Robots Reasoning with Cuts and Connections: Creating and Removing Entities

(Extended Abstract)

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ABSTRACT

Several tasks that autonomous service robots will be expected to do involve changing material objects by cutting or separating parts, then rearranging them to obtain assemblages satisfying certain properties. In this paper we describe a system to represent and reason about entities that disappear or are created by the robot through such actions. Entities are grounded in objects that the robot can perceive and manipulate, and reasoning provides specific parameters for the robot's actions. For this paper, our system has knowledge only of geometric aspects related to cutting and rearrangement of objects. We test our system in simulation, but also discuss how it can be connected to a robot's perception and control.

General Terms

Algorithms, Languages, Theory

Keywords

Reasoning in agent-based systems; Robot planning (including action selection, motion and path planning and manipulation); Robotic agent languages, middleware and formal methods for robot systems

1. MOTIVATION

As robotic agents become more capable the range of manipulation tasks they are to perform becomes also more varied. Consider robots intended for household tasks; they will have to tackle actions such as wiping, cutting, spreading, and scooping. Also, objects often have to be rearranged in ways that satisfy given constraints, which the robot should be able to represent and reason about.

Performing such actions competently requires physics and geometric reasoning to capture their continuous effects on the material objects around the robot. There is also the problem of making the respective knowledge actionable; the robots have to choose the positions where to scoop from, the trajectory of end effectors etc.

In contrast to robot control, most action representations used for agent control are inspired by the STRIPS formalism. Many variations exist, including probabilistic STRIPS and STRIPS with resources, but their common limitation for robot control is the treatment of action as a black box, which doesn't express the causal relation between *how an action is executed* and *what effects it causes*.

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Appears in: *Proceedings of the 15th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2016), J. Thangarajah, K. Tuyls, C. Jonker, S. Marsella (eds.), May 9–13, 2016, Singapore.*

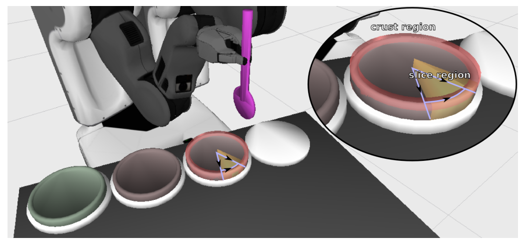

Figure 1: Robot preparing to cut out a crustless slice of pizza.

Here, we investigate representation and reasoning mechanisms to enable robotic agents to plan and execute cutting actions. Consider a robot with a collection of pizzas with assorted toppings sprinkled unevenly on their surfaces, and a set of customers, each with their own preferences for toppings. The robot must cut out slices, then regroup slices onto plates; there are constraints on how slices can be arranged before delivery. Though seemingly contrived, this is a problem a human would tackle with ease, even if it contains various subproblems that are current and interesting for robotics. The robot needs to have a way to represent the pizzas and where the toppings are; it needs to cope with the fact that pizzas will be cut and slices rearranged– objects pop in and out of existence as a consequence of the robot's actions.

We show a system able to represent and reason about entities that disappear or are created by the robot. The reasoning tackles the sub-symbolic level as well, to give the robot specific descriptions of the actions needed to obtain a given outcome. Currently, our system only treats geometric aspects of cutting and rearrangement of objects, not physics. Our contributions are:

- (○) A world state representation with entities that can be destroyed or created by removing or adding parts
- (○) Managing the interaction between entities created by manipulating physical parts and entities asserted as task goals
- (○) A grammar for object arrangements, integrated into a planner
- (○) Integrated reasoning about cuts into a robot planning system
- (○) Grounding a fragment of common-sense reasoning into robot percepts and actions

We build and showcase our system around the pizza cutting and distributing scenario described above, but we argue that the lessons learned and concepts developed here improve a robot's competence in acting on the world, and the methods we provide can generalize beyond the specific showcase application. We work in simulation here, but with consideration of how to proceed on a real robot: what inputs our system needs from a robot's perception, and the procedures to clean up perception data. The output our system provides is usable by constraint-based controller similar to [1] to perform the motion on an actual robot.

2. OVERVIEW

Though our chosen problem domain is simple, it illustrates interesting robotics topics. First, our system must describe cutting out a part, and the connection types in its problem domain, from a logical level (asserting that a connection exists) down to spatial relations between physical objects.

Second, our system must capture structural constraints on arrangements and the implications of cutting actions. Our robot needs to know that pizzas can be cut into slices of a given shape, that slices cannot be put together into a pizza again, but that we do consider them an "Assembly" if they lie in a fan pattern on a plate.

Third, we need to track what entities exist in the robot's environment. Some entities are physical objects (for example slices), but it is convenient to consider arrangements of objects as being entities as well: for example, a fan of pizza slices, all lying on the same plate, are an "Assembly" that the robot can deliver to a customer.

Fourth, the problem of object identity after changes in form. For example, after cutting out the first slice, we still think of the resulting object as the same pizza. Another aspect of this problem is handling violations on structural constraints on arrangements. Removing the middle slice from an Assembly changes it into another arrangement type (in an Assembly, the slices should make up a fan).

Finally, the results of the robot's reasoning queries must produce action parameters: where to cut, where to put an object.

Fig. 2 shows a sketch of our system. A geometric level handles queries about obtaining trajectories for cutting, checking connection types between objects, obtaining object poses to establish a connection type. This level also defines some auxiliary annotations to assist in its reasoning. The mereotopologic layer handles queries about what cuts are necessary to separate parts out of physical objects, and about arrangements of physical objects and the structural constraints on them. It uses a spatial grammar to describe arrangements in terms of part and connection types. The task level receives the customer orders, and issues queries to the underlying levels in order to generate plans and actions for the robot.

The world state is described by the poses of the physical objects that the robot can perceive; these are the primitive entities. Further entities can be asserted by the task and mereotopological layers. The task layer asserts "ghost" entities that are needed to fulfill an order (they need not be initially associated to physical objects). The mereotopological layer asserts entities when physical objects are arranged in certain ways; to avoid proliferation, it only asserts an entity when it is maximal. Either layer can vote to remove an asserted entity when it is no longer needed (task layer) or no longer embodied in a collection of physical objects (mereotopological layer), but both must agree before removal occurs.

3. RELATED WORK

Learning control parameters for cuts, given a quality measure such as time taken, was tackled by [2]. Cut location, or deciding whether a cut is necessary, was not in the scope of that research.

Cutting as a "microworld" for common-sense reasoning appears in [3], which gives two formal theories for the cutting of solid objects. Formal theories of parthood and connection (mereotopology) are overviewed in [4], spatial grammars in [5]. We extend the previous work by insisting on action parameter production for a robot, and on spatial grammar parsing and its application to planning.

Our approach is related to general purpose common-sense reasoning, which includes reasoning about geometric and physical properties and interactions [6], and that formal methods applied to reasoning about assemblies have seen application for automatic generation of customizable furniture models [7].

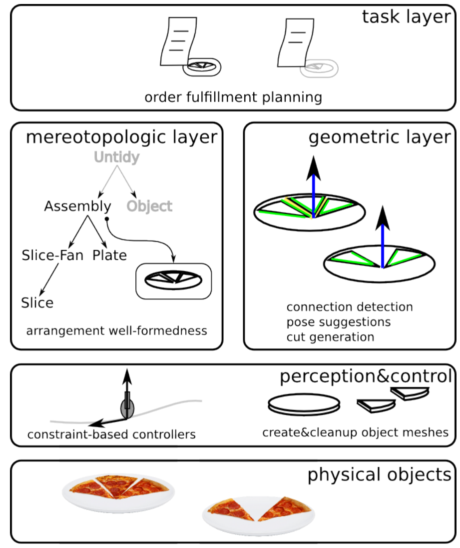

Figure 2: The layers of our system. The geometric layer annotates models of objects with information useful to analyze connections and suggest placements and cuts. The mereotopologic layer ensures arrangements of objects obey structural constraints. The task layer creates plans to fulfill customer orders and queries underlying levels.

4. CONCLUSION

We describe a robotic system able to reason about generating new parts out of materials it has at its disposal, and arrange those parts into assemblages that obey structural constraints.

Acknowledgements

This work is supported by the EU FP7 project *RoboHow* (Grant Agreement Number 288533).

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