AI Magazine Volume 13 Number 1 (1992) (© AAAI)

A Predictive Model for Satisfying Conflicting Objectives in Scheduling Problems

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The economic viability of a manufacturing organization depends on its ability to maximize customer services; maintain efficient, low-cost operations; and minimize total investment. These objectives conflict with one another and, thus, are difficult to achieve on an operational basis. Much of the work in the area of automated scheduling systems recognizes this problem but does not address it effectively. The work presented by this Ph.D. dissertation was motivated by the desire to generate good, cost-effective schedules in dynamic and stochastic manufacturing environments (Berry 1991).[1]

Experimental analysis is used to illustrate…the PCP approach within an advanced scheduling architecture.

It is argued that to achieve the required balance between objectives, a scheduling system must have the ability to relate the consequence of a decision to the satisfaction of overall objectives. The dissertation introduces the concept of a preference capacity plan (PCP) in an attempt to give automated schedulers this ability. PCP takes cognizance of both predicted demand for capacity and the interactions that exist between scheduling objectives.

Experimental analysis is used to illustrate the power, versatility, and practicality of the PCP approach within an advanced scheduling architecture. In conclusion, it is argued that by reasoning about the satisfaction of global objectives during the scheduling process, solutions of a consistently high quality can be produced.

The Scheduling Problem

Chapter 1 of the dissertation defines the problem of scheduling and, in particular, job shop scheduling. It describes the difficulties inherent in scheduling: its combinatorial explosiveness (Karp 1975), the conflicting nature of the requirements for a good schedule (Kivenko 1981), and the stochastic and dynamic nature of the scheduling environment (Graves 1981). It identifies a specific problem area within the scheduling domain and proposes an approach to its solution.

Scheduling in a manufacturing environment is subject to a wide variety of constraints. Many of these constraints relate to the satisfaction of *organizational goals*, that is, objectives that determine the economic viability of the manufacturing organization. For example, meeting due dates relates directly to the provision of good customer services, increasing productivity has more in common with maximizing return on investment, and the control of work-in-process (WIP) levels helps to maintain low-cost operations. As is explained in chapter 1, the three main objectives of a manufacturing facility (good customer services, low-cost operations, and maximum return on investment) are inherently incompatible. To remain economically competitive, a manufacturer must achieve a balance between these goals. A scheduling system must also consider the interactions that exist between these global constraints and must be capable of reasoning about their satisfaction to produce an efficient schedule.

The contributions of the work presented in this dissertation are a predictive model that can be used to represent the likelihood that management objectives will be met by the schedule and the mechanisms required to exploit the knowledge contained within this model. The advantages of such a predictive model are the control of the quality of schedules produced in a dynamic environment and increased search efficiency resulting from improved decision-making capabilities.

Scheduling and Reasoning with Uncertainty

The second chapter of the dissertation presents a three-part review of work relating to the domain of scheduling and techniques relating to informed decision making. The first section presents scheduling and sequencing theory. It includes methods and algorithms derived from the fields of operations research and management science. The second section describes a more recent development in the area of manufacturing scheduling. Several systems have been built that use advances in knowledge representation and search methodologies stemming from the AI field. The most significant systems (Fox 1983; Le Pape 1985; Smith, Fox, and Ow 1986; Collinot, Le Pape, Pinoteau 1988; Elleby, Fargher, and Addis 1988; Burke and Prosser 1989) are described, and both their strengths and weaknesses are explained. Particular emphasis is placed on their ability to cope with the multitude of conflicting, global objectives. The dissertation argues that the knowledge-based approach offers distinct advantages over the more traditional mathematically based algorithms, the main advantage being the ability to recognize that the environment is both stochastic and dynamic. However, none of the scheduling approaches, described in chapter 2, sufficiently addresses the problem of satisfying, simultaneously, the multitude of conflicting objectives that exist in all scheduling environments. A final third section explores the

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problem of intelligent decision making from the fields of probability theory and uncertainty theory. Recent advances in tackling the issue of uncertainty within knowledge-based systems are described (Pearl 1988; Cheeseman 1985), and particular emphasis is given to scheduling systems that have addressed the subject (Johnston 1989; Sadeh and Fox 1989). The chapter concludes with a restatement of the overall problem addressed by the dissertation.

The Preference Capacity Plan Approach

Chapter 3 presents the predictive approach proposed by the dissertation. A predictive model, PCP, is constructed. It is based on the argument that scheduling is basically a problem of resource contention.

Each resource has an individual PCP associated with it that represents the predicted demand for its capacity over time. The prediction accounts for preference constraints, including global preference constraints that indicate a desire to meet certain management objectives. In addition, it is designed to function in a dynamic environment, so any switch in management goals because of unexpected or extreme conditions can be reflected directly in the model. The construction process is described in full in chapter 3. Particular emphasis is placed on how the interobjective interactions are represented by PCPs, that is, how the interactions that exist between global preference constraints, such as meet due dates and minimize WIP levels, are built into the predictive model.

Chapter 3 also explains how the knowledge contained in the predictive model can be exploited within the scheduling process. It is argued that PCP can be used for several purposes: focus the attention of the scheduler onto the most highly constrained parts of the problem; contribute to decision making during the scheduling process by providing information about the likely satisfaction of objectives; supply information on the impact of a constraint relaxation; and, ultimately, improve the quality of schedules produced in a dynamic environment. All these functions are described in full, and their benefits or limitations within the scheduling process are explained.

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Test-Bed Scheduling Environments

In Chapter 4, a test-bed scheduling system is presented (Berry 1990). It was specifically designed to explore the capabilities of the PCP approach within a knowledge-based system. An empirical analysis is performed through a series of test sequences that are also described in this chapter. Finally, an analysis of the results is made and conclusions drawn. The test-bed system has a blackboard-based architecture that allows an opportunistic problem-solving approach to be adopted.

Chapter 5 presents a second test-bed system on which the PCP approach was implemented and evaluated. DAS (distributed asynchronous scheduling) is a distributed asynchronous scheduling system developed at the University of Strathclyde, Glasgow, Scotland, in a collaborative project with YARD Ltd. and ALCAN Plate Ltd. (Burke and Prosser 1989; Burke 1990; Prosser 1989). Its architecture and operation are briefly described in this chapter along with an in-depth explanation of how PCP was implemented and exploited within the DAS problem-solving mechanisms. Finally, a test-case analysis of the completed system is performed and the results described.

In both cases, the test results are shown to justify the argument made in chapter 3. They demonstrate that the PCP approach is effective in maintaining a balance in the satisfaction of management objectives. In particular, test results from the blackboard scheduler, which exhibits a clear control structure, illustrate the effectiveness of PCP in controlling schedule quality and search efficiency. Similarly, the clear benefit of using the PCP approach in the asynchronously controlled DAS system is shown in its power to maintain a consistently high-quality solution despite a highly dynamic environment.

Conclusions

The work presented in this dissertation was motivated by a desire to improve the quality of schedules produced in manufacturing environments. Determining the quality of a schedule is, in itself, a difficult problem. Ultimately, the success of a schedule can only be measured by the resulting economic success of the manufacturing organization and, therefore, is tied to many other aspects of the manufacturing process. However, there are some basic, though conflicting objectives that any organization would like to achieve through effective scheduling of its production process. It is argued that to achieve the required balance between these objectives, the scheduler must have the ability to relate the consequence of a scheduling decision to the satisfaction of global objectives. This problem is extremely complex and involves reasoning in an uncertain environment about the interactions that exist between such objectives as well as the more fundamental issues of interorder and intraorder interactions. The dissertation argues that by reasoning about the satisfaction of global objectives at the detailed scheduling level, the search can be guided toward producing more efficient results. To reason about the global implications of a decision, the scheduler must have access to a high-level and accurate view of the current scheduling problem.

The use of the PCP approach has four main aims within an incremental scheduling methodology:

The first aim is to satisfy the requirement for a high-level, or global, view of the problem. PCP is maintained dynamically to ensure the information is accurate and up to date.

The second aim is to focus the scheduling effort to increase search efficiency. Information extracted from PCP can be used to identify the most constrained parts of the problem from which the problem-solving effort should commence.

The third aim is to influence scheduling decisions and, therefore, maintain a balance between the satisfaction of global objectives. Both resource allocations and start-time assignments can be controlled by information from PCP that reflects a desire to produce a quality solution.

The fourth aim is to resolve conflict situations by assessing the impact of relaxation alternatives.

In conclusion, the work shows that by reasoning about the satisfaction of global objectives during the scheduling process, solutions of a consistently high quality can be produced. This process was enabled by the development of a predictive model that is based on the demand for capacity and also includes knowledge of the interactions that exist between scheduling objectives. However, it should be noted that there will still be a tradeoff to consider between computationally expensive predecision analysis and search efficiency in highly reactive environments.

Acknowledgments

This work benefited greatly from the support and guidance of J. T. Buchanan, K. Currie, R. Desimone, and N. Kay. The work was funded by the National Engineering Laboratory in East Kilbride, Scotland, under the Extramural Research Assistant Scheme.

Note

1. For information on obtaining a copy of this Ph.D. dissertation, contact the Department of Computer Science, University of Strathclyde, Livingstone Tower, 26 Richmond Street, Glasgow, G1 1XH, Scotland, United Kingdom. Telephone: (44) 41-552-4400. Fax: (44) 41-552-5330.

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AAAI-91

Proceedings of the Ninth National Conference on Artificial Intelligence

American Association for Artificial Intelligence, July, 1991. Anaheim, California

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