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Staff Scheduling Problem by means of Optimization Algorithms

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Abstract

Our application is placed in the domain of automatic generation of timetables. The generation of timetables is the assignment of employees to tasks in the goal of schedule during one fixed period, in general a week. This problem is by its nature a complex problem which requires the resolution of many constraints. Indeed, the SSP are usually addressed to the organization where a set of tasks must be achieved by a group of employees having their own qualifications, constraints and preferences. The organization imposes total regulations and tries to carry out such total objectives them such as the reduction of the total cost or the equitable division of the load of work between the employees. Research in this field gave place to several conference. The results resulting often are adapted to particular professional sectors. In this paper, we propose a general solution not depending on particular sector.

Key words : artificial intelligence, constraints programming, CSP, scheduler, solver, timetable.

1 Introduction

Constraint programming is a powerful paradigm for solving combinatorial search problems that draws on a wide range of techniques from artificial intelligence, computer science, databases, programming languages, and operations research. Constraint programming is currently applied with success to many domains, such as scheduling, planning, vehicle routing, configuration, networks, and bioinformatics. Constraint-based systems are generally quite expressive and are thus good for modelling complex problems. The CSP paradigm consists of a set of variables, each of which have a discrete and finite set of possible values (their domain); and a set of constraints between the variables which specify which combinations of values are allowed and which are

not. For this reason, this type of system is sometimes referred to as a finite domain constraint solver. A solution to a CSP is a set of variable-value assignments which satisfies all the constraints. Often, the computing power of the computers is not enough to examine all the possible combinations in an acceptable time, and it is necessary to introduce "reasoning" and the "heuristic ones" making it possible to reduce the combinative one and to guide research towards the good combinations. In this direction, the resolution practises of CSPs called upon techniques resulting traditionally from "the artificial intelligence".

The algorithms making it possible to solve of CSPs are called "solvers" of constraints. Some of these solvers were integrated in programming languages, thus defining a new "paradigm" of programming called "programming by constraints": to solve a CSP with a programming language by constraints, it is enough to specify the constraints, their resolution being dealt with automatically (without needing to program it) by the solveurs of constraints integrated into the language.

The aim of this paper is to describe how we realise a generic application based on the constraint programming field which works in two passes: first solving the constraint and next assigning the attributes to value of variables. Information about dependancies of variables is of higher interest for applications such as our API. where the process of programming includes the generation of the conditions (forced)

Different research notes that the constraints can be divided into two group: on the one hand the strong constraints which must absolutely be respected and on the other hand weak constraints that we could try to respect as possible. If we hold only strong constraints, the problem consists with find one solution between others which satisfies the constraints. If we would like to take in account the weak constraints, we must then add an evaluation function measuring the degree of respect of the weak constraints. It is a question of finding in the space of the solution respecting the strong constraints the solution which maximizes (or according to the case, which minimizes) this function.

The problem of satisfaction of constraints can be translated in the optimisation problem where the algorithm will look to initially violate the definite weak constraints like no priority (having a small weight) in the evaluation function before violating the priority weak constraints. Two steps are necessary:

- the determination of the solutions space respecting the strong constraints,
- then a research in this space of the solution minimizing or maximizing the evaluation function.

This problem is more similar with the optimization problem when the strong and weak constraints are both evaluate by this function. Then, the constraints satisfaction consists in only optimizing this function: We delete the stage of search for the solutions respecting the strong constraints, alone there remains the stage of minimization or maximization of the evaluation function.

2 Methods and Algorithms

2.1 Systematic search

From the theoretical point of view, to solve PSC is unimportant if one uses the systematic exploration of the solution space. From the practises view point where the effectiveness takes place. Even if the systematic methods of research (without additional improvement) appear very simple and not-effective, they are important because they form the base of the most advanced algorithms and more efficient. Just to only quote some most known

- Generate-and-test which consists with a complete labelling of the variables randomizing produced and, consequently, if this labelling satisfies all the constraints then the solution is found if not another labelling is produced.
- Technical Backtracking this method consists in prolonging a partial solution which indicates the consistent values for certain variables towards a complete solution thanks several time choosing a value for an other variable consistante with the values in the current partial solution.

2.2 Consistency technique

Another approach of the solution is based on the removal of the contradictory values of the domains of variable until we obtain the solution. These methods are called consistency technique based on the theories of graph and represented as a graph of constraint (network) where the nodes correspond to the variables and edges are labelled by constraints

2.3 Stochastic and heuristic algorithms

During the last years, the local strategies of research became popular. These algorithms gradually change soft values with all the variables. They use a distribution or hill climbing “metaphore” to move towards increasingly complete solutions To avoid wedging itself at least local they are equipped with various heuristic randomizing research. Their stochastic nature aims generally the guarantee of the “ perfection’ ’ provided by the systematic methods of research. Hill climbing is probably the most famous algorithm of research room. It starts by labelling variables by random and, with each stages, it changes a value of a certain variable in such a way that the labelling resulting satisfies more constraints. If a strict local minimum is then reached the algorithm starts again in another state produced by randomizing research, the algorithm stops as soon as a total minimum is found, for example, all the constraints are satisfied or a certain resource is exhausted.

2.4 Genetic Algorithms

The genetic approach is inspired by the concept of evolution observed in the real life. The idea is to create a population of individuals, each individual representing a possible timetable. Starting with a first population, one simulates the normal evolution towards better candidates with the optimal solution of timetable. The principal claim is that the more suitable individuals develop and are reinforced along generations, because the best individuals are most likely to survive for longer periods. Thus, it results the possibility of obtaining best the solution with the problem “ timetabling’ ’. represent by the most adequate individual.

However, all the attempts providing a rigorous proof to show that indeed the genetic algorithms converge towards an almost optimal solution failed all. It is difficult to provide such evidence because of nature of the problem. On the other hand the justifications are all intuitive and mainly based on the experimentation.

3 Implementation of the solution

The important point of this project was the possibility of generating automatically a timetable. This problem being NP-Complete, it was necessary to find a means of solving it in the fastest possible way. Moreover, at the time of the phase of research preceding the development, it appeared that very little of solution, even commercial, had such a solver. For example the software used by the University Bordeaux 1 for the management of the timetables makes only the checking of constraints and not the timetables generation.

3.1 Choice of Solver

Once the choice of the programming by constraint was carried out, it was necessary to find a solver because there was no question of coding to us even a traditional solver starting from rather complex algorithms. Among the possible solution found on Internet, Gnu-Prolog, SICStus Prolog, CHIP, we focalize ourselves on two solutions seeming better to agree

- **CHOCO** library java dedicated to the resolution of constraints, CHOCO seems a possible solution because it has many advantages: facilitated integration to code java making the interface between the data base and the solver, many constraints of higher order. Disadvantage, after having tested this solution, it proved that the solver has bad performance contradictory with documentation let it predict. Indeed, of many modules being failing, it was not possible to optimize the resolution, which makes this solution completely unusable (obselete).
- **Mozart** It is a platform of development implementing the OZ language. OZ allows almost all the types of programming: declaratory, functional, object, etc and by constraints. This platform thus has a library of resolution which is relatively powerful and reliable: Mozart is developped partly by SICStus Prolog. Moreover Mozart is portable on all architectures more common to date.

3.2 Rapid presentation of the problem

Schematically, for a timetable, one needs teachers, courses, students, buildings (rooms). The problem is to place all the lesson in the week. However, each teaching gathers a teacher and students who must not have several simultaneous lesson. The rooms of course are limited, then it is necessary that the obtained result corresponds to a realizable solution. With final, each teaching, will need a certain type of room and each type of room will be available in a limited number. The objectif one is thus that at every moment, the number of teaching simultaneous occupying a certain type of room does not exceed the quantity available of this resource.

3.3 Data structure

course Mozart has a record data type, making it possible to store information in a structured way. A teaching can thus be represented thanks to such object. The component fields will be:

- **name** this one is single and is recovered in the base. This does not intervene in calculation but makes it possible to identify each course/lecture in order to have an interpretable result
- **start** its hour of beginning. It is this value which will be calculated for each teaching
- **duration** number of course/lecture (example 36h).
- **professor** the teacher to whom is allocated this course
- **size** the type of room in which the course must proceed

Of all these data, it will have there only the hour of beginning which will be calculated and allocated to each course if a solution is found. We ,in addition, decided to manage the temporary values by crenel of ten minutes.. This allows more performance to the solver.

Teacher The teachers are represented only succinctement. Indeed, only the useful information to their subject are their identifier and their unavailabilities.

Week The week is divided into crenels of 10 minute. The daytime starts at 8 a.m. and finishes at 7 p.m.. Monday will thus proceed over crenel 1 to 66, Tuesday 67 to 133, etc. The ferries days are made inalienable, before all traitments..

3.4 Principle of solver operation

Hours of beginning of courses are not fixed but represented by their domains of values. Any value in the domain being potentially correct, The constraints solver tries to solve them in order to arrive at a solution. At the beginning, these domains cover all the week, each course can start at any time. Then, they will be tiny room following various types of constraints: those which are basic, taking care so that courses :

- don't overlap various days, that
- the breaktimes are respected,

Then some more complex which check that any course overlap, and the quota of rooms are respected, etc

3.5 Application of the basic constraints

After dialogue, it was agreed various pauses: Thursday afternoon is left free, the crenels of 12h30 → 14h are them too. For these two cases, we dispose of a function DayBreak its operation is relatively simple: it takes

a crenel as well as a list of course. For each one of these courses, it withdraws domain, hour of beginning, the crenels incompatible with this constraint, i.e. for a course having for one duration of 3h, it is necessary to except eliminate from the domain the pause in it even as well as the two crenels preceding at the beginning of morning or from afternoon.

3.6 Application of the no “coarse” constraints

This constraints relate to the courses which do not overlap because, either they relate to interdependent groups (group/sub-group), or they concern the same teacher. In these two cases, in more of avoiding to overlap they must be separated by ten minutes. With this intention, we have the functions `NoOverlapLectures` and `NoOverlapSession`. The first of these two functions takes in parameter the list of courses which do not overlap (incompatibles), especially useful for the same affected professor for two or several courses. The second is rather used for the courses assigned to the same group of students. These two functions guarantee the coherence of the obtained result. For the respect of the number of rooms available, one uses another function `AtMostLecture` intervenes once the courses are placed (once that a possible solution was found on the levels of the teachers and the students. The function takes in parameter a list of course needing a specific room as well as the available number of this this one. Thus the treatment amounts counting, for each crenel, the number of courses provided in the list overlapping. This number should not exceed the second parameter. This very powerful constraint, from a complexity point of view in time, it is the weakness of our solution it would require to be improved (worked over again)! Once all the constraints posed, a solution should be found not violating any of those. With this intention, it is enough to launch the solver included in the platform of Mozart development.

4 The Java Module

The solver computes and stores in a data structure the part of the information which is relevant for a given set of constraints. (a skeleton of timetable). To complete the informations we use the Java module which maps with all crenels of solution the name of course, teacher, group and room. This “two passes” approach is simpler and more efficient than the usual one. The interest of such a module is to work on an image of the data base. Indeed, this one is made up starting from objects representing each one of tuple, organized by tables in forms of collections. The handling of data is some thus facilitated. This information must be formatted in files intended to be exploited by the solver.

Once that this one to find a solution, it generates an output file of which the data are treated by the Java module. Some aspect such as the personal attribution of the rooms to the various courses, are not manage by the solver and must thus be dealt with by java module. Once exhaustives, the data is then inserted in the data base. It can then be extracted by Web interface which will exploit them, to post a timetable. A sending an e-mail makes it possible to hold the teaching supervisor to inform of the computation result. The different functionalities offered by the Java modules are articulated mainly with the turn two packages: `tables` which contains the classes allowing the handling of the data and `solver` gathering all the tools necessary to the data processing in entry and exit of the solver.

4.1 Gestion of constraints of materials

4.1.1 Small recall

Each room has to the more five materiels(retroprojector, videoprojector, television, etc). For a teaching, a professor can need a specific material present only in certain rooms. He must inform it at the level of the Web interface and the application will have to then manage this new constraint the best possible one. The solver guarantees that a teaching has a room. But it does not allow it in a personal way. Consequently, it cannot take into account the constraints of materials of each teaching. This task is left to the Java module implemented in the classes `tables.Room`, `tables.Course`, `tables.Solver.output` cfr figure 2.

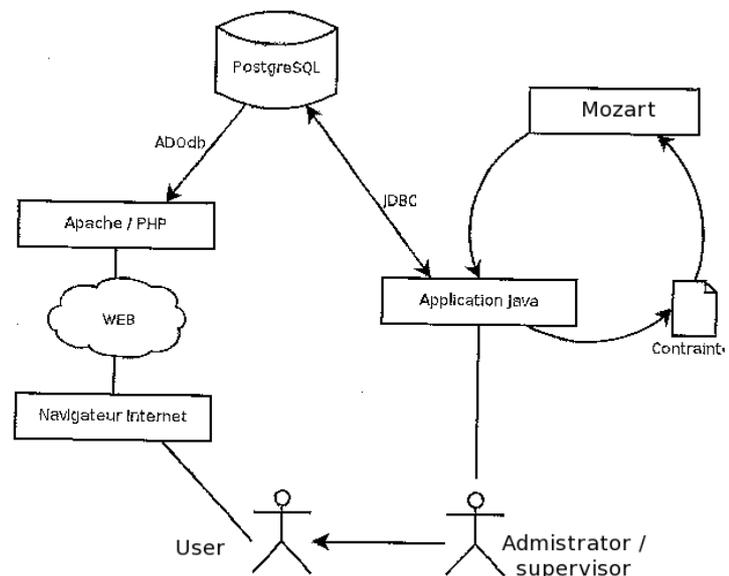


Figure 1. API architecture

4.1.2 Principle of the algorithm governing the attribution of rooms

The objectif of this algorithm is to assign to each teaching a room by respecting the best possible constraints of materials. First of all, we classify the course/lesson by type of room in decreasing order of a number of necessary materials. Then, for a given course, we associate with each material present an element coming from a super-increasing sequence. We recall to reader that a sequence (a_n) is call a super-increasing sequence, if it satisfies the following property:

$$\forall j : \sum_{j=0}^{i-1} a_j < a_i$$

It is easy to show that $a_n = 2^n$ is a super-increasing sequence and this is the smallest possible super-increasing sequence. Let N = a number of materials available of a certain type, we associates to the first material 2^{N-1} , to the second (if there exists) 2^{N-2} , so on to each material available in the data base or related to an integer of the super-increasing. type. Then, we add an integer associated with the materials with C . This sum will be noted SC . We make in the same way for each room available compatible to the type of the course R_i , we will note result SR_i . At this stage, course C and all the free rooms R_i are respectively associated an integer SC and SR_i , it remains to find the room which would more correspond (on the level material) to course. For that we apply the following algorithm.

```
choiceRoom(integer SC,ListRoom Ri):Room;
result <- createliste();
integer rm;
```

```
For i from 1 to Nb-Free-Room do
  if (SC == SRi)
    //The room has exactly the material
    // needed
    return Ri;
  fi;
od;
```

```
For i from 1 to Nb-Free-Room do
  rm <- returnMoney(SC,Ri);
  result.put(Si, rm);
od;
```

```
//output is a room associated with the
//smalest integer
return min(resulta;
end;
```

```
returnMoney(Integer SC,Room Ri):integer;
integer weighth, res <- SC;
list Super-list<-Ri.weighthingMaterial();
Sort-Decreasing(Super-list);
```

```
while(!(empty(Super-list)) && res!=0) do
  weight <- Next(Super-list);
  if (SC <= res)
    res <- res - weighth;
  fi
od;
return res;
end;
```

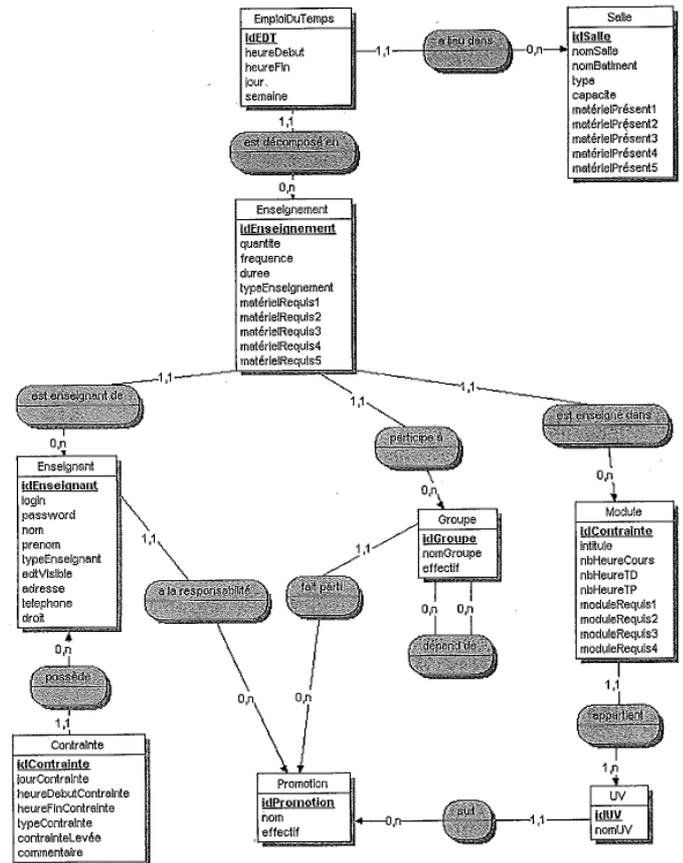


Figure 2. Final MCD

4.2 Gestion of remedial class

Our application makes it possible to a teacher to catch up with a cancelled or missed course. For that we develop an algorithm which proposes choices of crenel for a remedial class. The algorithm creates a table representing the future days, then, we remove all the crenels corresponding to the constraints of the teacher. Then we remove the crenels where the teacher and/or the students are incompatible by paying attention to the dependences of group and subgroup. The second part of the algorithm scours the remaining crenels in the table and keeps only those which are

Table	Nb of lines	Size of lines	Size of table
Room	450	180	81000
Course	900	207	186300
Contrainte	4500	122	549000
UV	600	78	46800
Module	2900	160	464000
Group	1000	146	146000
Teacher	1000	87	870000
SST	320000	58	185560000
		T. bytes	20413100
		Total Ko	20413.18
		Total Mo	19.193

Table 1. Computation volumetry

compatible with the duration of the course. It only remains to find a room. It should be noted that the algorithm seeks in priority the room in which this course should have taken place.

4.3 Volumetry

For sample taken into account University Bordeaux 1, we roughly have 5 constraints per teacher in the worst case, roughly 5 modules by UV, 10 courses by group and 32 weeks of course per annum. The occupied disk space will be unimportant on the other hand it is difficult to envisage the response time because depend on the machine, the algorithm and the heuristic ones. We made tests for two promotions of a computer department time was rather short.

5 Conclusion

The automatic realization of a SST with multitudes of constraints is a very difficult problem NP-Compleat. But thanks to Mozart and with the algorithms which we added, we are successful propose a suitable API of which reaction time depending on the heuristic ones. From an accessible interface since any navigator on internet, all necessary data can be entry to design a SST. One can, moreover, to generate the individual SST for a teacher, a student or a room with a safety i.e. it is necessary to be identified to have access to this service. and that. We do not claim completely to replace the man by the machine, but we let us propose to him a substantial help with a task not always easy to realize. Its generics reside in the fact that it does not apply solely to the field taken in example. Developed with free tools, it makes it possible to save licence (free charge).

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	Lundi	Mardi	Mercredi	Jeudi	Vendredi	Samedi
8	Modèles de calcul J Bétréma. Amphi Kastler/A9	CMA G1 A Arnold	RES G2 M Hachet	RES G1 A Pécher	CMA G3 A Dicky	Réseaux P Guibton Amphi Kastler/A9
9		SAK1 /A9	SAP3 /A9	SSAK /A9	COM G1b Mme Perrier	RES G3 N Bonichon
10					COM G1b Mme Perrier	RES G3 N Bonichon
11	MC G2 N Saheb	MC G3 P Carrière	SE G1 D Mercier	SE G2 P Rorhin	Angl G2b Mme Lemarquis	COM G2b YY
12	SAK1 /A9	AAC /A10	008/A28	009/A28	Compléments de Mathématiques et d'Algorithmique S Zvonkin Amphi Kastler/A9	
13					MC G1 J Bétréma	
14					COM G3a XX	
15					Mme Lasserre	
16	COM G2a Mme Perrier	Angl G3a J Bernault	COM G1a Mme Lasserre	Angl G2a M Cocquhat	Ang G1b Mme Lechaud	SE G3 D Mercier
17	Angl G1a J Bernault	0/A21	0/A21	Angl G2b Mme Lechaud	SAP3 /A9	008/A28
18						
19						
20						

Le 11 octobre

Réunion de rentrée lundi 22/09 de 9h à 10h Amphi Kastler/A9.

Les TDs commencent la semaine suivante.

CMA: Compléments de Mathématiques et d'Algorithmique

Angl: Anglais

RES : Réseaux

MC: Modèles de calcul

SE: Systèmes d'Exploitation

COM: Communication

Figure 3. SST generate by our application