From Structure to Actions: Semantic Navigation Planning in Office Environments

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Semantic Navigation at a Glance

- Abstract, action-based navigation
- Abstract, region-based environment model with meaning attached to the regions
- Abstract, relation-based localisation

Inspired by human navigation patterns
Objectives

**Robust Navigation**
- Tolerate localization variance
- Tolerate imprecise and outdated maps
- Tolerate dynamic and semi-dynamic obstacles

**Portability**
- Robot with a different set of actions
- Environment with different properties

**Limited sensors**
- Sensors are expensive
- Sensors cannot detect every object in an environment

**Flexible user interface**
- Abstract commands
- Human user
- Mission control system as user
System Context

Mission Control System

User Interface → Manager → Semantic Navigation

Semantic Mission Planner → Semantic Mapping → Semantic Localisation

Mission Data Analysis → Navigation Data Analysis

Execution Unit → Basic Control

Service Robot

- Semantic Level
- Symbolic-Semantic Level
- Subsymbolic-Symbolic Level
- Subsymbolic Level

Data Flow
Semantic Region Map

- Abstract environment model
- Metric features
- Topological features
- Semantic features
- Spatial relations
Region Geometry

- Abstracts from the real region contour
- Three connected rectangles
- Mandatory central rectangle
- Optional left and right sub-rectangles

\[ G_R = (x, y, w, h, \gamma, w_l, h_l, y_l, w_r, h_r, y_r) \]
Topology

- Discrete relative orientation between regions
  - R1 northOf R2
  - R1 eastOf R2
  - R1 southOf R2
  - R1 westOf R2

- Connected neighbors
  - R1 neighborOf R2

- Hierarchy
  - R1 containedIn R2
Region Class

- Represents the semantic meaning of a Region
- Region concept in the ontology
  - Used to declare the available region relations
  - Used for generic rules
- Application dependent sub-concepts
Semantic Positions

- Abstract navigation points
- Defined via relations to regions nearby
- Discrete relations for distance, relative orientation
- Implicitly derived from the Semantic Region Map by the semantic environment model
Robot Actions

- Robots are able to perform complex, symbolic actions

- Action concept in the ontology
  - Robot actions are instances of the Action concept

- Reachability concept in the ontology
  - Connects semantic positions to a reachability graph
  - Edges are labelled with robot actions

```plaintext
Action[].
Reachability[].
```
Semantic Navigation Algebra

- Derive symbolic region orientation from the region geometry
- Convert local semantic position relations between regions
- Decouple the environment and robot model from region orientations

?SP[localSouthSideOf->?R2]
   ?R1[hasOrientation->West] AND ?R2[hasOrientation->North] AND
Environment Modeling – Step 1

Generic Procedure

- Model robot actions as instances of the Action concept

Office Robot

Diagram showing relationships between "TransitDoor", "FollowWall", "TurnFromDoor", "Action", "DriveStraight", and "TurnToDoor".
Environment Modeling – Step 2

Generic Procedure
- Identify relevant region classes for the environment
- Model them as instances of the Region concept

Office Robot

```
Region
  ├── Corridor
  └── Room

Region
  └── Door
```
Environment Modelling – Step 3

Generic Procedure

- Identify relevant semantic positions
- Determine relations between semantic positions and regions
- Determine neighborhood relations between the identified semantic positions

Office Robot

Door neighborOf Region
Door neighborOf Corridor
Environment Modelling – Step 4

Generic Procedure

- Identify pairs of neighboring semantic positions that can be reached by a robot action

Office Robot
Navigation Planning

- Given:
  - Current semantic position of the robot
  - Description of the target position

- Extract reachability graph from knowledge base
  - Nodes: Semantic positions
  - Edges: Reachability instances

- Retrieve target semantic position from knowledge base
- Plan shortest path in the reachability graph
Summary

- Semantic Region Map
  - Abstract environment model with metric, topological and semantic features
- Semantic Positions
  - Abstract navigation points, characterised by relations to regions nearby
- Semantic model of robot actions
  - Action and Reachability concept in the ontology
- Semantic Navigation Algebra
  - Decouples the environment and robot model from region orientations
- Generic modelling methodology
  - Steps to follow when modelling an application domain
- Semantic Navigation Planning
  - Shortest path search on an inferred reachability graph
Thank you for your attention!