Exclusivity-based allocation of knowledge

Madalina Croitoru, Sebastian Rudolph

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(Extended Abstract)

Madalina Croitoru
University of Montpellier 2
France
croitoru@lirmm.fr

Sebastian Rudolph
Karlsruhe Institute of Technology
Germany
rudolph@kit.edu

ABSTRACT

The classical setting of query answering either assumes the existence of just one knowledge requester, or the knowledge requests from different parties are treated independently from each other. This assumption does not always hold in practical applications where requesters often are in direct competition for knowledge. We propose a formal model for this type of scenario by introducing the Multi-Agent Knowledge Allocation (MAKA) setting which combines the fields of query answering in information systems and multi-agent resource allocation.

Categories and Subject Descriptors

K.6.0 [**Management of Computing and Information Systems**]: General—Economics

General Terms

Economics, Theory

Keywords

Auction and mechanism design

1. INTRODUCTION

Conjunctive query answering (between a knowledge requester and a knowledge provider) constitutes the de-facto standard of interacting with resources of structured information: databases or ontological information systems. The classical setting in query answering is focused on the case where just one knowledge requester is present. In case multiple requesters are present, the queries posed by different parties are processed and answered as independent from each other, thus making the multi-requester scenario a straightforward extension of the individual case.

While the above practice is natural in some cases, the assumption that queries can be processed independently clearly does not always hold in practical applications where the requesters are in direct competition for information. Let us consider for instance a multi-agent setting, with requester agents concurrently demanding information from a provider agent (example scenarios include military applications, news agencies, intelligence services, etc.). Of course, in this context, requester agents will not be willing to share "sensitive" information with other agents.

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A structurally related problem is the multi-agent resource allocation (MARA) setting [2]. However, in such a setting (i) the agents ask for resources (not knowledge) and (ii) agents *a priori* know the pool of available resources. Work in this field either aims at bidding language expressiveness or algorithmic aspects of the allocation problem (see for instance [5, 1, 4] and others). The notion of multiplicity of resources, or resources used exclusively or shared has also been recently investigated in a logic-based language [6].

In the proposed multi-agent knowledge allocation (MAKA) setting, the n requester agents, at some given time (in a single-step), ask for knowledge (and not resources). They express their requests in the form of conjunctive queries that are endowed with exclusivity constraints and valuations, which indicate the subjective value of potentially allocated answers. Knowledge allocation poses interesting inherent problems not only from a bidding and query answering viewpoint, but also in terms of mechanism design.

The aim of this paper is to motivate and introduce the novel problem of Multi-Agent Knowledge Allocation and lay down future work directions opened by this setting: increased expressivity, dynamic allocations, fairness, multiple providers etc.

2. QUERYING WITH EXCLUSIVITY CONSTRAINTS

In [3] we fully introduce our framework of exclusivity-aware querying as a basis for the MAKA bidding formalism. In the following, we will just provide an intuitive overview of this work by the means of an example. Consider the following predicates: actor, director, singer (all unary), marriage and act (binary) and five constants AJ (Angelina Jolie), BP (Brad Pitt), MMS (Mr. and Ms. Smith), JB (Jessica Biel), JT (Justin Timberlake). A *knowledge base* consists of ground facts such as:

actor(AJ)	director(AJ)	marriage(AJ, BP)
actor(BP)	singer(JT)	act(AJ, MMS)
actor(JB)		act(BP, MMS)

If we consider a set of variables $V = \{x, y\}$ and the set of constants $C = \{\mathtt{AJ}, \mathtt{BP}, \mathtt{MMS}, \mathtt{JB}, \mathtt{JT}\}$, then $\mathtt{actor}(x)$, $\mathtt{act}(y, \mathtt{MMS})$, $\mathtt{marriage}(\mathtt{AJ}, \mathtt{BP})$ are all *atoms* over the sets P and C.

Since in the MAKA scenario, requesters might be competing for certain pieces of knowledge, we have to provide them with the possibility of asking for an atom exclusively (exclusive) or not (shared). This additional information is captured by the notion of *exclusivity-annotated* atoms, ground facts and queries.

Some exclusivity-annotated atoms would for instance be: $\langle \mathtt{actor}(x), \mathsf{sh}\rangle$, $\langle \mathtt{marriage}(\mathtt{AJ}, \mathtt{BP}), \mathsf{exc}\rangle$ etc.

Note that the idea of exclusivity annotation is a novel concept going beyond the classical query answering framework. We assume an order exclusive $\succeq$ shared being used for query answering. It allows to specify concisely that an answer delivered exclusively is suitable for a knowledge requester who demanded that information shared (but not vice versa).

For example, a query asking exclusively for marriages between actors and directors (where only the "marriage" itself is required as exclusive information, but the "actor" and "director" knowledge is sharable with other knowledge requester agents) is:

$$\langle \texttt{marriage}(x,y), \textsf{exclusive}\rangle \wedge \big((\langle \texttt{actor}(x), \textsf{shared}\rangle \wedge \langle \texttt{director}(y), \textsf{shared}\rangle) \vee (\langle \texttt{actor}(y), \textsf{shared}\rangle \wedge \langle \texttt{director}(x), \textsf{shared}\rangle)\big).$$

There is only one answer to this query w.r.t. our previously introduced knowledge base: $\mu = \{x \mapsto \texttt{AJ}, y \mapsto \texttt{BP}\}$. This means that $\texttt{marriage}(\texttt{AJ},\texttt{BP})$ can only be exclusively allocated (as $\langle \texttt{marriage}(\texttt{AJ},\texttt{BP}), \textsf{exclusive}\rangle$) but the $\texttt{director}(\texttt{AJ})$ and $\texttt{actor}(\texttt{BP})$ atoms can be either "shareably" allocated with other requesters ($\langle \texttt{actor}(\texttt{BP}), \textsf{shared}\rangle$) or exclusively allocated only to one requester agent ($\langle \texttt{director}(\texttt{AJ}), \textsf{exclusive}\rangle$).

3. THE KNOWLEDGE ALLOCATION PROBLEM DEFINED

Multi Agent Knowledge Allocation (MAKA) can be interpreted as an abstraction of a *market-based* centralized distributed knowledge-based system for query answering. In such a MAKA system, there is central node a, the *auctioneer* (or the *knowledge provider*), and a set of n nodes, $I = \{1, \ldots, n\}$, the *bidders* (or the *knowledge requesters*), which express their information need (including exclusivity requirements) via queries, which are to be evaluated against a knowledge base $\mathcal{K}$, held by the auctioneer.

The auctioneer asks bidders to submit in a specified common language, the *bidding language*, their *knowledge request*: $\langle q, \varphi\rangle$ where q is an exclusivity-annotated query and $\varphi : \mathbb{N} \to \mathbb{R}_+$ is a valuation function.

Following the ongoing example in the paper, a knowledge request for an exclusively known marriage between a known actor and a known director, where each such marriage information is paid 30 units for would be the singleton set $\{\langle q, \varphi\rangle\}$ with

$$\begin{aligned} q = \quad & \langle\langle \texttt{marriage}(x,y), \textsf{exclusive}\rangle \wedge \\ & \big((\langle \texttt{actor}(x), \textsf{shared}\rangle \wedge \langle \texttt{director}(y), \textsf{shared}\rangle) \vee \\ & (\langle \texttt{actor}(y), \textsf{shared}\rangle \wedge \langle \texttt{director}(x), \textsf{shared}\rangle)\big), \\ \varphi = \quad & k \mapsto 30 \cdot k. \end{aligned}$$

The valuation function $\varphi : \mathbb{N} \to \mathbb{R}_+$ can be defined in several ways. Assuming that $val_q^i \in \mathbb{R}_+$ denotes a bidder i's interest to obtain a single answer to a query q, standard valuation options are:

- naive valuation: $\varphi^n(|S|) = |S| \cdot val_q^i$,
- threshold valuation: $\varphi^t(|S|) = |S| \cdot val_q^i$ if $|\ S \ | \leq threshold_{q_i}^i$ and $|S| \cdot (val_q^i - discount_q^i)$ otherwise,
- budget valuation: $\varphi^b(|S|) = min\{\varphi_i(|S|), budget_i\}$ where φ_i can either be φ_i^n or φ_i^t.

Based on bidders' valuations, the auctioneer will determine a *knowledge allocation*, specifying for each bidder her obtained knowledge bundle and satisfying the *exclusivity constraints* (expressing that exclusivity annotations associated to atoms in the respective bundle are indeed complied with).

Given a knowledge base and a set of n bidders, a *knowledge allocation* is an n-tuple of subsets of the exclusivity-enriched knowledge base (i.e., the knowledge base atoms annotated with both exclusive and shared). An allocation needs to satisfy two conditions: First, we cannot allocate the same atom as both shared and exclusive. Second, an exclusive atom can only be allocated to one agent.

Given a knowledge allocation, one can compute its *global value* by summing up the individual prizes paid by the bidders for the share they receive. Obviously, the knowledge allocation problem aims at an *optimal allocation*, which maximizes this value.

Please see [3] providing more details and a full formalisation of the above intuitions, as well as a network representation of the problem, such that the winner determination can be cast into a max flow problem on the proposed graph structure.

4. CONCLUSION AND FUTURE WORK

We have introduced the problem of Multi-Agent Knowledge Allocation by drawing from the fields of query answering in information systems and combinatory auctions. To this end, we have sketched a bidding language based on exclusivity-annotated conjunctive queries. This approach opens up interesting work directions such as:

- **Extending the bidding language**: One straightforward extension would be to allow not just for ground facts (like $\texttt{marriage}(\texttt{AJ},\texttt{BP})$) to be delivered to the requester but also for "anonymized" facts (like $\texttt{marriage}(\texttt{AJ},*)$ or, more formally $\exists x.\texttt{marriage}(\texttt{AJ},x)$), which require handling adaption.

- **Extending knowledge base expressivity**: On one hand, the knowledge base formalism could be extended to cover not just ground facts but more advanced logical statements such as Datalog rules (used in deductive databases) or ontology languages. In that case, a distinction has to be made between propositions which are explicitly present in the knowledge base and those entailed by it.

- **Covering Dynamic Aspects of Knowledge Allocation**: In particular in the area of news, dynamic aspects are of paramount importance: news items are annotated by time stamps and their value usually greatly depends on their timeliness. Moreover we can assume the information provider's knowledge pool to be continuously updated by incoming streams of new information.

- **Multiple Providers**: Finally, it might be useful to extend the setting to the case where multiple agents offer knowledge; in that case different auctioning and allocation mechanisms would have to be considered. This would also widen the focus towards distributed querying as well as knowledge-providing web-services.

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