Asynchronous Weak-commitment Search for Solving Large-Scale Distributed Constraint Satisfaction Problems

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A distributed constraint satisfaction problem (Distributed CSP) (Yokoo *et al.* 1992) is a constraint satisfaction problem in which variables and constraints are distributed among multiple agents. Surprisingly a wide variety of AI problems can be formalized as CSPs. Similarly, various application problems in DAI which are concerned with finding a consistent combination of agent actions (e.g., distributed resource allocation problems, distributed scheduling problems, and multiagent truth maintenance tasks) can be formalized as Distributed CSPs. Therefore, we can consider a Distributed CSP as a general framework for DAI, and algorithms for solving Distributed CSPs as an important infrastructure in DAI.

The author has developed a basic algorithm for solving Distributed CSPs called *asynchronous backtracking* (Yokoo *et al.* 1992), in which agents act asynchronously and concurrently based on their local knowledge without any global control.

In this work, we develop a new algorithm called *asynchronous weak-commitment search*, which is inspired by the weak-commitment search algorithm for solving CSPs (Yokoo 1994). The main characteristic of this algorithm is as follows.

- A bad decision can be revised without an exhaustive search by changing the priority order of agents dynamically

In the asynchronous backtracking algorithm, the priority order of agents is determined, and an agent tries to find a value satisfying the constraints with the variables of higher priority agents. When an agent sets a variable value, the agent commits to the selected value strongly, i.e., the selected value will not be changed unless an exhaustive search is performed by lower priority agents. Therefore, in large-scale problems, a single mistake of value selection becomes fatal since doing such an exhaustive search is virtually impossible.

On the other hand, in the asynchronous weak-commitment search, when an agent can not find a value consistent with the higher priority agents, the priority of the agent is changed so that the agent has the highest priority. As a result, when an agent makes a mistake in value selection, the priority of another agent becomes higher; thus, the agent that made the mistake will not commit to the bad decision, and the selected value will be changed.

	asynchronous backtracking		min-conflict only		asynchronous weak-commitment	
n	ratio	cycles	ratio	cycles	ratio	cycles
10	100%	105.4	100%	102.6	100%	41.5
50	50%	662.7	56%	623.0	100%	59.1
100	14%	931.4	30%	851.3	100%	50.8
1000	0%	—	16%	891.8	100%	29.6

Table 1: Required Cycles for Distributed N-queens

The experimental results on various example problems show that this algorithm is by far more efficient than the asynchronous backtracking algorithm, in which the priority order is static. Table 1 shows the result on the distributed n-queens problem for asynchronous backtracking, asynchronous backtracking with the min-conflict heuristic (Minton *et al.* 1992), and asynchronous weak-commitment search. The required cycles, and the ratio of trials in which a solution is found within 1000 cycles are shown.

The priority order represents a hierarchy of agent authority, i.e., the order of decision making. Therefore, these results imply that a flexible agent organization, in which the hierarchical order is changed dynamically, actually performs better than an organization in which the hierarchical order is static and rigid.

References

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