Integrating Probabilistic Belief Revision and Planning for Mobile Robot Control

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Outline

Autonomous Mobile Robots

some nice picture

KURT robots:

- 3D laser scanner
- cameras

Autonomous Mobile Robots

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KURT robots:

- 3D laser scanner
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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

$\rightarrow$ inconsistencies in the global world model

Proposed Solution

1. general-purpose planner (HTN planner)
   - accepts a consistent planning task
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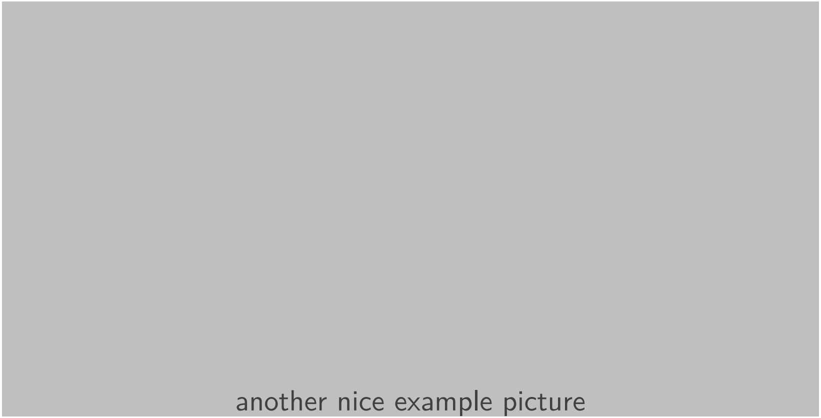
   - captures background knowledge about the world
   - detects inconsistencies
3. probabilistic belief revision model
   - keeps track of evidence for facts
   - decides on the most probable consistent world model

Outline

Physical Blocks World (“Copy Demo”, 1970)



Planning Domain Description (STRIPS)

goal specification

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

action specification

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

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?

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