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Track Co-Chairs: Mauro Dragoni, Fondazione Bruno Kessler, Italy
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Luca Basili, Vodafone, Italy
Enrica Sposato, Vodafone, Italy
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Bongjae Kim, Sun Moon University, South Korea
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Rosario Giustolisi, IT University of Copenhagen, Denmark

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Khalil Drira, LAAS - CNRS – Univ. Toulouse, France
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Track Co-Chairs: Matthias Güdemann, IOHK, Hong Kong
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Agents in Dynamic Contexts, a System for Learning Plans

Francesco Lanza
Dipartimento di Ingegneria -
Universitá degli Studi di Palermo
francesco.lanza@unipa.it

Patrick Hammer
Dept. of Computer and Information
Sciences - Temple University
patrick.hammer@temple.edu

Valeria Seidita
Dipartimento di Ingegneria -
Universitá degli Studi di Palermo
valeria.seidita@unipa.it

Pei Wang
Dept. of Computer and Information
Sciences - Temple University
pei.wang@temple.edu

Antonio Chella
Dipartimento di Ingegneria -
Universitá degli Studi di Palermo
antonio.chella@unipa.it

ABSTRACT

Reproducing the human ability to cooperate and collaborate in a dynamic environment is a significant challenge in the field of human-robot teaming interaction. Generally, in this context, a robot has to adapt itself to handle unforeseen situations. The problem is runtime planning when some factors are not known before the execution starts. This work aims to show and discuss a method to handle this kind of situation. Our idea is to use the *Belief-Desire-Intention* agent paradigm, its the *Jason* reasoning cycle and a Non-Axiomatic Reasoning System. The result is a novel method that gives the robot the ability to select the best plan.

KEYWORDS

Planning, BDI, Jason, Human-Robot Interaction

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1 INTRODUCTION

In a scenario where humans and robots cooperate and collaborate to reach a common objective, one of the most challenging issues is to endow the robot with the ability to plan actions during the execution phase proactively. Normally, the robot is programmed to pursue its objective by executing a plan, composed of a set of actions. The robot acts on the base of its knowledge of the environment and of the actions to perform. Given a "static" environment, where everything is apriori known, the robot follows designer and programmer prescriptions. In such a case, the robot is endowed with the ability to face and respond to all kind of inconveniences. Developers have all the means and information to face issues, at design time, so ideally nothing unexpected will occur while the robot is working.

However, in the case of robots and humans cooperating in a partially, or entirely, unknown environment, a desirable correspondence between a goal and a plan cannot be assured. Above all, it cannot be decided at design time. Here, the need of a completely autonomous robot aware of its objective arises. The robot has to be able to perceive elements from the environment and consequently to select the right plan for pursuing that objective. If the robot has not been endowed with the correct plans, it should be able to find new ones. Sometimes, the robot should be able to create its own plans (self-adaptive and evolutionary behavior). This latter situation corresponds to some extent to human autonomy and self-adaptation abilities and is one of the most urgent challenges in human-robot interaction.

An efficient way to face the aforementioned problem is using the agent-oriented paradigm. In particular, the BDI agent paradigm [1, 11] involves a deliberation ability of the agent, based on a continuous sense-action loop, and on existing beliefs. It allows the agent to realize a desire, an intention, with a plan available in its library of plans. The library of plans is compiled by programmers.

Several technological approaches in the literature describe possible implementations of BDI agents. One of the most known and efficient ones is the *Jason* framework together with its reasoning cycle [13]. *Jason* is a powerful instrument for realizing planning in uncertain environments, however, it is not totally suitable for our purposes.

The idea we present is to merge the Jason reasoning cycle with a Non-Axiomatic Reasoning System (NARS) [8, 12]. Both the *Jason* framework and NARS can be utilized to handle planning. *Jason* has a reasoning cycle implemented and coded inside an agent; it needs well specific and defined inputs from the outside to select a plan and this is the main limitation of *Jason* for our objectives. NARS, instead, is a general-purpose reasoning engine that does not have this limitation. NARS often allows constructing plans even in the absence of specific knowledge. It is based on information gained from observed correlations, or on structural similarities between existing plans, or both. The two systems alone are not able to completely solve our problem, but the strengths of both systems can be combined.

In the human-robot interaction domain, the interaction is at the same time a source of changes and a source of information useful for planning and for deciding on actions. Our research aims at obtaining a team of humans and robots behaving as a team of humans. In these cases, each time a teammate does not know how to terminate his work, he may ask for help to others. Using a Non-Axiomatic Reasoning System is a possible way to elaborate non-structured data

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(or input) coming from the environment. So, the idea we propose is to merge both the systems, *Jason* and NARS, and to create a system where the core is composed of one (or more) *Jason* agent that, typically, performs the usual reasoning cycle. Every time the *Jason* agent is not able to select a plan from the plan library, it invokes aid by NARS. NARS generates a plan to be added to the agent's plan library. NARS is used as an external reasoning system that helps the agent modifying its behaviors defined at design time.

2 RUNTIME PLANNING FOR BDI AGENTS

One central part of our approach is providing the right communication bridge between *Jason* and NARS. The two systems work upon different languages, so a translation of the main elements for communication is necessary. As main elements, we consider all the knowledge useful for reasoning about the action to perform to pursue an objective: beliefs, goals and plans.

The control cycle that regulates work among *Jason* and NARS is shown in Figure 1.

We took inspiration from what Meneguzzi et al. illustrate in [10] and from the recent progress included in [9] as regards the development of planning algorithms for BDI agent systems.

Let us suppose that a *Jason* agent owns partial knowledge of the environment and of the goals it has to achieve, its plans, actions and so on.

The *Jason* agent may face a couple of situations. The agent may find an applicable plan in its library or not; in the first case the process goes on as the *Jason* reasoning cycle prescribes, in the second case the agent invokes the reasoning system to support making a decision. A *Recovery Plan* is triggered by the agent launching an Internal Action. It informs NARS about the plan's failure and, when no alternative plan is available, it lets NARS effectively take the control until it finds a new solution. In the best case, NARS generates a plan that is then added in the agent's plan library and is successfully executed (*Push Plan into Intentions* and *Process Intention* activities), letting the *Jason* system take over again. In the latter case, the agent informs NARS that the generated plan was successful, so NARS revises the inner hypothesis that corresponds to the plan, increasing its truth value. The Truth Value is used to summarize the evident support for a plan, that's how its successes and failures are tracked. Indeed, NARS has a memory system where goals, plans, related parameters and contexts are stored. Each time a new generated plan is considered successful, NARS has a higher chance to keep it in its memory [1] to serve similar future situations.

In more detail, the *Jason* reasoning cycle has the control when a plan in the library matches the current beliefs and the current goal. Simultaneously, NARS listens for *inform requests* while receiving the agent's beliefs. During this period, the new plan pushed into the Plan Library, is scheduled following the *Jason* system scheduler based on the *round robin* algorithm. So the reasoning cycle, converts the plan into an intention and processes it. After the execution of the intention, NARS is informed about the success or the failure of the added plan; it takes note of the result of the action to enhance the success estimate of the plan-related hypothesis. If the new plan fails and it has been already converted into an intention, NARS is informed about that and the system checks the truth value (*expectation* following [12]) to decide whether the plan should be retracted.

It is worth to note that the method we propose uses a inferential (Non-Axiomatic Logic) approach to make the decision. Here, the only extra operation the *Jason* agent performs is to inform NARS about the results of the plan application, moreover the agent autonomously requests help from NARS.

The complexity of the initial system does not increase due to our additions: we succeeded in reaching this goal by re-planning at runtime without employing other resources than those required for invoking NARS.

The method we propose is not a mere ensemble of two different reasoning systems. We merged the two systems without changing the basic reasoning cycles, instead we only embedded NARS in the internal structure of the *Jason* agent, by using an Internal Action.

Allowing agents plan at runtime does not require deep changes in the structure of the code developed for the multi-agent application. In this way, developers only have to apply a few changes in their program, introducing only a recovery plan when they need to plan at runtime. The extension is merely focused on the framework, whereby each agent defined in the multi-agent system could call the new internal action to invoke NARS. This choice ensures runtime planning inside multi-agent applications and a high level of compatibility with the previous works [2–6]

2.1 Handling Plans in *Jason* using NARS

As mentioned before, the agent yields control to the external reasoning system using two processes that let NARS reason on beliefs and plans already present in the agent. The appropriate mechanism that lets the agent yield control to NARS is implemented using an extended Internal Action.

Algorithm 1: A pseudo-implementation for the reasoning system.

```
PL ← Agent.getPL();
BB ← Agent.getBB();
while Agent.isAlive() do
    P ← PL.getPlan();
    B ← BB.getBeliefs(P);
    if (isIntentionValid(P, B) then
        executePlan(P, B);
    else
        invokeNARS(PL, BB);
end
```

The Agent is endowed with a PlanLibrary attribute, a BeliefBase attribute, a TransitionSystem attribute and other attributes relevant for the agent. The agent is endowed also with a set of predefined Internal Action, the Jason framework lets us implements new ones. To extend the control cycle as mentioned in section 2, we developed a specific internal action that enables the agent to use the external reasoning cycle. The new *internal action class*, called *invokeNARS*, extends a class that involves NARS, called *NarsEngine*, and it implements the Internal Action interface.

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[1] NARS uses a fixed-sized memory, so forgetting is inevitable once its memory is at full capacity

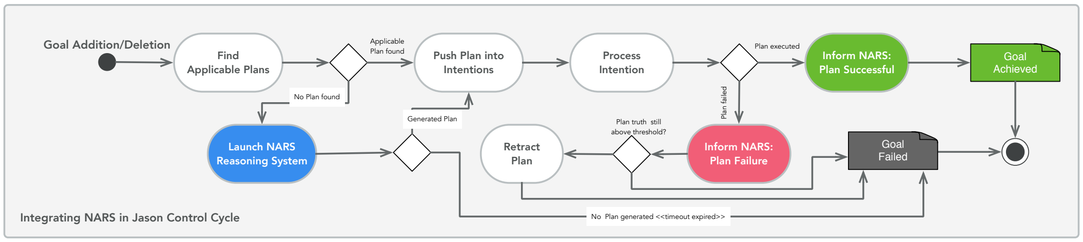

Figure 1: The standard AgentSpeak control cycle revised to merge it with OpenNARS. Extended and redrawn from [10].

The pseudo-code that implements the reasoning system is summarized in Algorithm 1. For each cycle, the agent checks if the intention associated with the plan is valid. In case it is valid, the agent executes the plan otherwise the agent launches the internal action that invokes NARS, passing the current list of plans and beliefs as an argument. The *NarsEngine* class is liable to perform the operation needed to develop the control cycle proposed in Figure 1.

Once, the agent executes the *invokeNARS* internal action the *execute function* is executed. This implements the handling process that translates the list of beliefs and the list of plans to the Narsese language. If no other plan applies, NARS takes control of the situation, with all knowledge owned by the agent.

The development of this reasoning system implies the *NarsEngine* class to refine agents from within using the TransitionSystem. The TransitionSystem is passed as an argument to the execute function, for the *invokeNARS* internal action. The content of the current PlanLibrary is modified at runtime by adding or retracting plans, based on the success-related truth value evaluation of NARS. In case NARS finds a new plan to add, it is usually an inner composition of existing plans and/or knowledge that has been extracted from observed correlations. The proposed model uses the list of plans to generate a new one, that applies to the current context.

3 DISCUSSION AND CONCLUSION

In scenarios where robots have to interact with humans, and in dynamic environments, one of the most challenging issues is to endow the robot with the ability to adapt to changes, to realize its goals autonomously.

Our long term work deals with developing a cognitive architecture able to operate in unsupervised and dynamic contexts [3–6]. In this paper, we focus on runtime planning, namely the creation or the composition of new plans when the one robot knows have turned out to be unsuccessful.

In this paper, we developed a novel model for a BDI reasoning cycle by using an extended reasoning system. We decided to use NARS [8] to assist during planning activities. The efficiency of NARS to learn procedure knowledge has been proven using the mechanisms described in [7]. NARS provides a robust reasoning cycle when robots have to produce standalone actions and when it is crucial to find alternative solutions to the ones determined at design time.

Even if *Jason* is able to operate in defined situations, the creation of the new control cycle has enhanced the ability of each *Jason* agent to find a solution to reach an objective. Moreover, the new control cycle, shown in Figure 1, did not alter the *Jason* reasoning cycle. This is a great advantage for developers and agent programmers who write programs using *Jason*. They only have to apply the new internal action where it is needed, without disrupting the code flow.

The novelty introduced involves the ability of the system to be autonomous in the sense that the system can find a plan (not known apriori) based on its, possibly acquired, knowledge. This is useful not only in the robotics context, but it may also be applied in several other kinds of complex systems, such as in the World Wide Web. The ability to modify itself from within is one of the most critical challenges for autonomous systems. However, the ability of NARS to hold generated plans in the memory is dependent on the size of the memory bag. This fact affects the system performance in terms of wasting knowledge and the ability to infer new plans.

Altogether, the proposed method can highly increase the autonomy of systems, also letting them better operate in scenarios where unexpected circumstances make existing plans fail, or where new plans to deal with novel situations are necessary.

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