Preface

Constraint programming and decision making are important. Constraint programming and decision making techniques are essential in the building of intelligent systems. They constitute an efficient approach to representing and solving many practical problems. They have been applied successfully to a number of fields, such as scheduling of air traffic, software engineering, networks security, chemistry, and biology. However, despite the proved usefulness of these techniques, they are still underutilized in real-life applications. One reason is the perceived lack of effective communication between constraint programming experts and domain practitioners about constraints, in general, and their use in decision making, in particular.

CoProd workshops. To bridge this gap, annual International Constraint Programming and Decision Making workshops CoProd'XX have been organized since 2008: in El Paso, Texas (2008, 2009, 2011, 2013, and 2015), in Lyon, France (2010), in Novosibirsk, Russia (2012), and in Würzburg, Germany (2014); CoProd'2016 was held in Uppsala, Sweden. Papers from the previous workshops appeared in [8]. This volume contains extended version of selected papers presented at the following CoProd workshops.

CoProD workshops aim to bring together, from areas closely related to decision making, researchers who design solutions to decision making problems and researchers who need these solutions and likely already use some solutions. Both communities are often not connected enough to allow cross-fertilization of ideas and practical applications.

CoProD workshops aim at facilitating networking opportunities and cross-fertilization of ideas between the approaches used in the different attending communities. Because of this, in addition to active researchers in decision making and constraint programming techniques, these workshops are also attended by domain scientists—whose participation and input is highly valued in these workshops.

The *goal of CoProD workshops is therefore to constitute a forum for inter-community building*. The objectives of this forum are to facilitate:

- The presentation of advances in constraint solving, optimization, decision making, and related topics;
- The development of a network of researchers interested in constraint techniques, in particular researchers and practitioners that use numeric and symbolic approaches (or a combination of them) to solve constraint and optimization problems;
- The gap bridging between the great capacity of the latest decision making/constraint techniques and their limited use.

CoProD workshops can impact these communities by easing collaborations and therefore the emergence of new techniques, and by creating a network of interest. The objectives of CoProD are also relayed all year round through the Web site constraintsolving.com.

Topics of interest. The main emphasis is on the joint application of constraint programming and decision making techniques to real-life problems. Other topics of interest include:

- Algorithms and applications of:
  - Constraint solving, including symbolic-numeric algorithms
  - Optimization, especially optimization under constraints (including multi-objective optimization)
  - Interval techniques in optimization and their interrelation with constraint techniques
  - Soft constraints
  - Decision making techniques

- Description of domain applications that:
  - Require new decision making and/or constraint techniques
  - Implement decision making and/or constraint techniques

Contents of the present volume: general overview. All these topics are represented in the papers forming the current volume. These papers cover all the stages of decision making under constraints:

- How to formulate the problem of decision making in precise terms, taking different criteria into account?
- How to check whether (and when) the corresponding decision problem is algorithmically solvable?
- Once we know that the decision problem is, in principle, algorithmically solvable, how to find the corresponding algorithm, and how to make this algorithm as efficient as possible?
- How to take into account uncertainty, whether it is given in terms of bounds (intervals), probabilities, or fuzzy sets?

How to formulate the problem of decision making in precise terms: case of single-agent multi-criterion decision making. Paper [3] shows that in many cases, we can efficiently formulate single-agent multi-criterion decision making problems in terms of constraints, and thus, known constraint-based techniques to solve these problems.

How to formulate the problem of decision making in precise terms: general case. In the general case, in addition to several criteria, we may also have several agents. There are two important aspects of multi-agent problems:

- First, even when different agents have similar interests, their estimates of the values of different criteria are often drastically different; the papers [2, 11] analyze how to best reconcile these differences and come up with a reasonable solution;
- Second, different agents may have different interests; such situations are analyzed in [14].

When are problems algorithmically solvable? It is known that the corresponding problems stop being solvable if there is a discontinuity. Interestingly, it turns out that for many problems, discontinuity is the only obstacle to algorithmic solvability; see, e.g., [6]. Even in the discontinuous case, many problems are algorithmically solvable in some weaker—but still physically meaningful—sense [7].

While some of these problems are algorithmically solvable, many of them are NP-hard, meaning that—unless P=NP—no feasible algorithm is possible that would always compute the exact solution to the corresponding problem; see, e.g., [5].

How to design efficient algorithms for solving the problems. In some cases, there already are algorithms for solving similar problems, but these algorithms only work under difficult-to-test assumptions. For example, many efficient algorithms rely on global assumptions about the problems, assumptions which—due to their global character—are difficult to check. It has been empirically determined that in many such cases, there is a version that only depends only on local (thus, easier-to-test) constraints. The paper [4] provides a general theoretical explanation of this result and a general algorithm transforming global constraint results into the corresponding local constraint ones.

In other cases, we do not have ready algorithms. In such cases, it is reasonable to see how we humans solve problems, and to borrow the corresponding ideas. This can be done on several levels: It can be done on the higher level, by simulating how we reason, or at a deeper biological level, by simulating how the brain works when we solve such problems.

On the reasoning level, one of the most efficient ways of how we humans solve problem is that we ignore unnecessary details and thus go to a certain level of abstraction. This is a trade-off: If we ignore too many important details, the solution becomes too far from optimal, but if we leave too many unnecessary details, the resulting requires too many computations; there needs to be an optimal level of abstraction. There is an empirical approach to finding such level, called similarity approach. The paper [16] provides a theoretical explanation for this approach.

On the biological level, it has indeed turned out to be computationally efficient to use neural networks, i.e., algorithms that emulate how our brain's neurons work. The paper [1] provides a theoretical explanation for this empirical success.

How to take uncertainty into account. The simplest type of uncertainty is an interval uncertainty, when instead of the exact value of a quantity x we only know its lower bounds $\underline{x}$ and its upper bound $\overline{x}$—i.e., the interval $[\underline{x}, \overline{x}]$ that contains this value.

Interestingly, interval uncertainty is in good accordance with how we often evaluate our experience: by only taking into account the largest possible value $\overline{x}$ and the last occurred value; the reasons behind such an evaluation are shown in [15]. Similarly, it turns that a good strategy in predicting the behavior of stock markets is to ignore its fluctuation and to only take into account its (local) minima and maxima; a theoretical explanation for such a strategy is given in [18].

In some situations, we only know the bounds on the quantities. In other situations, we know how these quantities depend on certain parameters—but we know the values of these parameters only with interval uncertainty. In particular, in control situations, the dynamics of a system is often described by a matrix whose dependence on several parameters is known, but for which the values of these parameters are only known with interval uncertainty [12] provides efficient algorithms for checking whether an important property like positive definiteness holds for all possible values if the corresponding parameters.

In addition to the interval of possible values, we may know the probabilities of different values within this interval (probabilistic approach) or, if we do not know these probabilities, the expert evaluations of how possible these values are (fuzzy approach).

In case of the probabilistic approach, one of the main problems is determining these probabilities. For the case of measurements, this problem is analyzed in [17].

For the case of fuzzy uncertainty, constraint optimization problems are analyzed in [10].

Known techniques of solving the corresponding problems are practically useful, but these techniques often involve making rather arbitrary choices that affect the result. For example, a known method of optimization under fuzzy constraints—proposed originally by L. Zadeh, the father of fuzzy logic, and by R. Bellman, a renowned specialist in optimization and control—strongly depends on the rather arbitrary selection of the unconstrained maximum. The paper [9] analyzed when the resulting solution does not depend on this selection.

Resulting applications. Papers presented in this volume include numerous applications, including applications:

- To control [12, 13]: how to take into account interval uncertainty,
- To economics [18]: how to predict stock market behavior,
- To environmental sciences and geosciences [3]: how to combine data of different types,
- To manufacturing [14]: how to optimally determine the production level.

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