Integrating Probabilistic Belief Revision and Planning for Mobile Robot Control

Max Mustermann

mmusterm@uos.de

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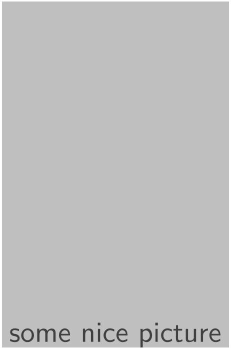
UNIVERSITÄT OSNABRÜCK

Table of Contents

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

Autonomous Mobile Robots

some nice picture

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
  - ...

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”

Planning

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

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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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   - detects inconsistencies

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1. general-purpose planner (HTN planner)
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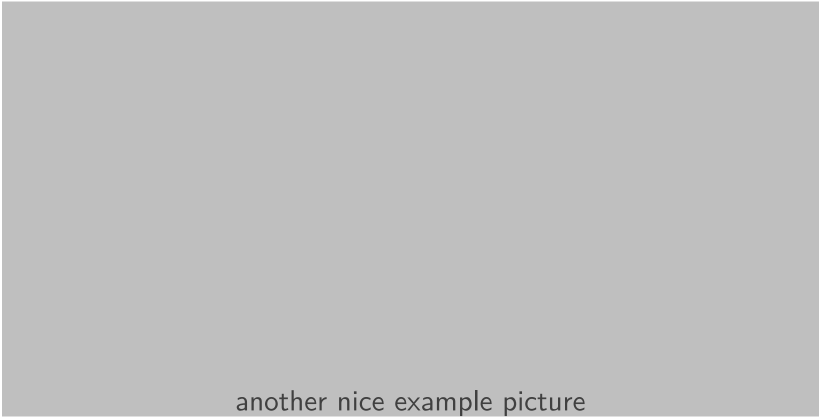
2. ontology in Description Logic (OWL-DL)
    - captures background knowledge about the world
    - detects inconsistencies
3. probabilistic belief revision model
    - keeps track of evidence for facts
    - decides on the most probable consistent world model

Outline

Physical Blocks World (“Copy Demo”, 1970)



Planning Domain Description (STRIPS)

goal specification

Goal(On(A, B) $\wedge$ On(B, C))

action specification

Action(PutOn(x, y),
Precond: On(x, z) $\wedge$ Clear(x) $\wedge$ Clear(y)
$\wedge\ x \neq z \wedge x \neq y \wedge y \neq z$
Effect: On(x, y) $\wedge \neg$ On(x, z) $\wedge$ Clear(z) $\wedge \neg$ 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: $\text{On}(C, A) \wedge \text{OnTable}(B)$
   - inconsistent information: $\text{On}(C, A) \wedge \text{On}(A, C)$
2. the world changes dynamically
   - how to integrate new information?

Outline

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?

Outline

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

Outline

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

color test

- item

1. enumerate

color test

- item

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color test

- item

1. enumerate