Theoretic Study of Distributed Graph Planning

(Extended Abstract)

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ABSTRACT

In situations where it needs the actions of different agents to accomplish a task, the planning for the task involves selecting and organizing the actions belonging to multiple agents. Most existing multi-agent planning approaches to solving such a planning problem rely on the global knowledge of the capabilities of the agents, and are confronted with difficulties when the availability of the global knowledge is impossible or undesirable. Previously, we have proposed a distributed multi-agent planning algorithm *Dis-graph planning* to address the difficulties, which enables multiple agents to cooperate in generating a plan without relying on the global knowledge. In the work of this paper, we performed a theoretical study of Dis-graph planning approach, discussing its critical features such as completeness, soundness and terminability.

Categories and Subject Descriptors

I.2.8 [**Problem Solving, Control Methods, and Search**]: Plan execution, formation, and generation; I.2.11 [**Distributed Artificial Intelligence**]: Multiagent systems

General Terms

Algorithms

Keywords

multi-agent planning, distributed planning graph

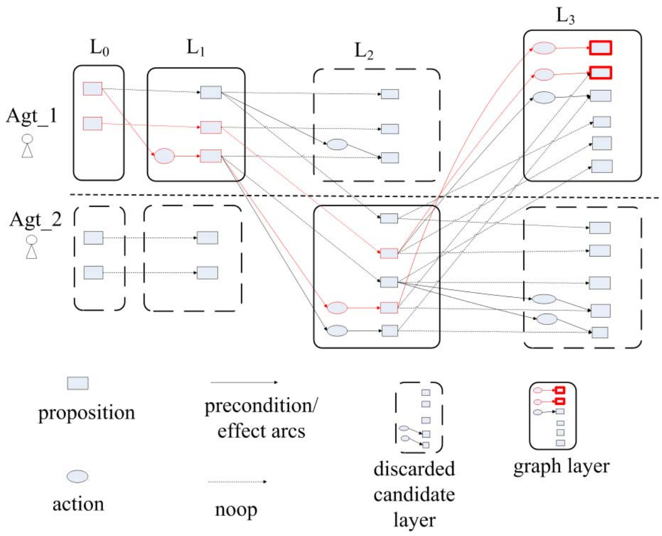

Figure 1: An example of Dis-graph

1. INTRODUCTION

In many real world scenarios, a complex task is often beyond the capability of a single agent. It requires multiple agents to cooperate with each other to accomplish the task. Planning for such a task involves the selection and organization of actions belonging to multiple agents.

Most existing approaches to solving a multi-agent planning problem fall into two categories [3] [2]. The first is centralized planning for multiple agents, where one agent is authorized to use multiple agents' actions to generate a plan in a centralized manner. The second follows the divide-and-conquer style, where a domain expert or an algorithm analyses the task and the actions of the agents, and decomposes the problem into sub-problems, so that the sub-problems can be solved by individual agents. Both of these approaches rely on the global knowledge of the capabilities (actions) of the agents, either for performing centralized planning or for performing problem decomposition. They are confronted with difficulties when the availability of the global knowledge is impossible or undesirable. This is especially true in dynamic and complex environments such as Service Oriented Computing (SOC)[5], where agents are not willing to reveal all information due to the concerns such as privacy and autonomy.

We have proposed Dis-graph planning [6] [7], which is an distributed variation of Graphplan [1] and enables agents to cooperate in planning without the reliance on the global knowledge. In this paper, we provide a theoretical analysis of Dis-graph planning approach.

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2. OVERVIEW OF DIS-GRAPH PLANNING

Dis-graph is a distributed variation of the traditional planning graph proposed by Blum et. al [1]. Unlike the planning graph that is constructed by one agent, Dis-graph is constructed by multiple agents, as illustrated in Fig 1. In the beginning, each agent constructs L_0 in its local memory according to the given initial state. Each layer following that is constructed in two steps. Firstly, each agent constructs a *candidate layer* in its local memory with its actions. Secondly, the agents select one agent's candidate layer as *graph layer*. The agent owning the selected candidate layer marks the selected layer as graph layer, whilst the other agents discard their candidate layers.

Plan extraction is interleaved with the construction of Dis-graph. Plan extraction can be performed by distributed backtracking, or by mapping the Dis-graph into a DisCSP and solving the DisCSP [7].

3. PROPERTIES OF DIS-GRAPH

A Dis-graph is different from a traditional planning graph in that, whilst a layer in a traditional planning graph includes all applicable actions in the domain, a layer in a Dis-graph includes the applicable actions of one agent. This results in differences in the construction of the graph and the termination conditions of the planning, as described below.

Whilst a traditional planning graph has a *fixed-point* [4], in a Dis-graph we need to distinguish two types of fixed-points: *interim local fixed-point* and *global fixed-point*.

DEFINITION 1. *Interim Local Fixed-point:*
An interim local fixed-point *of agent Agt is a graph layer k such that the candidate layer constructed by Agt has the same propositions and proposition mutexes as graph layer k.*

DEFINITION 2. *Global fixed-point*
The global fixed-point is a graph layer k where k is the smallest number such that for $\forall l > k$, graph layer l has the same propositions and proposition mutexes as graph layer l.

Theoretical analysis shows that:

- Every agent Agt has at least one interim local fixed-point in a Dis-graph.
- There is a *global fixed-point* for a Dis-graph. The *global fixed-point* is the first graph layer that all agents have it as an *interim local fixed-point*.

We define a certain group of layers after global fixed-point as a *super-state*.

DEFINITION 3. Super-state
A super-state *is a finite sequence of graph layers after the global fixed-point k such that, if the candidate layer generated by an agent Agt after global fixed-point contains non-$NOOP$ actions, then at least one graph layer in* super-state *is the candidate layer of Agt.*

When selecting a candidate layer as a graph layer, the agents must follow the following rules:

- Before the global fixed-point layer k is reached, the agents avoid selecting the candidate layers of agents at their interim local fixed-points;
- After the global fixed-point layer k is reached, the agents repeat selecting candidate layers with non-$NOOP$ actions one by one, i.e. repeat the *super-state*.

The termination conditions in traditional graph-based planning (Graphplan [1]) can not be applied to Dis-graph planning directly. Dis-graph planning terminates on one of the two modified termination conditions:

- **Termination Condition 1**: reaching the *global fixed-point* L_k before all goal propositions are present in a graph layer without being mutexes; or
- **Termination Condition 2**: after the *global fixed-point* L_k is reached, the size of the nogood set of L_k does not change with the expansion of q layers continuously, where q is the length of the *super-state*.

It can be proved that, by following the candidate layer selection rules and the termination conditions described above, Dis-graph planning is

- sound, i.e. the resulting plan is guaranteed to be a correct solution to the planning problem;
- complete, i.e. a plan is guaranteed to be found for a solvable problem;
- terminable, i.e. it is guaranteed to terminate on an unsolvable problem.

4. CONCLUSIONS

Dis-graph planning is a distributed multi-agent planning approach based on graph-based planning. In this work we performed theoretical analysis and proved that the Dis-graph planning approach is complete, sound and terminable. (The details of the analysis and the proving are not shown in this paper due to the limit of space.)

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