Integrating Probabilistic Belief Revision and Planning for Mobile Robot Control

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Table of Contents

1 Introduction
   - Autonomous Mobile Robots
   - Hybrid control architecture
   - Planning

2 Planning

3 Description Logic

4 Belief Revision

5 Application Scenario
Outline

1. Introduction
   - Autonomous Mobile Robots
   - Hybrid control architecture
   - Planning

2. Planning

3. Description Logic

4. Belief Revision

5. Application Scenario
Autonomous Mobile Robots

KURT robots:
- 3D laser scanner
- cameras

some nice picture
Autonomous Mobile Robots

KURT robots:
- 3D laser scanner
- cameras

current PhD projects:
- mapping and integration of symbolic data
- calculating polygon maps from point clouds
- object recognition, building semantic maps
- **planning based on semantic maps**
Hybrid control architecture

- reactive layer
  - object recognition
  - following a path
  - navigating to a waypoint
  - grasping an object
  - ...

Autonomous Mobile Robots
Probabilistic Belief Revision and Planning
Hybrid control architecture

- reactive layer
  - object recognition
  - following a path
  - navigating to a waypoint
  - grasping an object
  - ...

- higher-level planning layer
  - sequence of high-level actions to perform a task
  - e.g., “open fridge; grasp bottle of beer; close fridge; go to living room; deliver beer to user”
Separate research area: action planning
- solving abstract planning problems
- large improvement over recent years
- many good planners readily available
Dissertation project

Goal of dissertation project

Using a general-purpose planner for mobile robot control, based on sensor data from 3D laser scanners and cameras
Dissertation project

Goal of dissertation project

Using a general-purpose planner for mobile robot control, based on sensor data from 3D laser scanners and cameras

Problems:

- incomplete and noisy sensor information
- changes in a dynamic environment
  → inconsistencies in the global world model
Proposed Solution

1. general-purpose planner (HTN planner)
   - accepts a consistent planning task
   - returns a sequence of actions
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2. ontology in Description Logic (OWL-DL)
   - captures background knowledge about the world
   - detects inconsistencies
Proposed Solution

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3. probabilistic belief revision model
   - keeps track of evidence for facts
   - decides on the most probable consistent world model
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Physical Blocks World ("Copy Demo", 1970)
Planning Domain Description (STRIPS)

**goal specification**

\[
\text{Goal}(\text{On}(A, B) \land \text{On}(B, C))
\]

**action specification**

\[
\text{Action( PutOn}(x, y), \\
\text{Precond: } \text{On}(x, z) \land \text{Clear}(x) \land \text{Clear}(y) \\
\quad \land x \neq z \land x \neq y \land y \neq z \\
\text{Effect: } \text{On}(x, y) \land \neg \text{On}(x, z) \land \text{Clear}(z) \land \neg \text{Clear}(y) )
\]
HTN Planning

Hierarchical Task Networks

- provide knowledge about the hierarchical structure of the planning domain
- dependency among actions can be given in the form of networks
- 3 different types of tasks:
  - primitive tasks (∼ STRIPS actions)
  - compound tasks (composed of simpler tasks)
  - goal tasks (∼ STRIPS goals, but more general)
Problems with real Sensor Data

Planners need a complete & consistent world model, but...

1. sensors are not perfect
   - incomplete information: On(C, A) ∧ OnTable(B)
   - inconsistent information: On(C, A) ∧ On(A, C)

2. the world changes dynamically
   - how to integrate new information?
Outline

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2. Planning

3. Description Logic

4. Belief Revision

5. Application Scenario
Description Logic

- family of knowledge representation languages
- used to represent terminological knowledge
- middle ground solution: more expressive than propositional logic, decidable or more efficient decision problems than predicate logic
- used in the semantic web (OWL-DL)
- many efficient reasoners are available
Using DLs for Planning

- create an ontology to encode constraints of the domain
- use a DL reasoner to detect inconsistencies

**Problem**

But: How to decide between multiple consistent worlds?
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2. Planning

3. Description Logic

4. Belief Revision

5. Application Scenario
Logical Belief Revision

- AGM postulates (Alchurrón, Gärdenfors & Makinson, 1985)
- how to integrate new and old facts in a consistent manner
- not directly applicable here, because accuracy information from the sensors is ignored
Probabilistic Belief Revision

- two main methods: Bayesian belief networks (Pearl, 1988) and probability kinematics (Jeffrey, 1965)
- beliefs as a probability distribution
- can be used to decide between different consistent world models based on, e.g.,
  - estimated accuracy of the object classification
  - source of information (user-given information, sensor data, ...)
  - amount of time since a particular piece of information was sensed
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Application Scenario

- office floor (rooms + corridor) with obstacles (tables, chairs)
- objects of interest: traffic cones, wooden cubes, ...
- tasks: bringing objects to target locations, generate target aggregates
- exogenous events (opening/closing doors, moving/adding/removing objects)
Questions?

Thank you for your attention!
Any questions?
Proofs, Definitions and Friends

Proof.

Proof

Definition

Definition

Lemma

Lemma

Theorem

Theorem
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