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Fusing DL Reasoning with HTN Planning

Rich Domain Planning for Mobile Robotics

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Abstract Action planning has been used in the field of robotics for solving long-running tasks. However, the definition of a planning problem for a complex, real-world robot is not trivial. The planning process could become intractable as its search spaces become large. The dissertation presented in this article introduces a novel approach which amalgamates *Description Logic* (DL) reasoning with *Hierarchical Task Network* (HTN) planning. The planning domain description as well as fundamental HTN planning concepts are represented in DL and can therefore be subject to DL reasoning; from these representations, concise planning problems are generated for HTN planning.

Keywords HTN Planning · DL Reasoning · Plan-Based Robot Control · Hybrid Deliberative Layer

1 Overview

In recent years, the robotics field has seen rapid advancements in both software and hardware areas. Good algorithms for perception, learning, planning, navigation and inferencing have been researched and used in autonomous robots. One advance is the development of a light weight manipulator. A mobile manipulator is a mobile robot equipped with a manipulator. It has the capabilities of a mobile robot in addition to the functionality associated with its manipulator. Tasks which could not be accomplished with merely a mobile robot can be achieved with it. However, the complexity of the planning problem becomes larger and more complex.

A typical mobile manipulator task is to pick and place, where the robot navigates to a certain place, grasps an object and places the object at a certain destination. To solve this task, the robot has to plan its movement in the environment and be able to recognize the requested object. It depends on the size of the environment, and for this task, on the number of rooms and objects. The more rooms and objects involved in the problem description the larger the search space is in the planning system. In a worst case situation, it can make the planning problem intractable.

It is often the case that even in a large planning domain, some of the rooms or objects are irrelevant for achieving the current goal. For example, rooms which are not traversable because they are closed. The planning system can recognize relevant rooms or objects once the extraction process has been completed. However, this might be too late and cause the problem to become intractable.

In the dissertation [3] the deliberative layer of such mobile manipulator is enhanced and named "*Hybrid Deliberative Layer*" (HDL). The HDL amalgamates *Description Logic* reasoning [1] and *Hierarchical Task Network* (HTN) planning [2].

2 The Hybrid Deliberative Layer

HDL extends the hybrid control architecture, which is usually used in mobile robotics, with a *Description Logic* reasoning system. Figure 1 shows the HDL in a robot control architecture. It consists of four components, an ontology model (*OWL-DL*), an inference module (*Pellet*) [7], a planning problem generator, and a planner (*J-SHOP2*) [6].

The planning-related information is stored in the ontology model instead of merely being the planning problem descriptions. One benefit of this approach is

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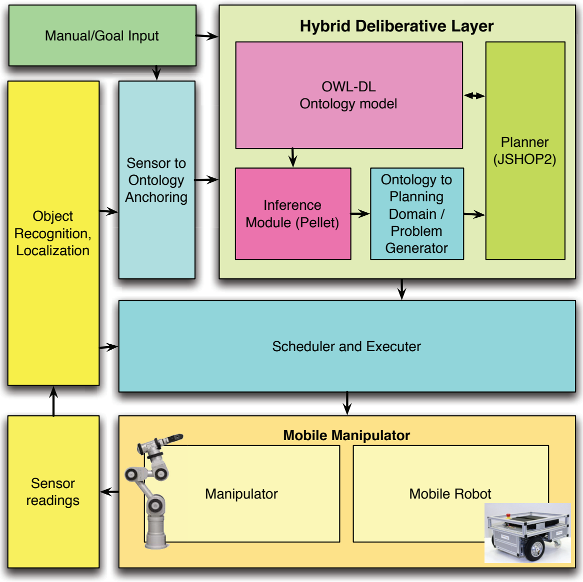

Fig. 1 HDL in a layered robot control architecture.

that even if, e.g., a huge number of rooms or objects are stored in the ontology model, only the planning-related objects or rooms are included in the problem description. The DL inference engine filters out irrelevant information and the planning problem generator generates a valid problem description for the planner.

Figure 2 shows the reasoning process over the DL model for extracting a planning problem description [5]. The DL model stores all necessary information for the planning system and the mobile manipulator. In addition to the objects and world model, it can store the planning domains as well. It is not limited to the mobile manipulator domain, but can also accommodate other planning domains. This information will not influence the overall planning performance, as only relevant instances are considered for the problem description. The DL reasoner filters the ontology model and generates a valid problem description for the HTN planner.

3 Concept

The objects and the planning related information have to be modeled and stored in the *Description Logic* representation. It consists of two parts, the *Terminological Box* (*TBox*) and the *Assertional Box* (*ABox*). The *TBox* stores the conceptual information and the *ABox* stores their instances.

The modeling of the planning concepts, like plans, tasks, etc., and their instances is detailed in the dissertation [3]. In this article, an example of the navigation domain's concepts is shown in Figure 3. The ellipses represent concepts in description logic. As seen in this figure, it classifies the concepts in a navigation domain, such as robot, room, door, building, etc. *DriveableRoom*, *DriveableRoomInBuilding*, and *OpenDoor* are concepts whose instances are automatically filled by applying the DL reasoner on the model. They do not need explicit instances assigned to them.

For example, the "*DriveableRoom*" concept is defined as a subconcept of the "*Room*" concept which has some open "*Door*". It is written in DL syntax as follows:

$$DriveableRoom \equiv \; Room \; \sqcap \; \exists \; hasDoor.OpenDoor$$

The DL reasoner infers the *ABox* and automatically adds the instances that fulfill the definition of being a member of the "*DriveableRoom*" concept. This feature is important in a dynamic environment in which the mobile manipulator functions as the number of rooms in the building remain the same but the state of its traversable property changes from time to time with the states of their doors.

4 Experimental Results

Table 1 gives an example of how specializing alters the number of states s, based on the number of rooms to consider in some concrete planning problems. As expected, using a more specific concept reduces the number of generated states s, which can improve planning efficiency by reducing the search space [4].

Table 1 Generated states for different specialisations of the *Fixed-Object* concept.

Condition	Number of states
s_{room}	16
$s_{room-in-building}$	8
$s_{driveable-room}$	8
$s_{driveable-room-in-building1}$	5
$s_{driveable-room-in-building2}$	3

Figure 4 shows the time for generating the plans in relation to the number of rooms. In the pure HTN approach, the planning time increases commensurately with the number of rooms in the problem description. The planning time is less than $2s$ for less than 25 rooms. It is $193s$ for 83 rooms and for more than this, the planner fails to generate a plan. In HDL, the overall planning time consists of DL-reasoning time plus HTN-planning time. The average time in HDL for up to 200 rooms is $3.5s$ [5].

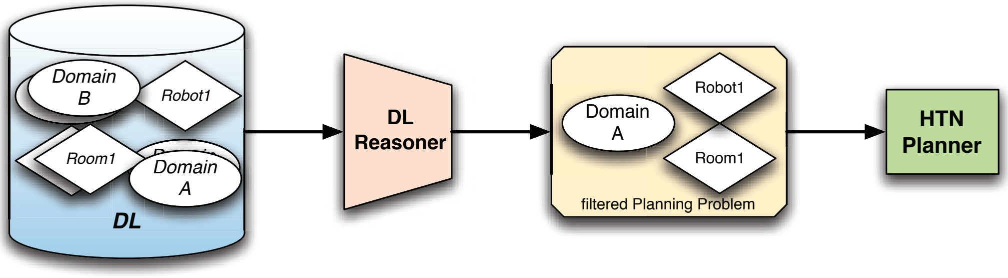

Fig. 2 A reasoning process over DL representation to extract a concrete HTN planning problem.

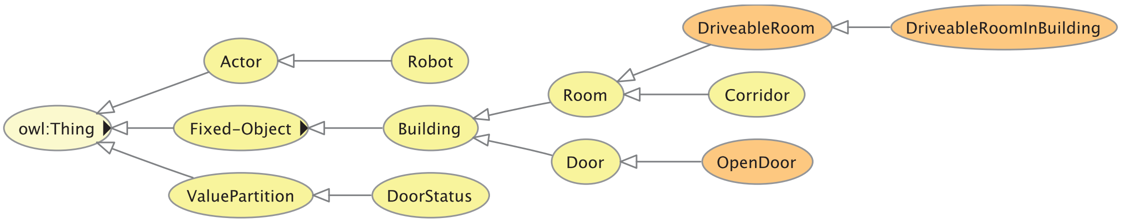

Fig. 3 Navigation domain's state concepts.

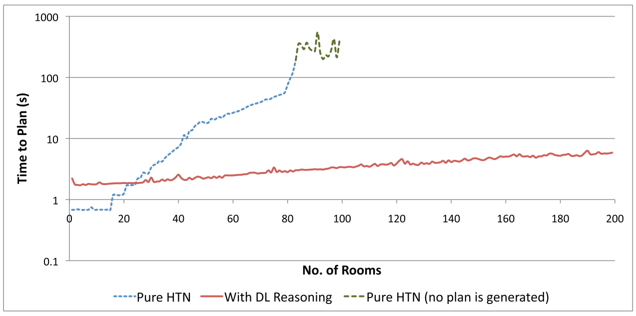

Fig. 4 Computation time (logaritmic scale) in the navigation domain [5].

5 Conclusions

This article has sketched the way how the dissertation [3] introduces and exploits the HDL system. It shows that combining DL reasoning with HTN planning in such way can benefit the overall planning process. In addition, one can use HDL as a planning repository, where a collection of domains are stored. Regardless of the size of stored planning domains and instances, the generated problem descriptions remain concise and contain relevant states necessary to extract the plans. As a result the planning time remains small. Details and some examples from the robotics and artificial intelligence fields can be found in the dissertation [3].

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