in [Mackworth 77]. More recently an efficient arc consistency procedure called AC-5 has been proposed in [DVH 91]. AC-5 runs in time proportional to the square of the size of the biggest domain, but can be easily specialized to a linear time algorithm for useful categories of constraints. These are referred to in [DVH 92] as functional and monotonic constraints. Briefly stated these are constraints such that suitable representatives in each domain suffice to test the validity of the constraint for the whole domains. Constraint C4 in the figure above is of this type. AC-5 forms the core of the structure instantiation scheme in Niobé. Additional optimizations are considered in Niobé by defining hierarchies on the PIMS domains reflecting frequently encountered musical constraints. For example, in the problem of instantiating chord sequences structures, constraints imposing particular melodic movements on the upper and lower voices are frequently used. Chord structures are thus supplied with an additional (hidden) domain comprising the sum of consecutive intervals in the chord. Melodic constraints can thus be redefined to act on the base note and sum-of-intervals domains avoiding the need to look into each particular interval composition of the chord. Domain hierarchies in Niobé are similar to those used in Echidna ([SH 91] for representing constraints on real numbers.

Musical constraints within a PIMS are in general conceived by the composer as having different degrees of importance. We describe next a mechanism implemented in Niobé for taking account of this fact.

#### 4.1.2 Soft Constraints in PIMS

Constraints in a PIMS can be assigned a degree of importance. In Niobé this is simply a number between zero (useless constraint) and one (required constraint). A valuation function  $v: P(\text{PIMS}) \rightarrow [0,1]$  is defined on PIMS instances as

$$v(P) = \min_{c \in P} [1 - a \mid a = \text{importance}(c) \text{ and } \sim \text{satisfied}(c)] \cup \{1\}.$$

Thus the value of PIMS instance P is equal to one minus the importance degree of the most important unsatisfied constraint c in P. The PIMS instantiation problem can then be redefined as follows: Given a PIMS P, find a PIMS instance  $Q \leq P$  such that  $v(Q) \leq v(R)$  for any PIMS instance  $R \leq P$ . A careful formalization of this way of handling soft constraints can be found in [Schiex 92]. Algorithm AC-5 has been extended in Niobé for computing maximum valued PIMS instances.

An important issue in the design of Niobé has been to provide a user friendly layer for PIMS construction and instantiation. We describe next the implementation of a graphical interface for Niobé written in PatchWork.

## 4.2 The Implementation

Niobé is implemented in Common-Lisp-CLOS. A PIMS, its domains and constraints are CLOS objects. A graphical interface in PatchWork is supplied for constructing and parametrizing these objects and for triggering the instantiation mechanism. PIMS instances can also be graphically interpreted, functionally transformed and displayed/edited in standard music notation by using suitable PatchWork editors. A PatchWork box representing Niobé defines entries for domains and constraints specification.. Additional entries allow constraint parametrizing using a simple pattern expressions syntax. For example, PIMS representing chords having at least one interval of a fifth between successive notes and not having two consecutive thirds can be supplied with the relevant constraint by the expression

(and (\* 7 \*) (not (\* 4 4 \*))).

Being represented by a PatchWork box, Niobé allows any patch to define entries for domains or constraint definition, thus taking full advantage of the visual programming aspects of PatchWork. The system and its graphical interface have been successfully employed for the generation of harmonic material for the latest piece of the composer Antoine Bonnet.

## Acknowledgements

We wish to thank Georges Bloch who pointed out that the graph/TSP approach was pioneered by Schoenberg himself in his harmony Treatise [Schoenberg 49], quoting Bruckner's "law of a shorter path". The minimization function was the harmonic link by common notes.

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