
Preface

Distributed search by agents is an important topic of distributed AI and has not been treated thoroughly as such. While the scope of work on multi-agent systems has grown steadily over the last decade, very little of it has spilled into distributed search. In contrast, the constraints processing community has produced a sizable body of work on distributed constrained search. Paradoxically, a community that concentrates on search algorithms and heuristics has created a distributed model for agents that cooperate on solving hard search problems. Traditionally, this field has been named *Ditributed Constraints Satisfaction* and lately also *distributed constraints optimization*. The present book attempts to prompt deeper response from the MAS community and hopefully to give rise to cooperative work on distributed search by agents. In order to achieve this high goal, the book presents the large body of work on distributed search by constrained agents. The presentation emphasizes many aspects of distributed computation that connect naturally to multi-agent systems, especially measures of performance for distributed search algorithms and the impact of delays in communication.

Distributed Constraints Satisfaction Problems (*DisCSPs*) have been studied over the last decade, starting with the pioneering proposal by Makoto Yokoo [18]. The first distributed search algorithm for DISCSPs - Asynchronous Backtracking (ABT) - was first published in complete format in 1998 [64]. The first book on Distributed Constraints Satisfaction Problems has appeared as early as 2000 [61]. The book includes most of Yokoo's early work - distributed search algorithms, both complete and stochastic, and some experimental evaluation of the algorithms. It took five more years for the extensive form of *ABT*, including three well-defined versions and a correctness proof, to be published. In total, 10 years elapsed between Yokoo's original proposal of Asynchronous Backtracking, to the final extended form in the AI Journal in 2005 [9]. This gives a clear demonstration of the intricacies of distributed search algorithms, which form the heart of the field and of the present book.

In the last six years, since the year 2000, the community of researchers in the field have had at least one yearly workshop. These activities have helped the field mature into one of the recognized disciplines of both Constraints Processing (CP) and Multi-Agent Systems (MAS). In fact, the yearly workshops have been taking place alternately within the CP conferences and the AAMAS conferences (and the general AI conference, IJCAI). The series of Distributed Constraints Reasoning (DCR) workshops served as the forum for a community of more than 50 researchers worldwide and has published more than 20 papers yearly on DISCSP.

The field of distributed constraints search now includes two main families of problems - Distributed Constraints Satisfaction Problems DISCSPs and Distributed Constraints Optimization Problems (DISCOP)s. With the rapid rate of published work on DISCSPs and DISCOPs a book is very much needed, to present in detail the accumulated body of work of all researchers. While preparing my tutorial talk for CP-2004 in Toronto, I first noticed that a short presentation of the field must include three parts. These three parts form the backbone of this book. The first and most important part introduces in great detail search algorithms for DISCSPs and DISCOPs. Quite a number of search algorithms have been proposed in recent years for both DISCSPs and DISCOPs and an in-depth exposition of all algorithms is long overdue. The algorithmic part of the exposition has also grown to include ordering heuristics. Both asynchronous heuristics and sequential ones have appeared in the DISCSP literature in the last three years. Asynchronous heuristics are accompanied by an innovative algorithm that enables *ABT* to include dynamic ordering of agents [74].

The second part of the presentation of Distributed Search by Constrained Agents includes a comprehensive study of distributed performance measures for all algorithms. Based on the resulting coherent and asynchronous scale of performance, an extensive experimental evaluation can be constructed. In the present book this part is in Chapter 10 and Chapter 11.

The third part of our presentation of current research on DISCSPs and DISCOPs relates to their inherent distributed nature and addresses potential problems. These can relate to potential delays in communication, or to a variety of other agent topics, such as privacy of information used during search. This book addresses communication problems like message delays in detail in Chapter 12 and measures the impact of delays on the performance of families of DISCSP search algorithms in Chapter 13. The first few steps in the direction of privacy preservation have been taken in the last four years, for example, investigating means of preserving privacy [10, 42]. However, this topic is left for a later addition when more work will have accumulated.

The book starts by describing the problems and by giving motivation for their great usefulness in today's distributed world. In order to solve DISCSPs one needs distributed search algorithms. The first asynchronous algorithm in the field was introduced a decade ago by the pioneering work of Makoto Yokoo [62, 64]. The asynchronous backtracking algorithm (ABT) is presented

in its modern form, as in [9]. *ABT* continues to be a central DisCSP search algorithm and will be used in two forms in the book, first, as a reference for all performance evaluations of other algorithms, second, as a basis for enhancement, regarding ordering heuristics.

The distributed nature of the search problem that is at the center of this book makes it a natural selection for a graduate course on this topic. Distributed search algorithms that are run by all agents and find a global solution can serve as a solid demonstration for distributed AI and multi-agent systems (MAS). A short introduction on Constraints Satisfaction Problems is needed, perhaps a bit more extensive than the one given in the first chapter. Part of the material in this book has been presented by me in the graduate course on Constraints Processing that I have been giving over the last four years in both my department at Ben-Gurion University and at the computer science department of the Open University. Emphasizing the distributed nature of DisCSP algorithms I have routinely focused all final projects of the students on my course on implementing and investigating distributed search algorithms.

This book focuses on the main research results in distributed constraints satisfaction and optimization over the last decade. Thus it can serve as a research asset to researchers and to graduate students that focus on distributed search by agents and in particular on DisCSPs and DISCOPs. It is my hope that this complete text can serve as a basis for a course on distributed search in AI. I believe that the accumulated work on search by constrained agents is an excellent algorithmic and clearcut example of the cooperation of agents in search.

The present book is the result of six very intensive years of research with my wonderful group of graduate students. My sincere thanks go to all of them, without whom the great research on Distributed Constraints would have not been possible. My deepest thanks to my students - Amir Gershman, Arnon Gilboa, Eliezer Kaplanski, Oz Lavee, Michael Orlov, Igor Razgon, Moshe Zazon, and Roie Zivan. The theses of Oz, Michael, and Amir have also been used extensively within the text of the relevant chapters. The chapter on *ADOPT* (Chapter 15) is completely taken from Amir's thesis. The extensive study and wonderful implementations of *ADOPT* by Amir have made him in my eyes the world's expert on the *ADOPT* algorithm. The contents of the outstanding thesis of Roie Zivan (which is still not written) are present in most of the book, from our papers on search algorithms (Chapter 6, Chapter 7), through our work on concurrent performance measures (Chapter 10), and to his brilliant work on asynchronous ordering heuristics (Chapter 9). I look back in appreciation on the great research road we have covered together and in excitement on what's yet to come.



<http://www.springer.com/978-1-84800-039-1>

Distributed Search by Constrained Agents
Algorithms, Performance, Communication
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2008, XX, 216 p., Hardcover

ISBN: 978-1-84800-039-1