LECTURE 6-1

Topological Path Planning

Introduction to AI Robotics (Ch. 9)

Quote of the Week

“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*

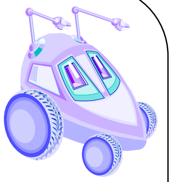
OBJECTIVES

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 interprets its sensors to extract meaningful data
- ***Localization***
  - The robot must determine it's position in the environment
- ***Cognition***
  - The robot must decide how to act to achiever 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)

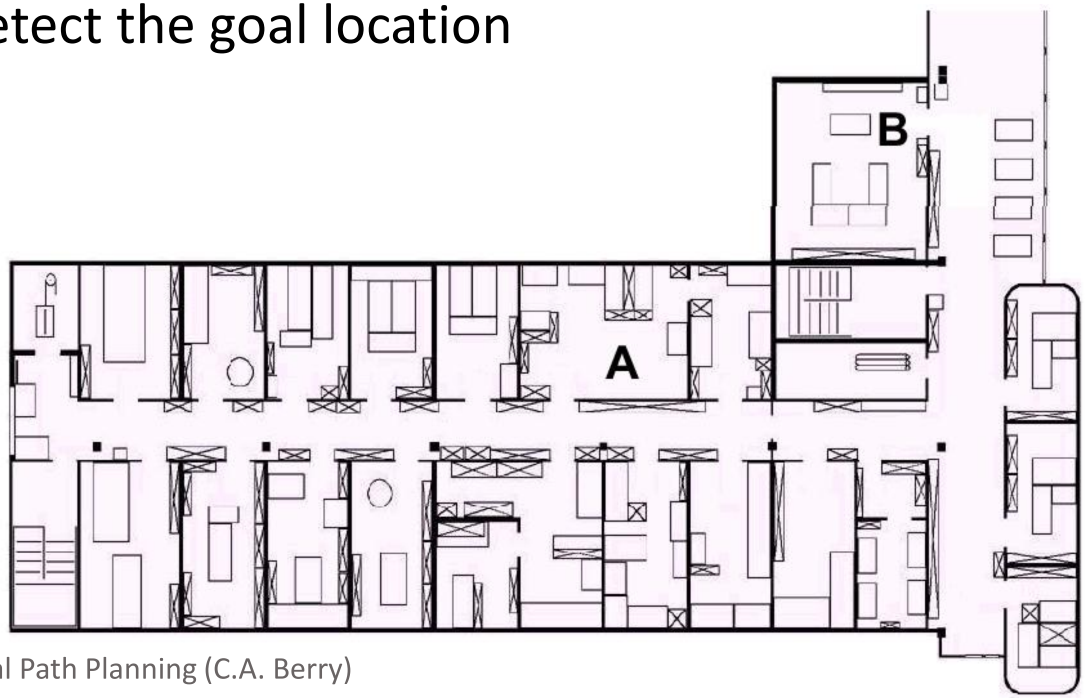
NAVIGATION PROBLEMS

- 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

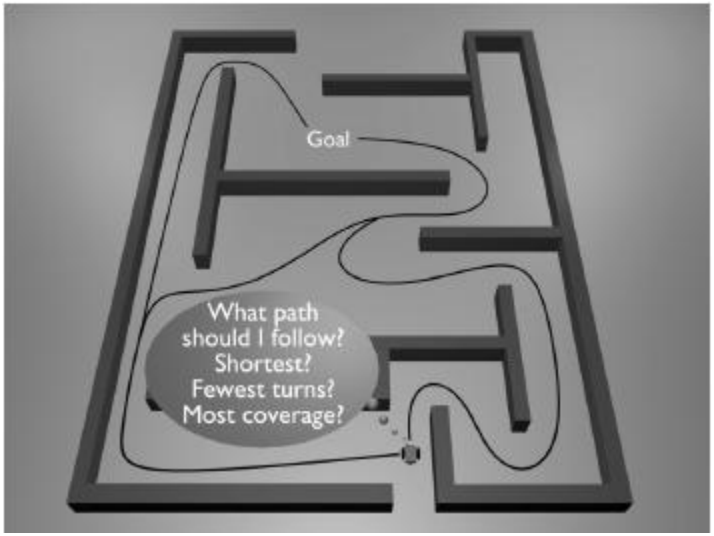
- There are many possible paths between the start and the goal point for a robot
- The robot finds all of them by searching the map
- To make this efficient, the map is turned into a ***graph***, a set of nodes and the lines that connect them
- A path planner looks for the ***optimal path*** based upon 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

- 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)
  - Natural – configuration of existing features for recognition (i.e. McDonald's golden arches)

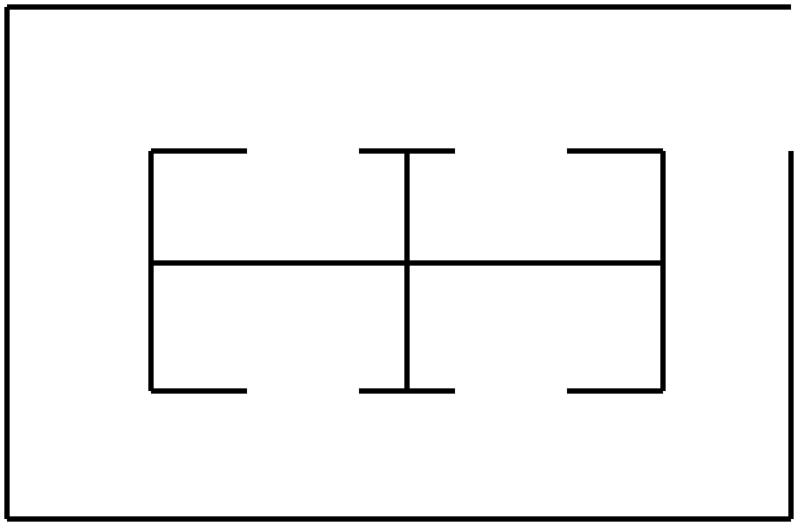
CRITERIA FOR LANDMARKS

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

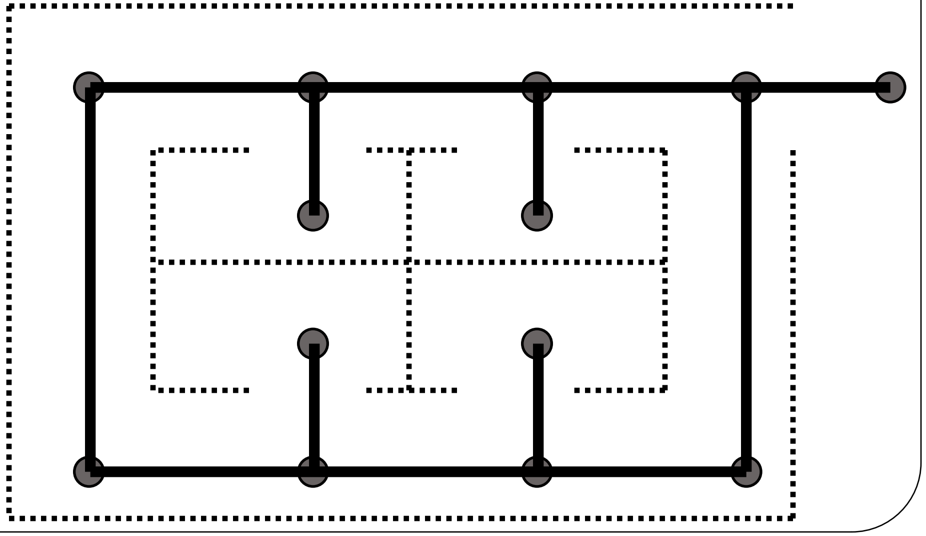
TOPOLOGICAL PATH PLANNING

- 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

floor plan

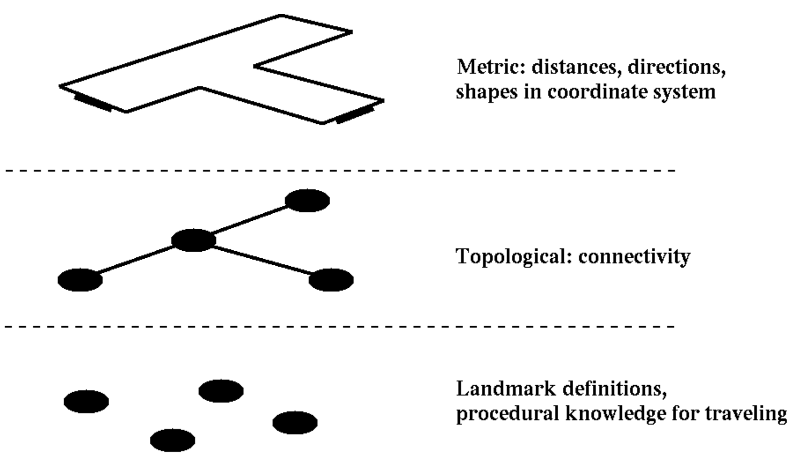


relational graph



DISTINCTIVE PLACES

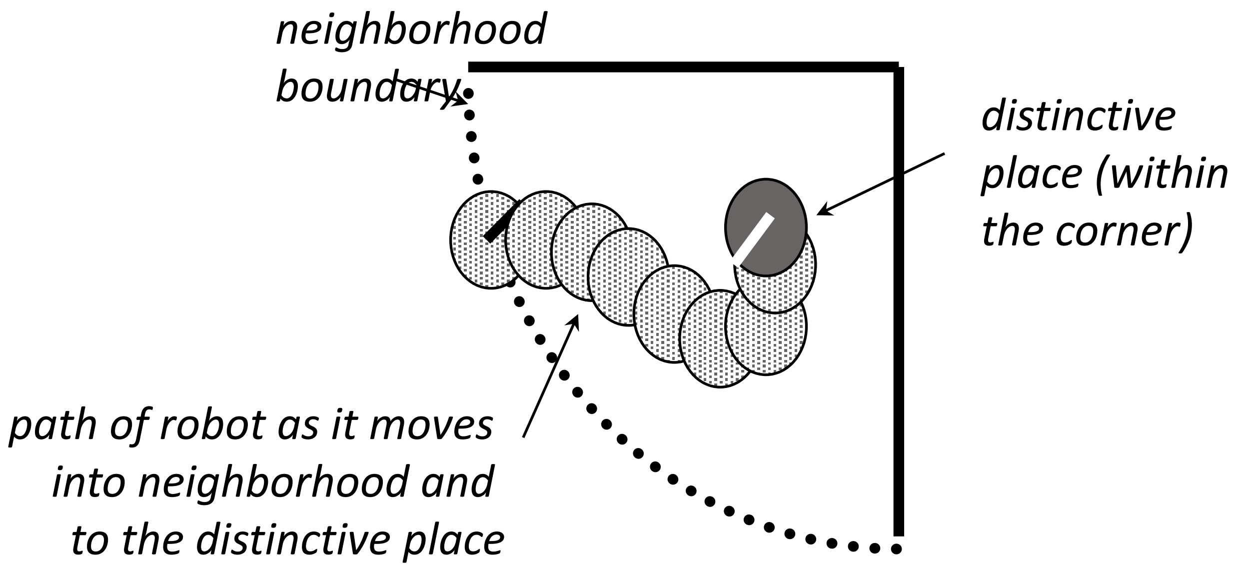
- A *distinctive place* is a landmark that the robot could detect from a nearby region called a *neighborhood*



- 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

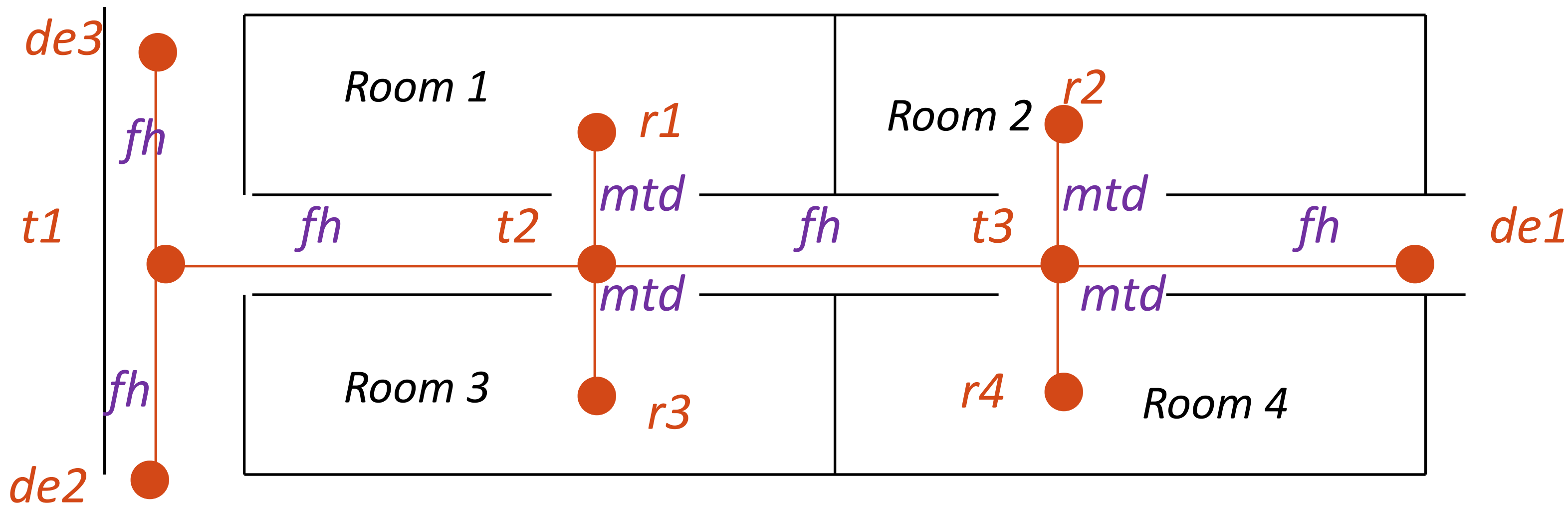
DISTINCTIVE PLACES

- 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



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 gate way
  - t: t – junction
  - de: dead end
  - r: room



TRANSITION TABLE FOR RELATIONAL GRAPH

	Room	T-junction	Dead End
Room	Undefined	Move through doorway	Undefined
T-junction	Move through doorway	Follow hall	Follow hall
Dead End	Undefined	Follow hall	Undefined

ADVANTAGES AND DISADVANTAGES

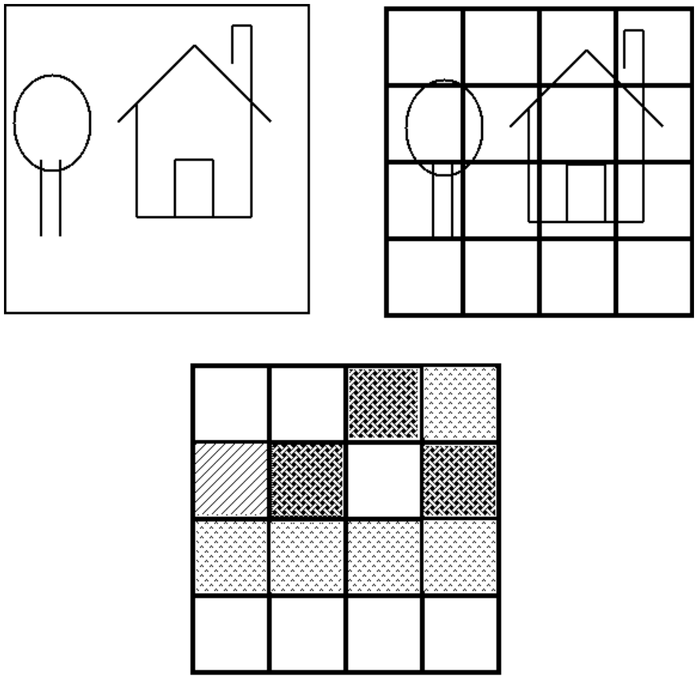
- It eliminates navigational errors at each node and build up a reasonable metric map
- Supports discovery of new landmarks as the robot explores an unknown environment
- A landmark must be unique at a node pair
- Good distinctive places are hard to perceive
- Landmarks were not locally unique
- There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



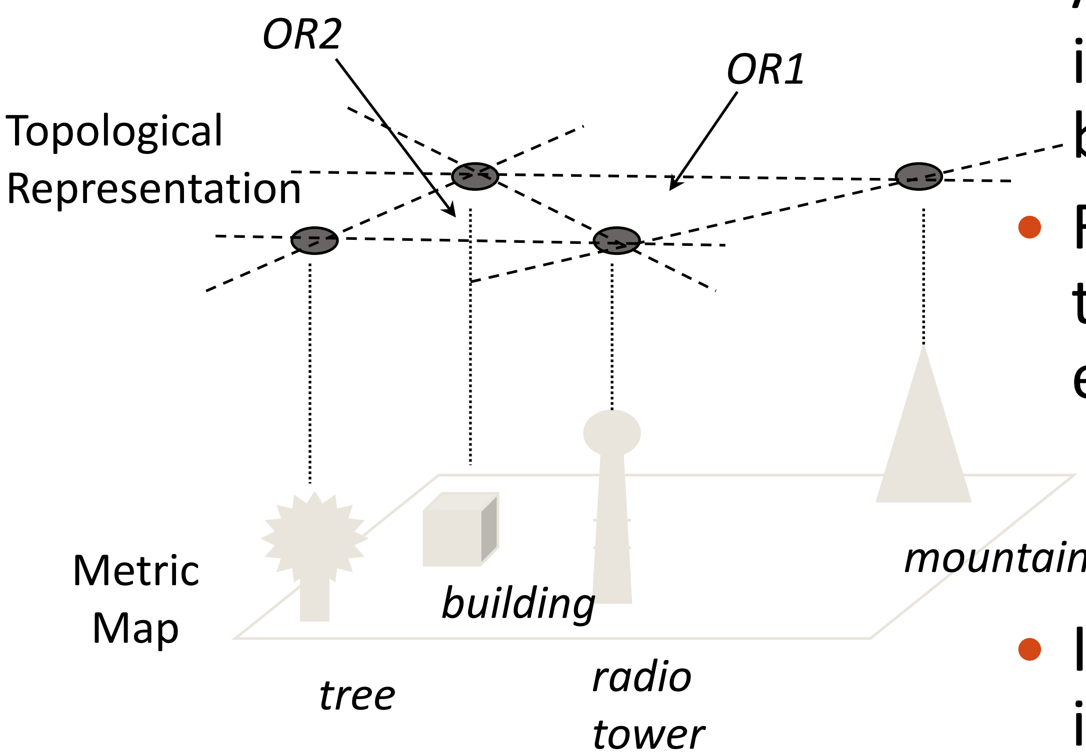
Home image

tessellated

image signature

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