Chapter III
Principles of Constraint Processing

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ABSTRACT

Solving combinatorial optimization problems such as planning, scheduling, design, or configuration is a nontrivial task being attacked by many solving techniques. Constraint satisfaction, that emerged from Artificial Intelligence (AI) research and nowadays integrates techniques from areas such as operations research and discrete mathematics, provides a natural modeling framework for description of such problems supported by general solving technology. Though it is a mature area now, surprisingly many researchers outside the constraint satisfaction problem (CSP) community do not use the full potential of constraint satisfaction and frequently confuse constraint satisfaction and simple enumeration. This chapter gives an introduction to mainstream constraint satisfaction techniques available in existing constraint solvers and answers the question “How does constraint satisfaction work?” The focus of the chapter is on techniques of constraint propagation, depth-first search, and their integration. It explains backtracking, its drawbacks, and how to remove these drawbacks by methods such as backjumping and backmarking. Then, the focus is on consistency techniques; the chapter explains methods such as arc and path consistency and introduces consistencies of higher level. It also presents how consistency techniques are integrated with depth-first search algorithms in a look-ahead concept and what value and variable ordering heuristics are available there. Finally, techniques for optimization with constraints are presented.
INTRODUCTION: WHAT IS CONSTRAINT PROGRAMMING, WHAT ARE ITS ORIGINS AND WHY IS IT USEFUL?

Constraint programming is an emerging software technology for declarative description and effective solving of combinatorial optimization problems in areas such as planning and scheduling. It represents one of the most exciting developments in programming languages of the last decade and, not surprisingly, it has recently been identified by the Association for Computing Machinery as one of the strategic directions in computer research. Not only it is based on a strong theoretical foundation but it is attracting widespread commercial interest as well, in particular, in areas of modeling heterogeneous optimisation and satisfaction problems.

What Is a Constraint?

A constraint is simply a relation among several unknowns (or variables), each taking a value in a given domain. A constraint thus restricts possible values that the variables can take; it represents some partial information about the variables of interest. For instance, “the circle is inside the square” relates to objects without precisely specifying their positions, that is, their coordinates. Now, one may move the square or the circle and still be able to maintain the relation between these two objects. Also, one may want to add another object, say a triangle, and to introduce another constraint, say “the square is to the left of the triangle.” From the user (human) point of view, the description of object relations remains transparent.

Constraints arise naturally in most areas of human endeavour. The three angles of a triangle sum to 180 degrees, the sum of the currents floating into a node must equal zero, the position of the scroller in the window scrollbar must reflect the visible part of the underlying document. These are some examples of constraints which appear in the real world. Constraints can also be heterogeneous and so they can bind unknowns from different domains, for example the length (number) with the word (string). Thus, constraints are a natural medium for people to express problems in many fields.

We all use constraints to guide reasoning as a key part of everyday common sense. “I can be there from five to six o’clock.” This is a typical constraint we use to plan our time. Naturally, we do not solve one constraint only but a collection of constraints that are rarely independent. This complicates the problem a bit, so, usually, we have to give and take.

What Is a Constraint Satisfaction Problem and Its Solution?

A Constraint Satisfaction Problem (CSP) consists of:

- a finite set of variables \( X = \{x_1, \ldots, x_n\} \),
- for each variable \( x_i \), a set \( D_i \) of possible values (its domain), and
- a finite set of constraints restricting the values that the variables can simultaneously take.

Although the domains can be infinite (for example, real numbers), frequently only finite domains are assumed. This chapter covers techniques working with finite domains which have received the most attention in constraint programming. Hence we are speaking about solving combinatorial problems. Note that values need not be a set of consecutive integers (although often they are). They need not even be numeric.

The constraint is any relation between the subset of variables. This relation can be defined in an extensional way, as a set of compatible (or incompatible) tuples of values, or in an intentional way, as a logical or arithmetical formula. We will present the constraint satisfaction algorithms usu-
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