Abstract

Real world problems are often overconstrained, ill-defined, or tolerate good though suboptimal solutions as long as those are found before a deadline. Such problems are often called partial constraint satisfaction problems (PCSPs). The model for PCSPs was initially inspired by classic constraint satisfaction methods. Another path leading to comparable notions and originating from fuzzy decision making is introduced in the present masters thesis, adding the following features to increase modeling capability: gradual satisfaction, priority, and compromises. Because of these additional degrees of freedom, fuzzy constraints must be fine-tuned for a certain task. However, such fine-tuning cannot be done for all possible instantiations of a problem, and thus is generally done on prototypical constraints. These templates are applied during run-time to a certain actual situation, i.e., dynamically adapted and applied only where necessary. This thesis describes issues arising from the existence of such dynamic constraints and how they are handled in the *FLIP++ optimization libraries. Examples from a steelmaking scheduling application are given. Theoretical analysis and some initial experiments indicate that this method makes PCS ready to confront real world problems.

Keywords

Fuzzy set theory; fuzzy scheduling; partial constraint satisfaction; fuzzy constraints; fuzzy constraint satisfaction problems; fuzzy multiple criteria optimization; possibility distribution; fuzzy decision making; compromising; importance scale; priority of constraints; repair based heuristics vs. constructive algorithms; scheduling in steelmaking; fuzzy planning and design; uncertainty; vagueness; fuzzy constraint relaxation; real-world scheduling; fuzzy expert system; fuzzy linear programming; fuzzy knowledge representation;

1. Introduction

In manufacturing industry such as steelmaking, the distinction between commercial viability and failure often lies in the ability to control the production process through efficient scheduling. Government as well as industry require practical approaches to a diverse set of complex scheduling and planning problems. While scheduling has been studied in isolation for many years, recent advances in artificial intelligence and operations research indicate a renewed interest in the area. In addition, the scheduling problem is being defined more generally, and work is beginning to consider the closed-loop use of scheduling systems in operational contexts. However, a primary source of difficulty in constructing good schedules stems from the conflicting nature of the objectives. As with many real life decision-making situations, it is usually not possible to perfectly fulfill all objectives when building new schedules. This applies to class-room schedules, staff-roostering, as well as production schedules in manufacturing. Existing approaches to scheduling tend to reduce the complexity of the problem by considering only a small subset of objectives.

In real world situations, it would often be more realistic to find viable compromises between the objectives. For many problems, it makes sense to partially satisfy objectives. The satisfaction degree can then be used to evaluate the achieved compromise. In addition, real objectives are often prioritized, therefore it is necessary to weight their satisfaction with importance factors. One especially straightforward way to achieve these two aspects of scheduling problems - to satisfy constraints to a certain degree, and to take into account relative importances - is the modeling of these constraints through fuzzy constraints. While fuzzy constraints are at least as powerful as other partial constraint satisfaction models [Slany94], they are particularly well suited for modeling, since constraints can be written in a format easily understood by human experts, and because they feature a robust behavior which needs almost no tuning to yield reasonable control. In addition, the evaluation of their gradual satisfaction can be very efficiently used to guide heuristic search methods, in order to find approximate *good* solutions while at the same time greatly simplifying the complexity of the scheduling problem.

Real world descriptions naturally contain vaguely formulated relations, because more details are not known or would anyway not lead to better results as they would be canceled out through uncertain data. These uncertain data values can be well modeled through the use of possibility distributions, which are special interpretations of a part of fuzzy set theory.

In this thesis we will focus on fuzzy constraint satisfaction and the relative implementation issues.

The following Chapters will be organized as follows:

- Chapter 2 covers general constraint satisfaction and gives an introduction to classical CSP methods.

- Chapter 3 deals with fuzzy set theory, the modeling of fuzzy constraints, the aggregation of fuzzy constraints, and fuzzy constraints of different importance. We explain in theory and by practical examples fuzzy set based constraints that help to model general multiple criteria optimization problems.

- In Chapter 4 can be found a short introduction and a classification of general scheduling problems.

- In Chapter 5 we present a steelmaking scheduling problem taken from the real world and investigate how schedules can be generated using fuzzy methods.

- In Chapter 6 we describe the more mature implementation of these concepts by the presentation of the *FLIP++ libraries.

- Chapter 7 treats the implementation and the design of the DynaFLIP++ library. We give a complete description of the CSI(C&F) programming language as well as many examples to illustrate the functionality of CSI(C&F). This Chapter closes with a rather simplified evaluation of the steelmaking schedules we introduced in Chapter 5.

- Finally, in Chapter 8 we draw general conclusions about the achieved results.