Foreword

Planning, constraints, agents, and interactive gaming in a dynamic environment – four areas that make for an exciting research challenge. These are the areas chosen by Alexander Nareyek for his Ph.D. thesis work, his work on the EXCALIBUR agent's planner, and the basis for the materials in this book. Future intelligent systems will work with other intelligent systems (people and machines) in open, dynamic, and unpredictable environments, and the ability to interleave sensing, planning, and execution for an agent will become an increasingly important topic.

Representing and reasoning about the constraints on activity or behavior in a domain is a powerful paradigm, which is useful in so many ways. It is especially useful when working in dynamic environments alongside other human and computer agents all with their own tasks, capabilities, and skills, which may be teamed and cooperatively deployed, or which may oppose one another. Such environments can only be partially modeled and there is much uncertainty to be coped with. Interactive gaming is a fertile area for finding ways in which to develop, test, and even deploy some of these powerful ideas.

Powerful and extendible ways to perform local reasoning and constraint management while retaining the global perspective to guide the search allows for a whole range of techniques which can be adapted to and scaled up to realistic applications. The methods can allow for the use of special purpose reasoners or constraint solvers for some of the constraint types. Yet the methodology allows for a coherent overview to be maintained.

I had the pleasure of working with Alex as part of his organizing team for the Workshop on Constraints and Planning at the National Conference of the American Association of Artificial Intelligence in 2000 (AAAI-2000). This workshop brought together a number of researchers who are seeking to mate planning technology developed in AI over some years, with the most powerful new techniques emerging from constraint satisfaction approaches. Alex's own work, reported in this book, is a key contribution to this important symbiosis. It could lead to much more realistic ways to employ planning and constraint satisfaction methods together for a range of tasks.

The work in this thesis also offers a basis to support multiple agents working in a dynamic mixed-initiative manner. This will require the representation of shared knowledge about tasks, behaviors, and plans, and local reasoning with this knowledge to allow for agents to perform their roles. Constraints on behavior offer a basis for such shared knowledge to support inter-agent activity.

The themes described in this thesis are at the very heart of AI approaches to planning, scheduling, and inter-agent communication and cooperation – the very stuff of Intelligent Systems.

Prof. Austin Tate, University of Edinburgh

Preface

Autonomous **agents** have become a key research area in recent years. The basic agent concept incorporates proactive autonomous units with goal-directed behavior and communication capabilities. These properties are becoming increasingly important, given the ongoing automation of human work. Users do not have to specify *the way* something is to be executed but rather *the goal* that is to be achieved. A reasonable way to pursue these goals must be found by the agents themselves. The agents do not have to act individually but can cooperate and perform coordinated group actions. Applications in electronic commerce, industrial process control, and the military sector are only the precursors of numerous forthcoming applications.

This book focuses on autonomous agents that can act in a **goal-directed** manner under **real-time constraints** and with **incomplete knowledge**, being situated in a **dynamic environment** where **resources may be restricted**. The real-time requirement means that an agent must be able to react within a small upper bound of response time, like milli- or microseconds. This is very important in dynamic environments, in which the agent must take external events into account. In addition, the agent's knowledge may be incomplete in many ways. Our main concern will not be with nondeterminism, i.e., different possible outcomes of actions; instead we will focus on the system's ability to handle a partially observable environment, i.e., where the closed-world assumption does not hold and a potentially infinite number of objects exist. Furthermore, the agent's actions may be constrained with respect to various resources, like food, energy, or money, and an agent may have optimization goals related to these resources. To satisfy these high requirements, this book enhances and combines paradigms like **planning**, **constraint programming,** and **local search**.

The application domain of this work is **computer games**, which fit the problem context very well since most of them are played in real time and provide a highly interactive environment where environmental properties are constantly changing. Low-level environment-recognition problems – like the processing of visual information and the spectrographic analysis of a noise – can be ignored, given the high-level environment information from the game engine, and the domain is variable enough to model all kinds of problem examples. In addition, these techniques are in great demand by the computer-games industry. This book therefore represents a useful combination of scientific contributions and application demands.

Chapter 1 elaborates the research subject, describes previous approaches, compares them, and draws conclusions for the techniques applied. The main contributions of this book are presented in Chapters 2 to 4.

To realize a declaratively formulated and efficiently executable search for an agent's behavior plan, the framework of constraint programming is applied as the basic paradigm throughout the book. Since dynamics and real-time computation must be supported, a combination of constraint programming with local search is developed in Chapter 2. An inclusion of domain-dependent knowledge to guide and accelerate search is achieved by so-called global constraints. These techniques form the basis for the real-time computation of an agent's behavior, while preserving the properties of declarativeness and variable applicability.

The problem of reasoning about an arbitrary number of objects in an agent's world and about an arbitrary structure of an agent's plan is tackled in Chapter 3. The framework of constraint programming is not normally designed for this purpose and is therefore enhanced by adding the ability to handle problems in which the search for a valid structure is part of the search process. The concept is combined with the local-search approach treated in Chapter 2. The techniques described in Chapter 3 establish the basis for ensuring that the search for an agent's plan can be carried out free from restrictions, like considering only a predefined number of objects in the world, and make it possible to guide the search toward interesting features, such as the optimization of resource-related properties.

The concepts and techniques treated in Chapters 2 and 3 were not specifically designed for the planning domain only and are applicable to a whole range of other domains such as configuration and design. Chapter 4 applies them to an agent's behavior planning, introducing the agent's planning model. The model focuses on resources and also allows a limited handling of an agent's partial knowledge.

The interplay of all parts – the realization of an autonomous agent – is demonstrated in Chapter 5. Some general solving heuristics are presented and applied to the Orc Quest problem and variations of the Logistics Domain. Real-time computation, a plan property's optimization, and the handling of dynamics are demonstrated.

The material presented here is part of the EXCALIBUR project[1] and is largely based on the publications [127] to [136]. More information on the EXCALIBUR project is available at:

`http://www.ai-center.com/projects/excalibur/`

[1] Please note that there is no relation to Brian Drabble's Excalibur planner [43].

Acknowledgments

I should like, first of all, to thank Professor Stefan Jähnichen for his general help and his support in context with the postgraduate course Communication-Based Systems. My thanks also go to the other professors involved in the postgraduate course and to the German Research Foundation (DFG) for providing the enhanced Ph.D. scholarship. The heated discussions in the postgraduate course were most helpful, the course's heterogeneous composition often forcing me to look at my work from another perspective.

My work greatly benefited from the collaboration with the planning & optimization department at the GMD-FIRST institute. The head of this department, Professor Ulrich Geske, supported me in every possible way, and I had many fruitful discussions with members of the department, e.g., Ulrich John and Dr. Armin Wolf – to mention but a few. The GMD-FIRST has a very pleasant work atmosphere, and I enjoyed a great deal of freedom in my research. I was also able to use the institute's very fine infrastructure and was provided with funding to attend conferences. These conference visits proved a highly positive experience, and I would advise every Ph.D. student to take advantage of such opportunities.

The detailed documentation of my work in the Internet drew an unexpectedly large resonance, and I wish to thank everybody that offered comments and suggestions on the Excalibur project's presentation.

Many of the reviewers of the papers on which this thesis is based offered valuable suggestions. In fact, in a sudden burst of opportunism, I decided to confine the rather humorous style to Sect. 1.3.2 because a reviewer of a paper that included an earlier version of this section "hated" the "writing style", and I don't want to put off solemn characters.

I am indebted to a great many other people for helping me while I was writing this thesis, too many to list them all. However, I wish to especially thank Dr. Gabriele Taentzer for help on algebraic graph grammars; Professor Eugene C. Freuder and Richard Wallace for providing me with the DIMACS travel grant, and Excalibur's commercial partners for their support of the project, which was closely related to my Ph.D. studies. My special thanks go to Andreas Graf of Cross Platform Research Germany, Nicolas A. L. Cosio of NICOSIO, and Johann Lotter of Conitec Datensysteme GmbH. In addition, many people helped me with practical and administrative matters such as organizing workshops related to the subject of my thesis. Many thanks to all of these!

Finally, I wish to express my gratitude to Professor Steve Chien and Professor Bernhard Nebel for acting as external reviewers, to Philip Bacon for polishing up my English, and to our system administrator Roger Holst for supporting my numerous test runs.

March 2001 Alexander Nareyek

Constraint-Based Agents
An Architecture for Constraint-Based Modeling and Local-Search-Based Reasoning for Planning and Scheduling in Open and Dynamic Worlds
Nareyek, A.
2001, XIV, 186 p., Softcover
ISBN: 978-3-540-42258-7