Topological Path Planning

*Introduction to AI Robotics (Ch. 9)*
“We are what we repeatedly do. Excellence, then, is not an act, but a habit.”

Aristotle
ANNOUNCEMENTS

- Lab 6 due on *Tuesday, 4/20/10*

- Quiz 11 on Ch. 9, Lec. 6-1 on *Thursday, 4/22/10*

- Lab 6 memo and code is due on Angel by midnight on *Thursday, 4/22/10*
OBJECTIVES

Upon completion of this lecture the student should be able to:

- Define the differences between natural and artificial landmarks and give one example of each
- Given a description of an indoor office environment and a set of behaviors, build a relational graph representation labeling the distinct places and local control strategies using gateways
- Describe in one or two sentences: gateway, image signature, visual homing, viewframe, and orientation region
- Given a figure showing landmarks, create a topological map showing landmarks, landmark pair boundaries, and orientation regions
NAVIGATION

• *Navigation* refers to the way a robot finds its way in the environment
• This is a difficult problem because it is rooted in uncertainty
• It is difficult for a robot to know exactly where it is and how to get to its next destination
NAVIGATION

- **Navigation** is one of the most challenging mobile robot competencies
- Successful navigation requires
  - Perception
  - Localization
  - Cognition
  - Motion Control
MOBILE ROBOT NAVIGATION

- **Perception**
  - The robot must interpret its sensors to extract meaningful data

- **Localization**
  - The robot must determine its position in the environment

- **Cognition**
  - The robot must decide how to act to achieve its goals

- **Motion Control**
  - The robot must modulate its motor outputs to achieve the desired trajectory
NAVIGATION AND REACTIVE ROBOTS

- Reactive robots have behaviors for moving about the world without collisions
- However, navigation is more purposeful and requires deliberation
- There are two types of navigation
  - Topological (qualitative)
  - Metric (quantitative)
- There are 4 questions for navigation
  - Where am I going? (human or mission planner)
  - What’s the best way to get there? (path planning)
  - Where have I been? (map making/updates)
  - Where am I? (localization)
NAVIGATION PROBLEMS

• The robot may need to use a map for *path planning* assuming that the map is correct or that the world does not change
• The robot may need to also find itself on a map and this is the *localization* problem
• If the robot is trying to find a location on a map without prior knowledge and it must use a good search strategy this the *coverage* problem
• If the robot does not have a map of its world then it must build a map as it goes along and this is the *mapping* problem (i.e. SLAM)
TWO NAVIGATION METHODS

How to navigate between A and B,

- Use *localization* with respect to a map to navigate to the goal B
- Use *behavior-based navigation* without hitting obstacles
  - Follow walls with obstacle avoidance
  - Detect the goal location
SEARCH AND PATH PLANNING

- There are many possible paths between the start and the goal point for a robot
- The robot finds all of them by searching the map
- To make this efficient, the map is turned into a graph, a set of nodes and the lines that connect them
- A path planner looks for the optimal path based upon some criterion (i.e. distance, safest)
- Path planning requires robots to perform higher-level thinking or reasoning
COMPETENCIES FOR NAVIGATION

- The robot must incorporate new information gained during plan execution. The planner must incorporate this new information as it is received in order to correct a planned trajectory.

- When a planner incorporates every new piece of information in real time, instantly produces a new plan and reacts this is called integrated planning and execution.

- Robot control can usually be decomposed into global and local behaviors or rules:
  - wall following \((local)\)
  - find objects \((global)\)
  - path planning \((global)\)
  - obstacle avoidance \((local)\)
PLANNER OPTIONS

- Some planners do not look for optimal paths but use a local map to plan a path and speed up the process.
- Other planners look for the first path that gets the robot to the goal.
- It requires a great deal of work to represent the environment, plan a path and convert the path to a set of movement commands to the robot.
SPATIAL MEMORY

• The world’s representation is the robot’s *spatial memory*

• Spatial memory supports 4 basic functions
  • *Attention* – what features or landmarks to look for?
  • *Reasoning* – can the robot fit through a space?
  • *Path planning* – what is the best way through this space?
  • *Information collection* – What does this place look like? Have I been here before? Has anything changed?
TWO FORMS OF SPATIAL MEMORY

- **Route (qualitative)**
  - Express space in terms of the connections between landmarks (egocentric view)
  - i.e. go to the stop sign and make a left at McDonalds

- **Layout (metric)**
  - Express space in a metric representation that have some approximate scale to estimate distances to travel (bird’s eye view)
  - Layout representations can be used to generate a route representation but not necessarily vice versa
TWO TYPES OF ROUTE REPRESENTATIONS

- **Relational**
  - Most popular, the robot connects the dots,
  - Focus on graph-like representation of spatial memory

- **Associative**
  - Focus on coupling of sensing with localization
  - Parallels the tight coupling of sensing to action found in reflexive behaviors

- *Relational techniques* support path planning
- *Associative techniques* support retracing known paths
Topological navigation depends on the presence of landmarks. A landmark is a perceptually distinctive feature of interest on an object or locale of interest (i.e. red door, McDonald’s). A gateway is an opportunity for a robot to change its overall direction of navigation (i.e. intersection of 2 hallways). Landmarks can be artificial – added to an object or locale to support recognition (i.e. interstate highway exit) or natural – configuration of existing features for recognition (i.e. McDonald’s golden arches).
CRITERIA FOR LANDMARKS

- Be readily recognizable
- Support the task dependent activity
- Be perceivable from many different viewpoints
TOPOLOGICAL PATH PLANNING

- A *relational graph* has nodes which represent landmarks, gateways and goal locations.
- The *gateways* are opportunities for the robot to change the path heading.
- The *edges* of the relational graph represent a navigable path.

ECE 497 Lecture 6-1: Topological Path Planning (C.A. Berry)
A distinctive place is a landmark that the robot could detect from a nearby region called a neighborhood.

Based upon cognitive science,
- Lowest level of representing space are landmarks (doors, hallways) and procedural knowledge to travel between them (follow hall, move thru door)
- Next level is topological which supported planning and reasoning in a relational graph
- Uppermost level is metric where the agent learning distance and orientation between landmarks in a fixed coordinate system
- Higher layers represent increasing intelligence
DISTINCTIVE PLACES

- The robot uses one behavior until it sees the distinctive place and then uses a different behavior in the neighborhood to landmark localization behavior in the neighborhood.

- Behaviors serve as local control strategies and releasers signal the entrance to a neighborhood.

![Diagram showing path of robot as it moves into neighborhood and to the distinctive place with labels for neighborhood boundary, distinctive place (within the corner), and path of robot as it moves into neighborhood and to the distinctive place.]

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CONTROL SCHEME FOR A RELATIONAL GRAPH

- The following floor plan has been made into a relational graph
- Each edge should be labeled with the appropriate *local control strategy (lcs)*
  - mtd: move through door
  - fh: follow hall
- Each node should be labeled with the type of gateway
  - t: t – junction
  - de: dead end
  - r: room
# TRANSITION TABLE FOR RELATIONAL GRAPH

<table>
<thead>
<tr>
<th></th>
<th>Room</th>
<th>T-junction</th>
<th>Dead End</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Room</strong></td>
<td>Undefined</td>
<td>Move through</td>
<td>Undefined</td>
</tr>
<tr>
<td></td>
<td></td>
<td>doorway</td>
<td></td>
</tr>
<tr>
<td><strong>T-junction</strong></td>
<td>Move through</td>
<td>Follow hall</td>
<td>Follow hall</td>
</tr>
<tr>
<td></td>
<td>doorway</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dead End</strong></td>
<td>Undefined</td>
<td>Follow hall</td>
<td>Undefined</td>
</tr>
</tbody>
</table>

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ADVANTAGES AND DISADVANTAGES

- It eliminates navigational errors at each node and build up a reasonable metric map
- Supports discovery of new landmarks as the robot explores an unknown environment
- A landmark must be unique at a node pair
- Good distinctive places are hard to perceive
- Landmarks were not locally unique
- There are also indistinguishable locations
ASSOCIATIVE METHODS

- *Associative methods* for topological navigation create a behavior which converts sensor observation into the direction to go to reach a particular landmark.
- The landmark or location must have
  - Perceptual stability
    - Views of the location that are close together look similar
  - Perceptual distinguishability
    - Views that are far away look different
- This is implicit in the idea of neighborhood around a distinctive place
VISUAL HOMING

- **Visual homing** is the use of image signatures to direct a robot to a specific location.
- An **image signature** is created by partitioning an image of a landmark or a location into sections.
- If the robot is in the neighborhood of the location, then the image measurements should be approximately the same pattern.
QUALNAV

- Qualitative navigation means to localize a vehicle to a particular orientation region

- An orientation region is a patch of the world defined by landmark pair boundaries

- A landmark pair boundary is an imaginary line drawn between two landmarks

- Robot creates an outdoor topological map as it explores the world

- It can also coarsely localize itself to a metric map
NAVIGATION SCRIPTS

- Path planning and execution are deliberative
- Cartographer maintains a map in the form of a graph and monitors progress
- Transition table is a high level sequencer
- Scripts specify and carry out the implied details of the plan