Knowledge representations for high-level and low-level planning

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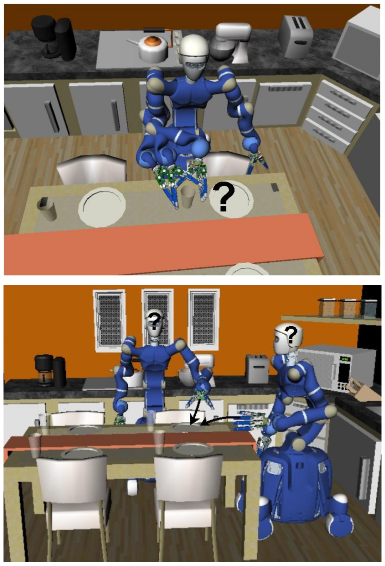

Figure 1: A humanoid robot is shown in a kitchen performing several tasks. (top) With a multi-fingered hand, a glass can be grasped in different ways. (bottom) Two robot placements are shown for grasping the plate on the table.

Problem statement

In general a service task like setting the table can be further resolved into several subtasks. When objects have to be grasped, choosing grasps and approach directions are problems that have to be solved. In Figure 1 two service tasks and their challenges are illustrated. Objects have to be moved from one location to another. A number possibilities for grasping a glass are shown in Figure 1 (top). The robot has to decide where to place itself to be able to reach an object. The number of robot placements is infinite (Figure 1 (bottom)). These issues have to be taken into account by a logical planner when planning a task.

Logical planners are expected to divide a task into a set of subtasks, e.g. first the closet is opened, then the dishes are taken out of the closet, the closet is closed and the dishes are transported to the table. Path planners are used for moving the robotic arm without collisions between two positions. A grasp planner provides good grasps for handling an object. A robot placement planner positions a robot for performing a grasp or a trajectory. The logical planner has to trigger the execution of the subtasks by appropriately parameterizing and using the low-level planners, i.e. the path planner, the grasp planner and the robot placement planner (Figure 2). Depending on the parameterization, e.g. the start and the goal robot arm configuration, a low-level planning problem may not be solvable. Either no collision-free path is found or the object cannot be grasped from the queried direction. However, a logical planner has no knowledge about the geometry of the scene and works with an abstract scene model where objects are represented by labels. It does not know e.g. from which direction an object can be approached best. Therefore a chosen subtask may not be executable. For the high-dimensional planning problems in service robotics, determining whether a solution exists is computationally too expensive. A brute force approach lets the logical planner propose a plan and test whether the plan is valid. In this process the low-level planners try to find a solution for assigned subtasks to determine the truth value of associated labels. This is repeated until a solution is found or a termination criterion is met (Dornhege et al. 2009), (Kaelbling

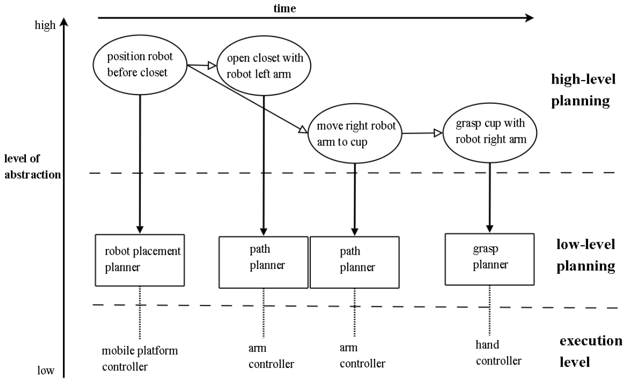

Figure 2: Different levels of abstraction during the planning and execution of a service task. High-level planning is equivalent with logical planning. Possibly parallel running actions are mapped to low-level planners. The planning results are then executed by divers robot controllers.

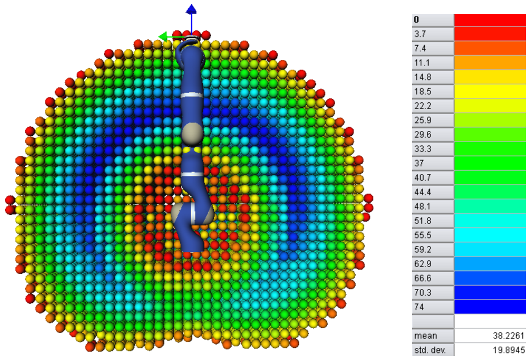

Figure 3: Visualization of the capability map. Regions in the center of the workspace (blue) can be reached with the largest number of poses.

and Lozano-Perez 2010). Since each of the low-level planning problems is already very complex, even simple tasks can take a long time to be solved. Furthermore, for objects like a coffee mug, directions exist from which the object is better graspable. To open a closet door or a dish washer, not every placement of the humanoid robot results in successful task execution. The humanoid robot may place itself so that it can grasp the door handle but opening the door is not possible. Therefore, models are needed that e.g. describe the capabilities of a robot. They can support decision processes, their parameter choices and reduce the search space.

The capability map

In the reachable workspace volume of the robot arm, positions can be reached in *at least one* orientation. In the dexterous workspace volume positions can be reached in *all* orientations (Craig 1989). However, in general seldom all orientations are needed. Let the *versatile workspace* of a robot arm describe with which orientations a position can be reached. A representation of the versatile workspace for a robot arm can be exploited by high-level and low-level planner types. It enables a task planner to predict whether an object is graspable or whether a certain trajectory is executable for the robot. This information helps to estimate whether an action is valid. Given a set of grasps for an object and a scene description, the representation can be used to estimate the difficulty of the planning problem. For instance, if a lot of grasps are unreachable, the scene could be very crowded and the target object could be difficult to reach resulting in long planning times. This information can be used by the task planner to e.g. consider a rearrangement of the scene to make the planning problem easier.

The *capability map* is a representation of the versatile workspace of a robot arm (Zacharias, Borst, and Hirzinger 2007). Using this knowledge representation good parameterizations for planners can be determined or the search space can be reduced. The capability map of a robotic arm describes how well regions of the workspace are reachable (Figure 3). A visualization of the versatile workspace facilitates analysis and interactive planning. The representation can be used to guide planning processes, make reliable predictions about the feasibility of tasks and avoid unsuccessful planning runs. The generation of the model is performed offline once and can then be used in online algorithms.

Applications

(Zacharias et al. 2009) presented an algorithm that uses the capability map to determine where given 3D trajectories are executable. The search method can be used to evaluate how well a robot is suited for specific environments or tasks. The determined number of solutions for the trajectory correlates with the ability of the robot to cope with disturbances e.g. objects left behind by a human. The method is especially suited to decide whether or not a task can be performed. This information can be used by a task planner to decide which planner or execution component to trigger. In (Zacharias et al. 2011) an ergonomics criterion in combination with the capability map was used to determine whether objects are graspable in a human-like manner. Good parameterizations for a path planner were derived. The path planner was then able to plan more human-like robot arm motion. The computation times and quality of the robot motion were significantly improved. This method can help a logical planner evaluate the feasibility of grasping tasks and obtain good planner parameterizations. (Pandey and Alami 2010) introduce the *mightability map* to reduce the search space in planning human-robot interaction tasks.

To be able to use logical planning to efficiently solve service robotics tasks, more knowledge representations like the capability map are needed to reduce the search space dimensionality and provide an intermediate layer between logical planning, geometrical planning and robotics.

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