

Integrating Probabilistic Belief Revision and Planning for Mobile Robot Control

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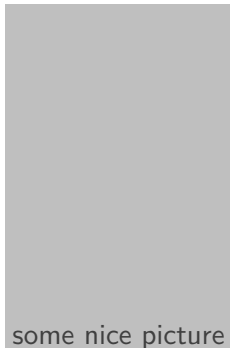
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Outline

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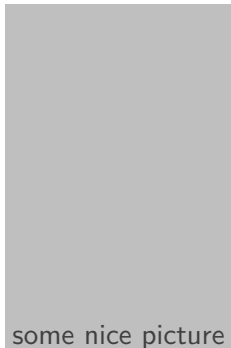
Autonomous Mobile Robots



KURT robots:

- 3D laser scanner
- cameras

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
 - ...

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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- 2** ontology in Description Logic (OWL-DL)
 - captures background knowledge about the world
 - detects inconsistencies

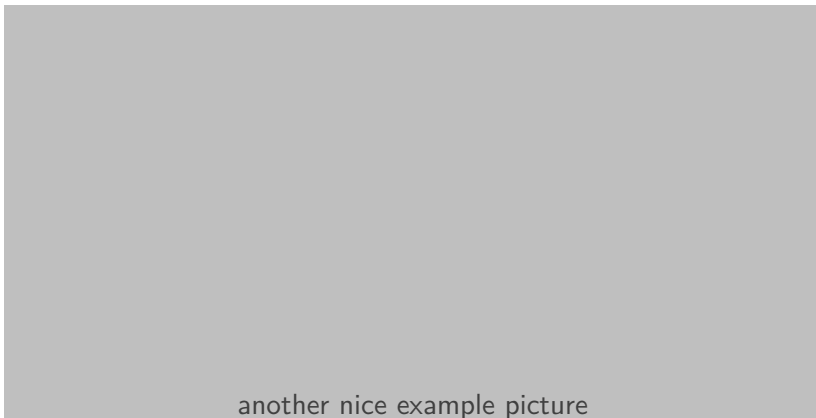
Proposed Solution

- 1** general-purpose planner (HTN planner)
 - accepts a consistent planning task
 - returns a sequence of actions
- 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

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Physical Blocks World (“Copy Demo”, 1970)



Planning Domain Description (STRIPS)

goal specification

 $\text{Goal}(\text{On}(A, B) \wedge \text{On}(B, C))$

action specification

Action(PutOn(x, y),Precond: $\text{On}(x, z) \wedge \text{Clear}(x) \wedge \text{Clear}(y)$ $\wedge x \neq z \wedge x \neq y \wedge y \neq z$ Effect: $\text{On}(x, y) \wedge \neg \text{On}(x, z) \wedge \text{Clear}(z) \wedge \neg \text{Clear}(y)$)

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 (\approx STRIPS actions)
 - compound tasks (composed of simpler tasks)
 - goal tasks (\approx 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?

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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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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

color test

■ item

1 enumerate

color test

■ item

1 enumerate

color test

■ item

1 enumerate