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# Finding new consequences of an observation in a system of agents

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## ABSTRACT

When a new observation is added to an existing logical theory, it is often necessary to compute new consequences of this observation together with the theory. This paper investigates whether this reasoning task can be performed incrementally in a distributed setting involving first-order theories. We propose a complete asynchronous algorithm for this non-trivial task, and illustrate it with a small example. As some produced consequences may not be new, we also propose a post-processing technique.

## Categories and Subject Descriptors

I.2.11 [Artificial Intelligence]: Distributed Artificial Intelligence — *Multiagent systems*

## General Terms

Algorithms, Theory

## Keywords

Distributed Consequence Finding, Incremental Consequence Finding, Abduction

## 1. INTRODUCTION

This paper deals with the problem of finding all interesting new consequences which can be derived from some observations, given a full clausal theory. A consequence is deemed *interesting* if it respects a given language bias, and *new* if it is a consequence of the observations taken together with the theory but was not a consequence of the theory alone. Consequence finding is a general reasoning problem which lies at the heart of many AI applications. By focusing on computation of *new* consequences, one can perform efficient online computation of interesting consequences, an essential feature in dynamic contexts. On top of it, some problems specifically require to compute only new consequences, such as abduction by the principle of *inverse entailment*. Indeed, the set of abductive hypotheses is exactly the set of the negation of new consequences of the negated observation wrt the background theory. The computation of new interesting consequences is thus a very important challenge.

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Of course, one can always compute new consequences by computing all consequences of the theory with and without the observations, and making the difference. But focusing only on new consequences is much more efficient, which can be especially interesting in context when information is accessed progressively. The research question we address in this paper is the following: does it still hold in a distributed setting? There exist methods for computing new consequences in a distributed setting [1], but restricted to the propositional case. On the other hand, some recent work [2] focus on computing interesting consequences of a first-order theory, but not only the new ones. We propose here a method that can deal with first order clausal theories while focusing on interesting new consequences. We introduce, in Section 2, (distributed) new consequence finding, and then present our algorithm (Section 3). Section 4 then concludes.

## 2. FINDING NEW CONSEQUENCES

A *clause* is a disjunction of literals. A clause  $C$  *subsumes* another clause  $D$  if there is a substitution  $\theta$  such that  $C\theta \subseteq D$ . A *clausal theory* is a set of clauses, interpreted as the conjunction of all clauses in it. A *consequence* of  $\Sigma$  is a clause entailed by  $\Sigma$ . A clause  $C$  *belongs to a production field*  $\mathcal{P} = \langle \mathcal{L} \rangle$ , where  $\mathcal{L}$  is a set of literals closed under instantiation, iff every literal in  $C$  belongs to  $\mathcal{L}$ . The set of all subsumption-minimal consequences of a theory  $\Sigma$  that belongs to a production field  $\mathcal{P}$  is called the *characteristic clauses* of  $\Sigma$  wrt  $\mathcal{P}$ [3], and denoted by  $\text{Carc}(\Sigma, \mathcal{P})$ . When some observations  $O$  are added to a clausal theory  $\Sigma$ , further consequences are derived due to this new information. Such new and interesting consequences are called new characteristic clauses. It is formally defined as the set of all subsumption-minimal consequences of  $\Sigma \cup O$  belong to  $\mathcal{P}$  that are not consequences of  $\Sigma$ , and denoted by  $\text{Newcarc}(\Sigma, C, \mathcal{P})$ .

We now consider a system of  $n_A$  agents  $a_0, \dots, a_{n_A-1}$ , each having a clausal theory  $\Sigma_i$ .  $I = \{0, \dots, n_A - 1\}$  denotes the set of indexes of all agents in the system. These agents make some new observations (or acquire new information), represented as a set of clauses  $O_i$ , possibly empty. The objective is to determine all the new consequences of those new observations  $O = \bigcup_{i \in I} O_i$  wrt the whole theory  $\Sigma = \bigcup_{i \in I} \Sigma_i$  belonging to the shared *target production field*  $\mathcal{P} = \langle \mathcal{L}_{\mathcal{P}} \rangle$ , that is, to compute  $\text{Newcarc}(\bigcup_{i \in I} \Sigma_i, \bigcup_{i \in I} O_i, \langle \mathcal{L}_{\mathcal{P}} \rangle)$ . This specifies a distributed new consequence finding problem. We emphasize that agents do not share their theories, though for better efficiency, they share their respective languages.

*Example 1.* Consider a system of 4 agents, whose knowledge (theory and new observations) is defined as follows:

