Information Sciences 411 (2017) 1–22

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

# Defeasible-argumentation-based multi-agent planning

Sergio Pajares Ferrando*, Eva Onaindia

*Departamento de Sistemas Informáticos y Computación, Universitat Politècnica de València, Camino de Vera s/n, Valencia E46022, Spain*

ARTICLE INFO

*Article history:*
Received 5 August 2016
Revised 29 April 2017
Accepted 9 May 2017
Available online 10 May 2017

*Keywords:*
Defeasible argumentation
Multi-agent planning
Multi-agent systems
Cooperation

ABSTRACT

This paper presents a planning system that uses defeasible argumentation to reason about context information during the construction of a plan. The system is designed to operate in cooperative multi-agent environments where agents are endowed with planning and argumentation capabilities. Planning allows agents to contribute with actions to the construction of the plan, and argumentation is the mechanism that agents use to defend or attack the planning choices according to their beliefs. We present the formalization of the model and we provide a novel specification of the qualification problem. The multi-agent planning system, which is designed to be domain-independent, is evaluated with two planning tasks from the problem suites of the International Planning Competition. We compare our system with a non-argumentative planning framework and with a different approach of planning and argumentation. The results will show that our system obtains less costly and more robust solution plans.



## 1. Introduction

One common problem in Artificial Intelligence (AI) is to select the best course of action for an agent; i.e, reasoning about *what to do*. This problem has been primarily addressed from two standpoints: the knowledge or epistemological perspective, which puts the emphasis on the representation of the world such that the solution of a problem follows from the representation; and the reasoning or heuristic perspective, mostly concerned with the information for solving the problem and reasoning on an abstract and formal representation of the world [23]. *Practical reasoning*, a research line primarily focused on the epistemological view, includes a great deal of epistemic reasoning, directed at determining what to believe [10,19]. *Automated planning*, on the other hand, is concerned with the computational process for the selection and organization of the actions. Back in the 90's, Pollock concluded that since epistemic cognition is defeasible, a planning agent must be prepared to revise its plans as its defeasibly held beliefs change, and it may have to acquire more information through reasoning to solve a planning problem [35].

The mainstream in practical reasoning lies in the use of argumentation theory so as to extend the means-end reasoning in classical planning with presumptive justifications for the adoption of a particular action. The predominant approach in practical reasoning relies upon Dung's argumentation framework over beliefs [13] such as proposals for arguing about the desires an agent should adopt and the plans the agent will intend in order to achieve those desires [37]; the study of the goal deliberation process [20]; or the generation of consistent plans from a set of conflicting beliefs [3]. Building argumentation plans for negotiating conflict resolution at a planning stage is also an interesting application of argumentation in practical reasoning [25]. Some other works, however, follow the notion of argument scheme proposed by Walton

* Corresponding author.
*E-mail addresses:* spajaresf@gmail.com (S.P. Ferrando), onaindia@dsic.upv.es (E. Onaindia).

http://dx.doi.org/10.1016/j.ins.2017.05.014
0020-0255/

[47] and present an approach in which arguments and conflicts are represented as argument schemes and critical questions, respectively [5]. This latter work has been one of the most popular approaches in practical reasoning, it has demonstrated its applicability in domains such as law, experimental economics or e-democracy [4,9,12] and it has also been exploited for the design of argumentation-based dialogues to support automated coordination in distributed planning [24], multi-agent deliberation dialogues [21] or the construction of joint plans [38].

Unlike argumentation-based approaches of practical reasoning, another line of investigation closer to *planning* also explores the relationships between classical planning and argumentation, building on a planning formalism and using argumentation to guide the reasoning process. A first step in this direction assumes that agent's deductions are not always certain information, but *plausible*, and the conclusions can be withdrawn when new pieces of knowledge are found; i.e., agents must use defeasible reasoning [34]. OSCAR is a goal-regression planner that essentially performs the same search of Partial-Order Planning (POP) but reasoning defeasibly about candidate plans at the end of the planning process [36]. In OSCAR, the search of a plan is also done defeasibly, thus enabling to reason about the impact of unexpected environmental conditions on the solution plans as well as selecting the plan which is less likely to fail at execution time. In the same line, another pioneer work presents a formal model of plans based on a defeasible argument system that is able to suggest aspects of a plan, criticize and revise the plan [14]. Both of these investigations, considered as the first steps towards building an *argumentation-based planning* system, have close similarities to the works on plan modification and replanning but rather than enforcing the planner to resort to replanning in light of new information, they consider planning within the context of a general defeasible reasoning system.

More recently, Simari et al. presented a defeasible argumentation framework for the definition of actions and the combination of these actions into plans [40]. This work lays the foundations of an argumentation-based formalism for constructing plans [17] by using Defeasible Logic Programming (DeLP) [15], a formalism that agents use to represent and deal with incomplete and contradictory information in dynamic domains. The formalism presented in [17], which we will refer to as DeLP − POP in the following, describes how the traditional POP algorithm is extended to consider arguments as planning steps.

Subsequently, further investigations on argumentation-based planning focused on the application of argument-based systems to Multi-Agent Planning (MAP). An argumentation-based dialogue protocol that enables agents to discuss candidate plans and reach agreements was proposed in [7,8]. In this work, candidate plans of the agents are generated by an external single-agent planner and the protocol is used for reasoning about the contradictory planning beliefs in the candidate plans and select a valid solution plan. Agents in [7,8] use argumentation to defend or attack the candidate plans put forward by other agents, but not for cooperatively building a plan contributed by multiple agents. Another interesting work that exploits the benefits of using argumentation in MAP emphasizes the utilization of argumentation to solve conflicts between sub-plans of different agents by means of deliberative dialogues based on argumentation schemes [43,44]. Conflicts may be caused by concurrent actions, plan constraints or norms that the agents must adhere to, and argumentation is used to analyze the conflicts that arise when several sub-plans of different agents are to be merged. Likewise, in this approach argumentation is not used for building a plan – this is accomplished by an external planner-, but for arguing at end of the planning generation. A different approach that also makes use of argumentation schemes proposes structured argumentative dialogues to coordinate plan-related tasks [24]. In this proposal agents coordinate their beliefs and intentions using a dialogue game based on an argumentation scheme and its critical questions. Authors propose a strategy to choose relevant questions so as to improve the efficiency of dialogues and they empirically prove the benefits of the approach in identifying the points of disagreement to come to an agreement on the best plan.

On the other hand, the first formal extension of DeLP − POP to a multi-agent context wherein agents are assumed to have planning and argumentation capabilities is presented in [31]. Specifically, this work proposes a formal dialogue for an incremental argumentative plan search, by which agents exchange plan proposals and arguments for and against such proposals. To the best of our knowledge, this work represents the first attempt to use an argumentation-based MAP mechanism for a cooperative construction of plans. Subsequently, the works in [28–30] present the evaluation of the formal approach in some practical domains like a transit journey planning service and ambient intelligent applications.

In this paper, we present the formalization of Q − DeLP − POP[1] and its extension to a MAP environment (Q − DeLP − MAP), an argumentation-based MAP system that elaborates on two previous contributions: an initial formalization of a multi-agent argumentative planning model in the framework of DeLP − POP [31] and a preliminary implementation of such argumentative MAP model in a domain of ambient intelligent applications [28,29]. The former version of the argumentation model was able to deal with rich argumentative representations but exhibited a limited planning capability. Q − DeLP − MAP, however, greatly outperforms the previous system by exploiting, among other things, the reuse of argumentative dialogues during the construction of the search tree, which allows us to tackle problems of the International Planning Competitions (IPC).[2] Additionally, Q − DeLP − POP provides a more sophisticated specification of the *qualification problem* in planning, defining novel relationships between argument steps and action steps of a plan. Overall, the aim of this paper is to put together and exploit the investigations carried out in [31] and [29] in order to come up with a domain-independent, fully integrated and operative argumentation-based MAP model.

[1] Q stands for *Qualification problem* [18].

[2] http://ipc.icaps-conference.org/.