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# Multi-Agent Assumption-based Planning

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**Abstract.** The purpose of this paper is to introduce a dialectical theory for plan synthesis based on a multi-agent approach. This approach is a promising way to devise systems based on agent planners in which the production of a global shared plan is obtained by conjecture/refutation cycles. Contrary to classical approaches, our contribution relies on agents' dialectical reasoning: in order to take into account partial knowledge and heterogeneous skills of agents, we propose to consider the planning problem as a defeasible reasoning where agents exchange proposals and counter-proposals and are able to conjecture *i.e.*, formulate plan steps based on hypothetical states of the world. The argumentation dialogue between agents is a joint investigation process allowing agents to progressively prune objections, solve conjectures and elaborate solutions step by step.

## 1 Introduction

The problem of plan synthesis achieved by autonomous agents in order to solve complex and collaborative tasks is still an open challenge. Increasingly new application areas can benefit from this research domain: for instance, cooperative robotics [1] or composition of semantic web services [2] when considering actions as services and plans as composition schemes. From our point of view, multi-agent planning can be likened to the process used in automatic theorem proving. In a sense, a plan can be considered to be a particular proof based on specific rules, called actions. In this paper, we draw our inspiration from the proof theory described by Lakatos. According to [3], a correct proof does not exist in the absolute. At any time, an experimentation or a test can refute a proof. If one single test leads to a refutation, the proof is reviewed and it is considered as mere conjecture which must be repaired in order to reject this refutation and consequently to become less questionable. The new proof can be subsequently tested and refuted anew. Therefore, the proof elaboration is an iterative non monotonous process of conjectures - refutations - repairings.

The same is true of our approach. The plan synthesis problem is viewed as a dialectical and collaborative goal directed reasoning about actions. Each agent can refine, refute or repair the ongoing team plan. If the repairing of a previously refuted plan succeeds, it becomes more robust but it can still be refuted later. If the repair of the refuted plan fails, agents leave this part of the reasoning and explore another possibility: finally "bad" sub-plans are ruled out because there is no agent able to push the investigation process further. As in an argumentation with opponents and proponents, the current plan is considered as an acceptable solution when the proposal/counter-proposal cycles end and there is no more objection.

The originality of this approach relies on the agent’s capabilities to elaborate plans under partial knowledge and/or to produce plans that partially contradict its knowledge. In other words, in order to reach a goal, such an agent is able to provide a plan *which could be executed if certain conditions were met*. Unlike “classical” planners, the planning process does not fail if some conditions are not asserted in the knowledge base, but rather proposes an Assumption-Based Plan or *conjecture*. Obviously, this conjecture must be *reasonable*: the goal cannot be considered “achieved” and the assumptions must be as few as possible because they become new goals for the other agents. For instance, suppose that a door is locked: if the agent seeks to get into the room behind the door and the key is not in the lock, the planning procedure fails even though the agent is able to fulfill 100% of its objectives behind the door. Another possibility is to suppose for the moment that the key is available and then plan how to open the door etc. whereas finding the key might become a new goal to be delegated. To that end, we designed a planner that relaxes some restrictions regarding the applicability of planning operators.

Our approach differs from former ones in two points. First of all, unlike approaches that emphasize the problem of controlling and coordinating a posteriori local plans of independent agents by using negotiation [4], argumentation [5], or synchronization [6] *etc.*, the dialectical theory for plan synthesis presented here focuses on generic mechanisms allowing agents to jointly elaborate a global shared plan and carry out collective actions. Secondly, by elaboration, we mean plan production and not instantiation of pre-defined global plan skeletons [7, 8]. This is achieved by composing agents’ skills *i.e.*, the actions they can execute for the benefit of the group. Thus, the issues are: how can agents produce plans as parts of the global proof with their partial and incomplete beliefs? what kind of refutations and repairs agents can propose to produce robust plans? and how to define the conjecture - refutation protocol so as to converge to an acceptable solution plan?

In this paper, we introduce the two main components of the dialectical plan synthesis theory: the conjecture module that allows agents to produce plan with assumptions (sect. ??) and the dialogue controller (sect. ??).

## 2 Primary Notions

In order to define the language used in our approach, we will start with a first-order language  $\mathcal{L}$  in which there is a finitely many predicates symbols and constants symbols and no function symbols. A *state* is a set of ground atoms of  $\mathcal{L}$ . Since  $\mathcal{L}$  has no functions symbols, the set  $S$  of all possibles states is guaranteed to be finite. An atom holds  $p$  in  $s$  iff  $p \in s$ . If  $g$  is a set of literals (*i.e.*, atoms and negated atoms), we will say that  $s$  *satisfied*  $g$  (denoted  $s \models g$ ) when there is a substitution  $\sigma$  such that every positive literal of  $\sigma(g)$  is in  $s$ .

Let introduce now, the definition of a planning operator used in our approach. A planning operator define a transition function from a state to another.

**Definition 1 (Planning Operator).** A planning operator is a triple  $o = \langle name(o), precondition(o), effects(o) \rangle$  whose element are as follows:

- $name(o)$  the name of the operator,  $n(x_1, \dots, x_k)$  where  $n$  is a symbol and  $x_1, \dots, x_k$  define operator's parameters.
- $precond(o)$  and  $effects(o)$  the preconditions and effects of  $o$ , respectively defining the literals that must be hold in the state where the operator is applied and the literals that must be added, denoted  $effect(o)^+$ , or removed, denoted  $effect(o)^-$ , to compute the transition function.

In classical planning, a planning operator is applicable to a state  $s$  if it is ground and  $s$  is a state such  $precond(o) \subseteq s$ . Our approach relaxes this constraints: all operators are applicable to a state  $s$ . Hence, we must distinguish facts that hold in  $s$  and facts that do not hold. These facts are called *assumptions*. An assumption define a literal  $p \in precond(o)$  such  $p$  do not hold in  $s$ . We use  $assump(o)$  to denote the set of assumptions needed to apply a operator  $o$  in a particular state  $s$ . The result state of applying  $o$  to  $s_i$  is the state:  $s_{i+1} = ((s_i \cup assump(o)) - effects^-(o)) \cup effects^+(o)$ .

For instance, consider the initial belief state of an agent  $s_0 = \{at(cont,loc1)\}$  and a simple operator that can be performed by this agent to move a container from a location to another:

```
move(c,l1,l2)
  precond: connected(l1,l2), at(c,l1)
  effects:  ¬at(c,l1), at(c,l2)
```

In this example, the agent has no information about the connection between the locations  $loc1$  and  $loc2$ . In order to apply the move operator, the agent must put forward the assumption  $connected(loc1,loc2)$ . The result state of applying the move operator is the state:  $s_1 = \{connected(loc1, loc2), at(cont,loc2)\}$

In a multi-agent context, the assumption done by this agent could be refined by an other agent enable to connect the two locations. Hence, an assumption can be viewed as a subgoal to reach by other agents.

Before going further, we must present two main issues. First, we say that an assumption is a precondition of an operator  $o$  that do not hold in the state  $s$  where the operator is applied. Thus, there are two cases: if a precondition  $p$  is not contained in  $s$ , the fact must be added to the agent's belief and simply considered as *hypothetical fact*. But, if a precondition does not hold because its negation is contained in  $s$ , the agent must first remove the negation before adding the precondition. We call this kind of assumption a *fact negation*. Second,

### 3 Proof Board

### 4 Dialectical Mechanisms

### 5 Conclusion

The dialectical plan synthesis theory model represented in this paper relies on plan production and revision by conjecture/refutation cycles: for a given goal, agents try collaboratively to produce a valid proof, *i.e.*, a plan. In order to demonstrate the goal

assigned to the system, agents interact by using a conventional dialogue approach that can be split in two layers: *informational layer*, which defines the conventions to refine, refute or repair conjectures and *contextualization layer*, which defines the conventions to allow agents to change the dialogue state. The dialogue rules are described according to the *proof board*. The proof board represents the public part of the communication storing the different exchanges between agents.

The advantage of the dialectical plan synthesis is to merge in the collaborative plan generation, the composition and the coordination steps. It also includes the notion of uncertainty in the agents' reasoning and allows the agents to make conjectures and to compose their heterogeneous competences. Moreover, we apply conjecture/refutation to structure the multi-agent reasoning as a collaborative investigation process. However, former works on synchronization, coordination and conflict resolution are integrated through the notions of refutation/repairing. From our point of view, this approach is suitable for applications in which agents share a common goal and in which the splitting of the planning and the coordination steps (when agents have independent goals, they locally generate plans and then solve their conflicts) becomes difficult due to the agents strong interdependence.

Our perspectives are to deepen our understanding of the notion of plan robustness in terms of resources availability and agents' competences (how much redundancy is needed? *etc.*) Finally, criteria must be found to characterize how much a plan is easy to refute or to repair and devise heuristics for the investigation process as well as to detect critical competences/resources and to be able to overhaul ongoing teams of agents.

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