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Application of reinforcement learning for agent-based production scheduling

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Abstract

Reinforcement learning (RL) has received some attention in recent years from agent-based researchers because it deals with the problem of how an autonomous agent can learn to select proper actions for achieving its goals through interacting with its environment. Although there have been several successful examples demonstrating the usefulness of RL, its application to manufacturing systems has not been fully explored yet. In this paper, *Q*-learning, a popular RL algorithm, is applied to a single machine dispatching rule selection problem. This paper investigates the application potential of *Q*-learning, a widely used RL algorithm to a dispatching rule selection problem on a single machine to determine if it can be used to enable a single machine agent to learn commonly accepted dispatching rules for three example cases in which the best dispatching rules have been previously defined. This study provided encouraging results that show the potential of RL for application to agent-based production scheduling.

Keywords: Reinforcement learning; *Q*-learning; Dispatching rule selection

1. Introduction

1.1. Manufacturing scheduling

A long and profitable life is every enterprise's goal. For a manufacturing enterprise, to maintain profitability requires that they continually excel in converting raw materials into value-added products that meet the customers' needs. This conversion procedure consists of a set of complicated and interrelated activities such as designing, planning, production, inventory control, quality assurance, etc. To remain competitive in the market, manufacturers must focus on continually improving their processes. Production scheduling that translates the detailed process plans into the shop floor schedule is one of the most important processes in manufacturing systems. A good production schedule can provide such benefits as increased shop throughput, enhanced customer satisfaction, lower inventory levels, and increased utilization of resources. Therefore, there is a great need for good scheduling strategies.

Scheduling problems essentially involve completing a set of jobs with a limited number of manufacturing resources under a number of constraints to optimize a particular objective function. These problems are known to be hard and usually belong to the NP-complete class of problems (Morton and Pentico, 1993; Pinedo, 1995). Research in production scheduling has been conducted for many decades and a large number of algorithms and heuristics have been developed for various scheduling problems. A scheduling problem consists of three components: a machine environment, specific job characteristics, and one or more optimality criterion (Brucker, 2001). The machine environment represents

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the type of the manufacturing system that will execute the developed schedule. The manufacturing system may be a job shop system, flexible manufacturing system (FMS), cellular manufacturing system, transfer line, etc. Job characteristics represent such factors as the number of operations, the precedence relations among operations, and the possibility of preemption (whether the job can be split). Optimality criteria are the objectives to pursue when scheduling the jobs. Common objectives include minimizing makespan, mean flow time, mean lateness, the number of tardy jobs, and mean tardiness. All the three components mentioned above specify the variety and complexity of each scheduling problem.

A scheduling problem may be comprised of two subproblems: job routing and job sequencing problems. A job routing problem involves assigning the operations of jobs to the specific machines. Such problems result from the allowance of routing flexibility. Routing flexibility depends on the capability of the machines. A versatile machine is capable of performing different operations. The versatility of the various machines in a shop essentially supports the possibility for the existence of alternative process plans for a job. Routing flexibility is a key issue that has increasingly attracted attention in modern manufacturing systems. A FMS, which consists of a set of computer numerically controlled machines (CNC) linked with an automated material handling system, is a computerized system that is able to produce mid-volume and mid-variety products with high levels of efficiency. The FMS provides routing flexibility due to the capability of NC machines.

Once the route of a job is specified, decision makers must determine the production sequence of the jobs awaiting their next process in the machine queue. That is a job sequencing problem. A simple approach to such problems is to adopt dispatching rules. A dispatching rule is a priority rule used to determine the order in which the jobs waiting in the machine queue are to be processed as soon as a machine becomes available. Dispatching rules are useful for finding a reasonably good schedule. The dispatching rules are attractive because of their simplicity and ease of implementation. A variety of dispatching rules have been proposed in recent decades, with Panwalkar and Iskander (1977) identifying the existence of more than 100 distinct rules. Scheduling in industry may require meeting several objectives simultaneously. However, a dispatching rule often favors one performance measure only at the expense of other performance measures. In addition, the manufacturing environment usually changes over time. Therefore, the specific dispatching rule employed in such a dynamic environment should be free to change as well.

One of the most notoriously difficult systems for the scheduling community is the job shop system. The strategy of a job shop is based on producing a wide variety of products in very low volumes. Specific customer orders are commonly produced in the job shop manufacturing system. Producing such variable products requires different sequences. In a traditional job shop layout, machines are functionally grouped together. For the case of an actual shop floor, uncertainties (i.e., machine breakdowns, material or tool shortages, transportation delays, etc.) complicate the scheduling problem making it more difficult to solve. Therefore, several assumptions are usually made to simplify the problem (i.e., resources are always available, all the jobs are known in advance, all the operation processing times are known and constant, transportation times are ignored, etc.). However, application of too many such assumptions may result in the treatment of scheduling problems that would be considered unrealistic. That is why the job shop scheduling problems have attracted so much attention over many decades.

1.2. Agent-based approach

Due to the structural rigidity of classical centralized control architectures in manufacturing, the decentralized (or heterarchical) control structure has drawn more attention (Crowe and Stahlman, 1995; Dilts et al., 1991; Duffie and Prabhu, 1994). One of the most important properties of the heterarchical structure is that the decision-making responsibilities are fully distributed to each component of the system. Each component is autonomous and possesses local knowledge that is sufficient to accomplish its own task. The task that a single component is unable to finish alone may require the cooperation of a cluster of components. Communication is a means of establishing such cooperation between the autonomous components. Under the guidance of such a control architecture, the requirements of the next generation of manufacturing systems, such as good fault-tolerance, ease of reconfigurability and adaptability, and agility, can be achieved (Shen and Norrie, 1999).

In recent years, a new paradigm called agent technology has been widely recognized as a promising paradigm for developing software applications able to support complex tasks. From the perspective of a software application, an agent can be viewed as a computational module that is able to act autonomously to achieve its goal (Weiss, 1999; Brenner et al., 1998). A general definition of the software agent is "An agent is a computer system module, capable of acting autonomously in its environment in order to meet its design objectives" (Shen et al., 2000). Wooldridge and Jennings defined an intelligent agent as a hardware or software-based computer system with the properties such as autonomy, social ability, reactivity and pro-activeness (Murch and Johnson, 1998). The idea of agent-based approaches has also offered a promising solution for