Robot Manipulation Planning with Co-safe LTL Goals

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ExCAPE Meeting 2015
Robot Manipulation

Packing/unpacking
Preparing food
Serving at a Cafe
Task Formulation

Objects

Locations of interest with labels

Atomic Propositions

Object X is at a location with label Y

Manipulation Task:
Co-safe LTL formula over these atomic propositions
Temporal Manipulation Tasks

• State of the art in manipulation
  – A to B (Reachability)

• Complex tasks involve many steps
  – Detailed order may be irrelevant to user
  – Choice may determine feasibility

Offer snacks to all guests and ask for tip from the guests already served.

\[ \bigwedge_{i=1}^{k} (\Diamond (\text{snack} \in \text{guest}_i \land \Diamond \text{tip} \in \text{guest}_i)) \]
Challenges

- $\geq 6$ DoF Manipulator
- Complex Workspace
- Many Objects
- Temporal Task

HUGE continuous search space

? Abstraction

Smaller Problem
Smaller Problem
Smaller Problem

? Solving Strategy
Planning Framework

Manipulation Problem
Complexity: Dimensionality of manipulation

Planning Task (Co-safe LTL) → DFA → Modified 3-Layered Synergistic Planner → Continuous Trajectory

Abstraction

Actions  Objects  Workspace

Complexity: Dynamics of the system

Navigation Problem

Object

Action

Workspace

[ICRA 2015]
Abstraction - Overview

• Labeled, weighted graph
### Abstraction - Node

**Composition of**
- Action being performed
- Object locations
- End effector location
- Object in gripper

<table>
<thead>
<tr>
<th>An abstraction graph node</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Action</strong></td>
</tr>
<tr>
<td><strong>Object 1 Location</strong></td>
</tr>
<tr>
<td><strong>Object 2 Location</strong></td>
</tr>
<tr>
<td><strong>Robot Location</strong></td>
</tr>
<tr>
<td><strong>Object in Gripper</strong></td>
</tr>
</tbody>
</table>
Abstraction - Action Graph

- Currently 4 actions
  - Grasp, Place
    - Precomputed primitive
    - Performed using visual feedback
  - Hold, Move
    - Require planning
    - Must consider model of environment
- Could be extended to add more actions
Abstraction - Example
Synergistic Layers

Do not reconsider actions already found

Only some actions require motion planning
Example - Baxter Cafe

First trash the empty can, then offer snacks to all guests and ask for tip from the guests already served.

\[
\Diamond \left( \text{can} \in \text{trash} \land \bigwedge_{i=1}^{k} \Diamond \left( \text{snack} \in \text{guest}_i \land \Diamond \text{tip} \in \text{guest}_i \right) \right)
\]
Example - PR2 Simulation

Task: Move object of interest to region of interest

◊ (object of interest ∈ location of interest)
## Runtime

<table>
<thead>
<tr>
<th>Scenario</th>
<th># Objects</th>
<th># DFA States</th>
<th># Reachable Nodes in Product</th>
<th>Avg Total Task Planning Time (s)</th>
<th>Avg Total Motion Planning Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baxter</td>
<td>3</td>
<td>10</td>
<td>19,370</td>
<td>0.94</td>
<td>0.70</td>
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<td>498,000</td>
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<td>31.15</td>
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</tbody>
</table>

All results averaged over 50 runs
Take-aways

• Formulate manipulation tasks in co-safe LTL
  – Challenge: high dimensional continuous space

• First work to address this problem
  – Through novel abstraction and synergistic planning

• Possible future directions:
  – Faster discrete search
  – Apply abstraction to other manipulation task