Distributed Planning and Coordination in Non-deterministic Environments

Antonín Komenda
Agent Technology Center
Czech Technical University in Prague
komenda@agents.felk.cvut.cz

Jiří Vokřínek
Agent Technology Center
Czech Technical University in Prague
vokrinek@agents.felk.cvut.cz

Michal Pěchouček
Agent Technology Center
Czech Technical University in Prague
pechoucek@agents.felk.cvut.cz

Gerhard Wickler
AIAI, University of Edinburgh
Edinburgh, Scotland
g.wickler@ed.ac.uk

Jeff Dalton
AIAI, University of Edinburgh
Edinburgh, Scotland
jeff@inf.ed.ac.uk

Austin Tate
AIAI, University of Edinburgh
Edinburgh, Scotland
a.tate@ed.ac.uk

ABSTRACT

We present a demonstration of a multi-agent prototype for distributed planning and coordination in dynamic non-deterministic multi-actor mixed-initiative environments. The system provides flexible planning, replanning, and task allocation. The key technologies utilized in the system are (*i*) I-X hierarchical planner with (*ii*) agent-based architecture and (*iii*) commitment-based plan representation. The implementation of the system was verified and evaluated in simulated environment. The experimental validation confirms the performance, stability, and robustness of the system in complex scenarios. In this demonstration we present the compilation of the most representative scenarios.

Categories and Subject Descriptors

[**DEMO**]: ACADEMIC SOFTWARE

Keywords

commitments based planning, HTN planning, non-deterministic environment, multi-agent simulation, mixed-initiative

1. INTRODUCTION

The presented prototype is based on the concept of a multi-layer planning architecture. The planning process for the overall plan is distributed among an arbitrary number of autonomous agents. The planning hierarchy of the entities is not predefined, and it emerges during planning. Each agent knows only its own planning domain, which describes the agent's capabilities in the terms of the environment domain. These private personal domains are described in the form of Hierarchical Task Networks. The planning process is initiated by externally tasked agent(s). The tasks are typically added by a human operator using the system's human-machine-interface (HMI). An I-X Process Panel, which is part of the I-X architecture, is used as the HMI. The agent tries to fulfill the task goals and may need to incorporate the sub-plans of other agents, in the case it is not able to fulfill the task on its own. Such agents recursively run the same planning process until the whole plan is formed and ready for execution. In the phase of incorporating sub-plans, the agents need to mark parts of the plans where the other agents continue plan execution. For that purpose, the designed concept of plan interconnection by synchronization-points can be used.

From the perspective of one agent, the planning process can be divided into three layers, which form the multi-layer planning architecture. In the strategic layer (the topmost layer), the I-X HTN Planner (which originated in the O-Plan planner) [3] is used, creating an abstract plan for the long-term time horizon. The plan instantiating process uses distributed resource allocation based on the multi-agent contract-net-protocol [2]. With the help of this protocol, the appropriate subordinate agents are found. The tactical layer (the middle layer) optimizes the plan using the early-as-possible scheduling heuristic. The effect is directly proportional to the amount of the non-determinism in the world. The operational layer (the bottommost layer) plans potential refinements of the tactical actions. One of these actions is the agent's movement, where the path is planned using the A* algorithm. The other responsibility of the operational layer is the execution of all low-level actions in the scenario simulator.

All plans are described in the form of social commitments (substituting plan actions). The commitment is a knowledge-base structure describing the agent's obligation to change the world-state and a set of rules for what the agent should do if the obligation is not satisfiable. The proposed structure is an extension of a widely used formalization of commitment [6]. The proposed commitment recursiveness [1] enables more expressive description of the decommitment rules and thus the replanning process. The introduction of causal commitment inter-referencing enables real-time replanning. The mutual bindings of commitments form a commitment graph. The graph can be used for the process successively solving exceptional states (replanning). The replanning process by means of social commitments can be described as successive

Cite as: Distributed Planning and Coordination in Non-deterministic Environments, A. Komenda, et al., *Proc. of 8th Int. Conf. on Autonomous Agents and Multiagent Systems (AAMAS 2009)*, Decker, Sichman, Sierra and Castelfranchi (eds.), May, 10–15, 2009, Budapest, Hungary, pp. XXX-XXX.

decommitting [1]. For decommitment purposes, three basic decommitment rules were used: full decommitment, delegation, and relaxation [5]. The most suitable decommitment rule set and ordering for non-deterministic domains was according to [4] used, taking delegation, relaxation, and full decommitment in that order.

2. PROBLEMS ADDRESSED

This section presents the problems have to be solved to fulfill the requirement for planning system able to plan in dynamic non-deterministic environments. The overview of the problems follows:

- **Distributed planning** – Planning in such an environment is realizable only as a distributed process. This affirmation is supported by several facts: the objects of planning are naturally distributed in the world, the robustness of the planning process is a key issue, and finally, each entity have to hold its own private knowledge of its capabilities in form of a planning domain.
- **Distributed resource allocation** – Integral part of the planning process is resource allocation both of the acting entities in the world and of the static resources. The allocation process must be appropriately integrated with the planning system and similarly, the planning process has to be robust with respect to the mentioned constraints in the environment.
- **Distributed plan execution and synchronization** – The distributed plan consisting of several personal plans has to be executed by the entities. The plan has to be robust enough to be able to minimize its volatility and do not need to be completely replanned in a case of any non-determined effect.

The next section describes one of the verification scenarios. The scenario is designed to show all of the key aspects of the prototype in synoptical scale.

3. SCENARIO

The demonstration[1] shows realistic disaster relief scenario. In the South part of an island, a natural catastrophe generates unpredictably injured victims in three highlighted towns. The scenario is extended such that a commander agent has an I-P^2 (I-X Control Panel) to allow for mixed-initiative planning and the state subscription interfaces and protocols are used to allow state monitoring for the commander through a selective subscription mechanism. The human operator adds the high-level tasks into its to-do list. Successively, the state of each task can be changed. Commander agent broadcasts tasks to heal injuries in the South towns. There are medical doctor unit agents waiting in a town in the North of the island. The medics negotiates their transports to appropriate towns. Possibly the agents representing helicopters are used (and supported by truck agents for transporting to and from the airports). The heal-injuries action (of the medics) can by performed only if there is a medical supplies in the town (shown with a number bar over the town icon). So, the medics requests the delivery of medical supplies too and the trucks transport it into the towns with injured people. Then, the medics can heal injuries.

[1]http://agents.felk.cvut.cz/download/video/iglobe.avi

As the only source of the medical supplies is in the civil hospital in the North part of the island (blue H icon). Later on, the commander decides to build a mobile (field) hospital at the designated beacons (rainbow-colored icons). The commander broadcasts the tasks to build mobile hospitals and the builders respond. The builders negotiate the transports (using the trucks) and the construction material (the hospitals cannot be build without the material in place – number bar over the beacon icon). The first hospital is built in the South-East part of the island (green H icon) and two more come after (South, South-West). Thereafter, the medical supplies are transported from the mobile hospitals, which optimizes caring for injured.

The processes of the healing and building of the mobile hospitals are simultaneous and share the transport units.

4. ACKNOWLEDGEMENTS

Effort sponsored by Czech Ministry of Education grant 6840770038 and supported by the European Research Office of the US Army under grant number W911NF-08-1-0041.

5. ADDITIONAL AUTHORS

Dušan Pavlíček, Agent Technology Center, Czech Technical University in Prague

6. REFERENCES

[1] A. Komenda, M. Pěchouček, J. Bíba, and J. Vokřínek. Planning and re-planning in multi-actors scenarios by means of social commitments. In *Proceedings of the International Multiconference on Computer Science and Information Technology (IMCSIT/ABC 2008)*, volume 3, pages 39–45. IEEE, october 2008.

[2] R. G. Smith. The contract net protocol: High level communication and control in a distributed problem solver. *In IEEE Transactions on Computers*, C-29(12):1104–1113, 1980.

[3] A. Tate. Intelligible AI planning. In M. Bramer, A. Preece, and F. Coenen, editors, *Research and Development in Intelligent Systems XVII (Proc. 20th ES)*, pages 3–16. Springer, 2000.

[4] J. Vokřínek, A. Komenda, and M. Pěchouček. Decommitting in multi-agent execution in non-deterministic environment: Experimental approach. In *AAMAS '09: Proceedings of the eight international joint conference on Autonomous agents and multiagent systems*, 2009.

[5] J. Vokřínek, A. Komenda, and M. Pěchouček. Relaxation of social commitments in multi-agent dynamic environment. In *Proceedings of International Conference on Agents and Artificial Intelligence (ICAART09)*. Springer, 19-21 January 2009.

[6] M. Wooldridge. *Reasoning about Rational Agents.* Intelligent robotics and autonomous agents. The MIT Press, 2000.