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Semantical Information Graph Model toward Fast Information Valuation in Large Teamwork

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Abstract. Sharing information is critical to large teamwork for cooperative decision making in dynamic and partially observable environments. To be effective, other than building a full information coverage, agents should valuate how a potential receiver could be benefited with a piece of given information. In this paper, we propose a fast valuation model with complex network based graph modeling and analysis, which help to indicate the information importance to a given information base. Similar to vague information valuation by humans, the key is that important information always significantly changes their complex information graph with its incorporation. Therefore, we calculate the semantic based value of this new information in a graph model and build a local graph evaluation algorithm to estimate information graph evolution, instead of performing expensive complete graph search. Although the decision may be not precise, similar to human communication, it is good enough to disseminate valuable information around the team.

1 INTRODUCTION

As a paradigm of distributed artificial intelligence, cooperative multi-agent systems are popular in various application domains including disaster response, anti-terrorism and planet exploration. In those systems, agents are required to complete tasks cooperatively to achieve the common goal. However, when the number of agents scales up, they are highly distributed and have to perform in a dynamic and partially observable environment. In this case, information sharing is critical for distributed agents to make rational decisions [1]. Although intensive studies have been carried out, state of the art fails to build practical algorithms for large-scale multi-agent systems, where agents are required to valuate how a potential receiver could be benefited from the given information with communication cost. With decision-theoretic approach, decentralized agents inherit the constraint of partial observability and their valuation falls within DEC-POMDP model, which is intrinsically NEXP-COMPLETE. Therefore, precise computation of information utilities is either infeasible or computational costly in a large system [2].

The information sharing problem in large teams can be modelled as follows. Decentralized agents have to make decisions about how to share information, based on their limited observations of the team. Due to their heterogeneities, not all agents in the system are interested in a given piece of information [3]. In this case, other than building full information coverage around the team, information sharing aims at ensuring agents get their desired information in a timely manner. For example, in city rescue domain, an agent driving the fire truck cares more about the city traffic condition than the news of finding a victim. Therefore, to effectively share information, agents have to estimate their teammates' information needs from their own knowledge.

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2 FAST INFORMATION MODEL

More generally, let agent a be the candidate receiver of information I, and $IB = \{I_1, I_2, ..., I_k, ...\}$ denotes its information base, which contains a set of information known or received by the agent a. Before a teammate decides whether to send information I to a, it has to figure out its importance to a. In this paper, we propose a novel fast valuation approach with information graph modeling and complex network based analysis, which help to indicate the information importance to a given information base. The roadmap of this approach is illustrated as Figure 1 and our research consists of two ways.

The first way is called analysis roadmap, which is shown with blue solid arrows in Figure 1. Its objective is to help us understand how humans can make fast and vague information valuation, so as to build a similar valuation process on a lightweight agent to estimate the information importance for their teammates. In this roadmap, similar to human information processing modeled as semantical connections in their mind, each information in a given information base can be abstracted as an edge of an information graph, where its terminologies are abstracted as ontological nodes and predicate is abstracted as a link between them. Because terminologies are always mentioned in several information and the edges representing these information are connected by common terminologies, the information base can be modelled as an interconnected graph shown in Figure 1.(a). However, when the information base expands, the graph becomes large as a complex network shown as Figure 1.(b). The objective of the information valuation is to find the importance of a new information when it is incorporated into given information base. From our analysis in Figure 1.(c), the information valuation equals to incorporate an extra edge representing the new information to the information graph.

The key innovation of this approach lies in our observation that people will think a piece of information is important because it can significantly change the structure of semantic connections in their mind. In an extreme case, if new information can connect two previously separated graphs formed by the information base into one interconnected unit, all the information is connected and humans will rate it with high priority [4]. According to this observation, we hypothesize that information importance can be measured by the changes of semantic distance between all information with the incorporation of new one. In this paper, we analyzed the semantic based information importance in graph theory and found it more likely to be determined by the nodes that are closer to this new edge. In this case, a local search algorithm is carried out to calculate the information value.

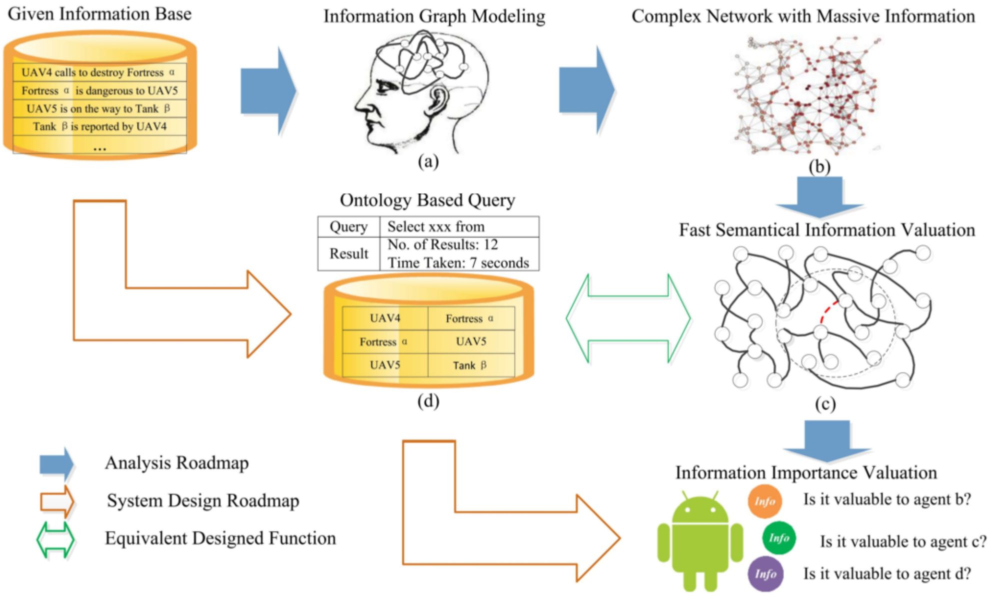

Figure 1. Methodology roadmap

Based on our design of local information graph search algorithm, we may jump to our system design roadmap. As the green hollow equivalent arrow shows, the local graph search can be transformed into a limited number of equivalent queries, which can be easily carried out in the information base in Figure 1.(d). Although the local graph search algorithm can be implemented on the information graph model, it is still resourceful to maintain such a large graph model in a lightweight agent. On the other hand, the equivalent queries can be implemented without building a memory costly large-scale information graph. Since no global database query is required at each time, the information valuation in our design can be performed fast in a lightweight agent module with a part of the concepts involved.

3 A CASE STUDY

To manifest the design above, we deploy our approach in a multi-UAV cooperative search domain. A group of UAVs are deployed in a given area to cooperatively search several targets. All UAVs could communicate with others to report their own speed, location, and the information about targets so as to achieve cooperative path planning in searching. When a target is detected, a piece of information is reported to help other UAVs to adjust their activities. For example, a UAV's information base could be illustrated as Figure 2.

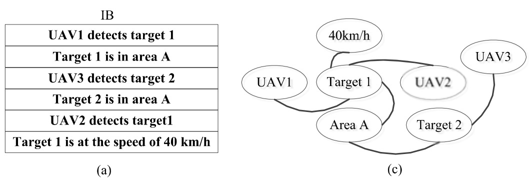

Figure 2. The information base of a UAV in cooperative search. (a) The information base. (b) Its graph representation.

When the team scales up, the amount of information increases very quickly and overwhelming information may be created to the UAV controllers. If only valuable information is presented to each UAV controller, the interface to the controllers is much helpful. Therefore, we ask 40 users to use the multi-UAV coordination interface to report

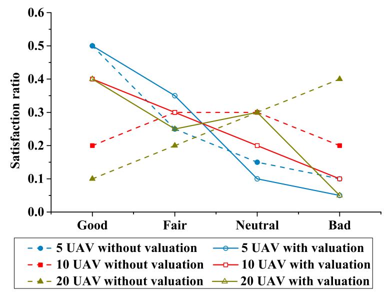

Figure 3. User experience satisfaction survey

their satisfaction about the information sharing. In our study, there are two groups. One is to use the interface with our approach, but the other is tested with all information shared. The user experience is categorized into four levels: good, fair, neutral and bad. According to the result shown in Figure 3, our fast valuation approach always helps to improve the user experience. In addition, when the number of UAVs scales up with huge amount of information created, our approach is more prominent on offering good user experiences.

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