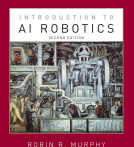
13 Topological Navigation

What is navigation?

How do animals navigate?

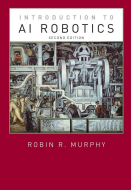
Are there different types of navigation?

Which one is the best?



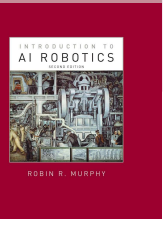
13 Specific Learning Objectives

- Name the four questions of navigation, the associated robotic functions, and the areas of artificial intelligence those functions draw upon.
- Explain the role of spatial memory in navigation and the four basic functions of special memory.
- Contrast route, or topological navigation, with layout, or metric, navigation.
- Define the difference between a natural and artificial landmark and give one example of each.
- Define gateway, perceptual stability, and perceptual distinguishability.



13 Specific Learning Objectives (Cont.)

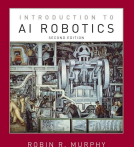
- Given a description of an indoor office environment and a set of behaviors, build a relational graph representation labeling the distinctive places and local control strategies using gateways.
- Compare and contrast relational and associative methods of topological navigation



13 Introduction to Navigation

- Navigation is a fundamental robotics problem because it involves almost everything about AI robotics:
  - Sensing
  - Acting
  - Planning
  - Architectures
  - Hardware
  - Computational efficiencies
  - Problem solving

- **Criteria for Evaluating Path Planners:**
  - **Complexity**
  - **Sufficiently represents the terrain**
  - **Sufficiently represents the physical limitations of the robot platform**
  - **Compatible with the reactive layer**
  - **Supports corrections to the map and re-planning**

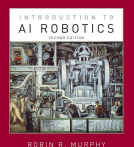


Navigation: 4 Questions

- Navigation is about getting to a specific location. It is a fundamental ability in autonomous mobile robotics

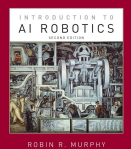
- Four questions and primary aspects of navigation:
  - Where am I going?
    - Usually defined by human operator or mission planner
  - What's the best way to get there?
    - Path planning: qualitative and quantitative
  - Where have I been?
    - Map making
  - Where am I?
    - Localization: relative or absolute

Simultaneous Localization And Mapping (SLAM)



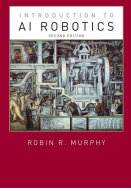
Navigation Requires Spatial Memory

- Spatial memory: A robot's world representation and how it is maintained over time
  - Provides methods and data structures for processing and storing information derived from sensors
  - Organized to support methods that extract relevant expectations about a navigational task
- Four basic functions of Spatial memory:
  - Attention: What features or landmarks to look for next?
  - Reasoning: Can I fit through that door?
  - Path Planning: What is the best way through this building?
  - Information collection: What does this place look like? Have I ever seen it before? What has changed since I was here before?



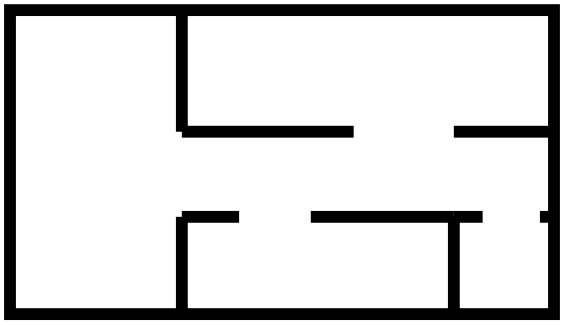
Navigation Requires Spatial Memory (Cont.)

- Two forms of Spatial memory:
  - Qualitative (route):
    - Express space in terms of connections between landmarks
    - Dependent upon perspective of the robot
    - Orientation clues are egocentric
    - Usually cannot be used to generate quantitative (metric/layout) representations
  - Quantitative (metric or layout):
    - Express space in terms of physical distances of travel
    - Bird's eye view of the world
    - Not dependent upon the perspective of the robot
    - Independent of orientation and position of robot
    - Can be used to generate qualitative (route) representations

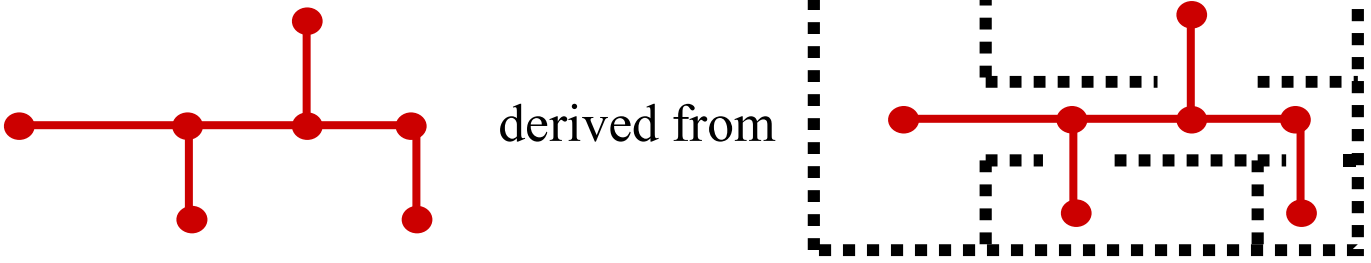


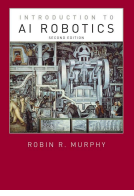
Navigation Requires Spatial Memory (Cont.)

- Examples of two forms of spatial memory
  - *Layout (or Quantitative, or metric)*

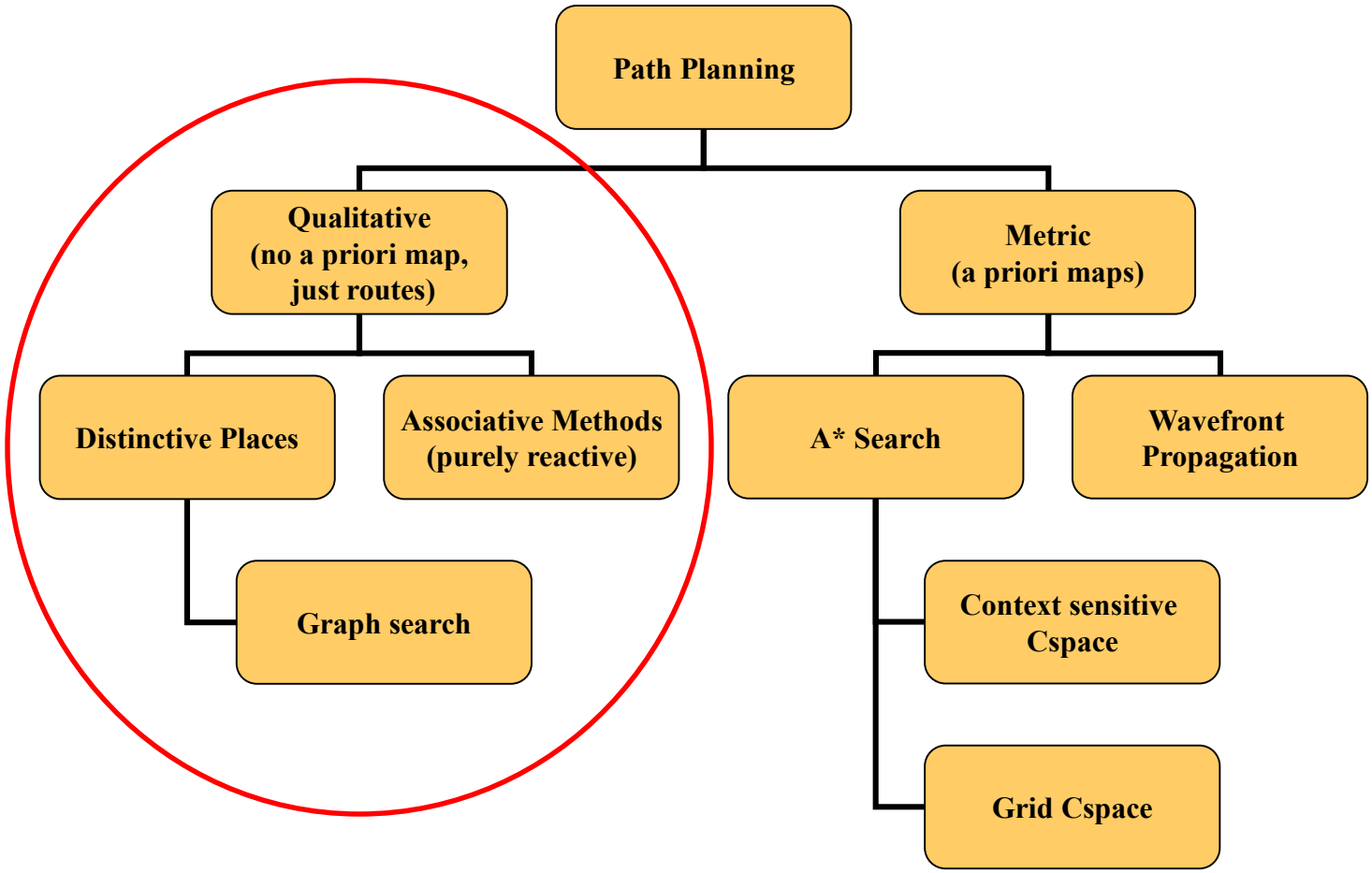


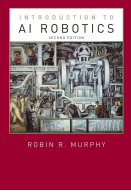
  - *Route (or qualitative)*





Path Planning



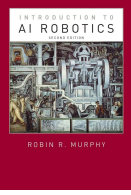


13 Route, or Qualitative Navigation

- Also referred to as topological navigation
- Based upon points of interest
  - E.g., landmarks

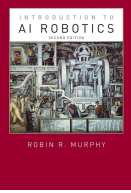
- Why Qualitative Navigation?
  - Don't have GPS indoors
  - Don't always have lasers
  - People don't have to accurately measure distances, just turn right at the end of the hall

- But… qualitative navigation has become less important, still a good thing to know



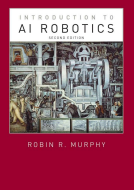
Topological Maps Use Landmarks

- A *landmark* is one or more perceptually distinctive features of interest on an object or locale
- *Natural landmark*: configuration of existing features that wasn't put in the environment to aid with the robot's navigation (ex. gas station on the corner)
- *Artificial landmark*: set of features added to the environment to support navigation (ex. highway sign)

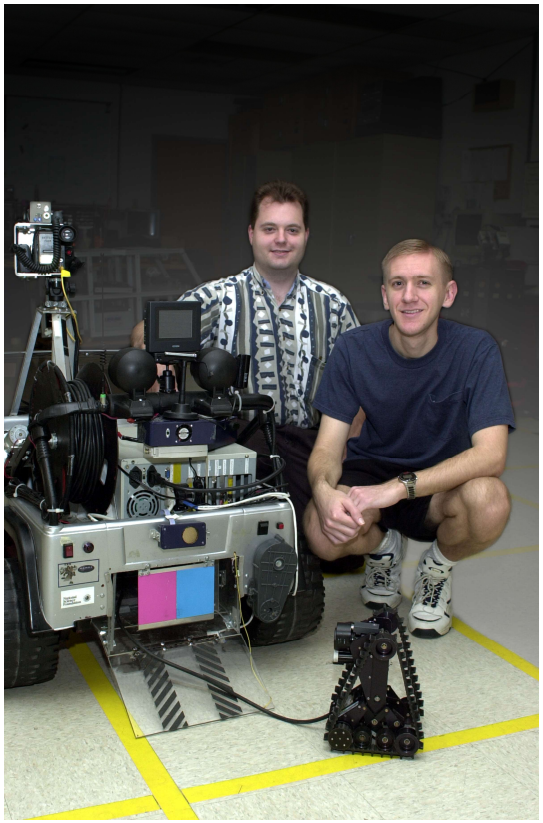


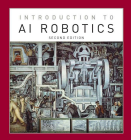
Desirable Characteristics of Landmarks

- Readily recognizable (can see it when you need to)
  - Passive
  - Perceivable over the entire range of where the robot might need to view it
  - Distinctive features should be globally unique, or at least locally unique
- Perceivable for the task (can extract what you need from it)
  - ex. can extract relative orientation and depth
  - ex. unambiguously points the way
- Be perceivable from many different viewpoints



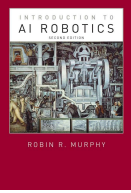
Example Landmarks





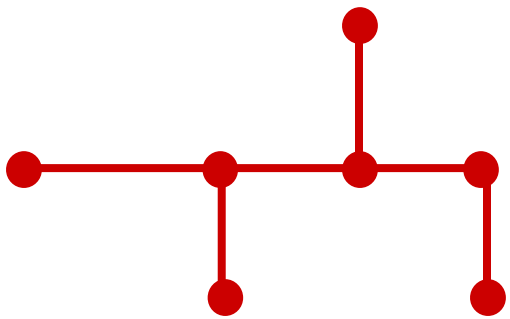
Two Methods

- *Relational*
  - E.g., “Go down the hall, turn to the left at the dead end, and enter the second doorway on the right”
  - Precise metric information not used
  - **Spatial memory is a relational graph, also known as a topological map**
  - Use graph theory to plan paths
- *Associative*
  - **Spatial memory is a series of remembered viewpoints, where each viewpoint is labeled with a location**
  - Good for retracing steps



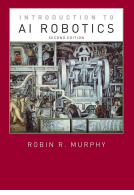
Relational Methods

- Represent world as graph or network of nodes and edges
  - Nodes: represent gateways, landmarks, or goals
  - Edges: represent a navigable path between two nodes; can also have additional information attached (e.g., direction, terrain type, behaviors needed to navigate the path)

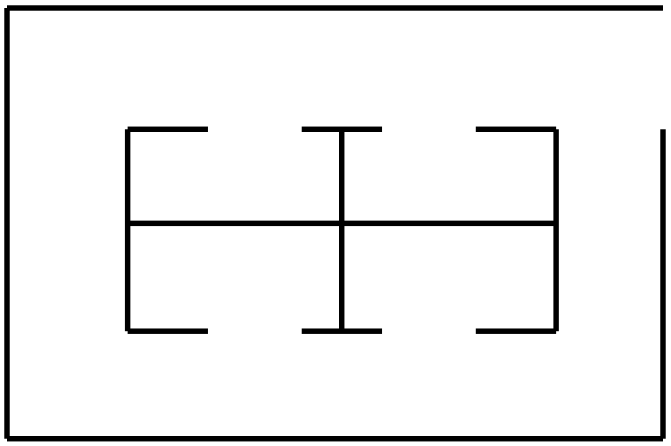


Gateway

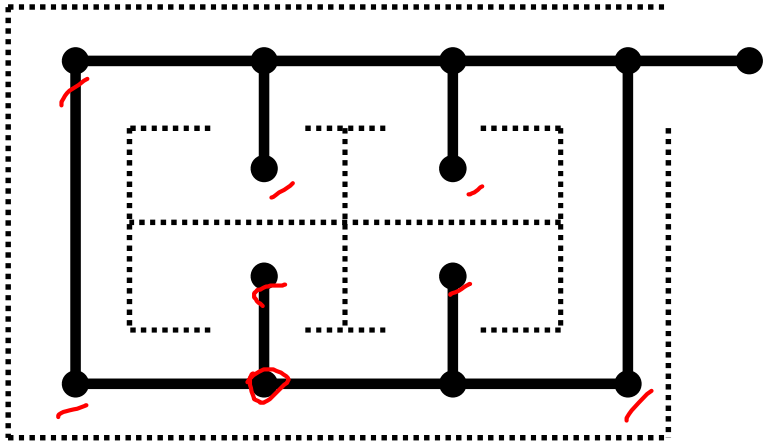
- **Special case of landmark, where robot has opportunity to change its heading**
- **Examples: intersection of hallways**



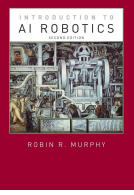
Derive Relational graph from floor plan



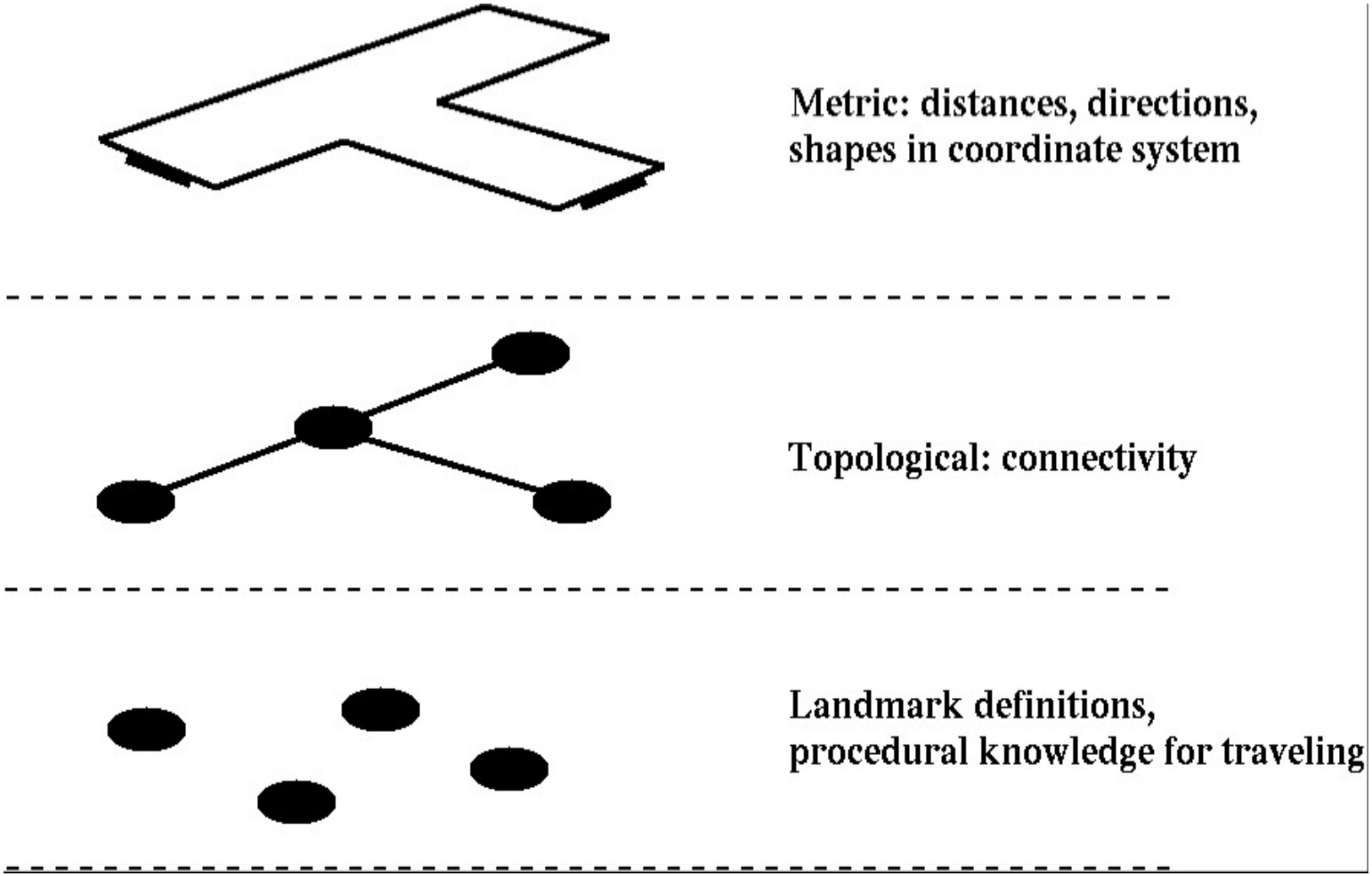
floor plan

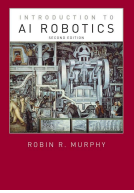


Relational graph



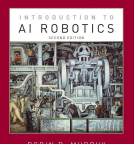
13 Kuipers & Byun: Spatial Hierarchy



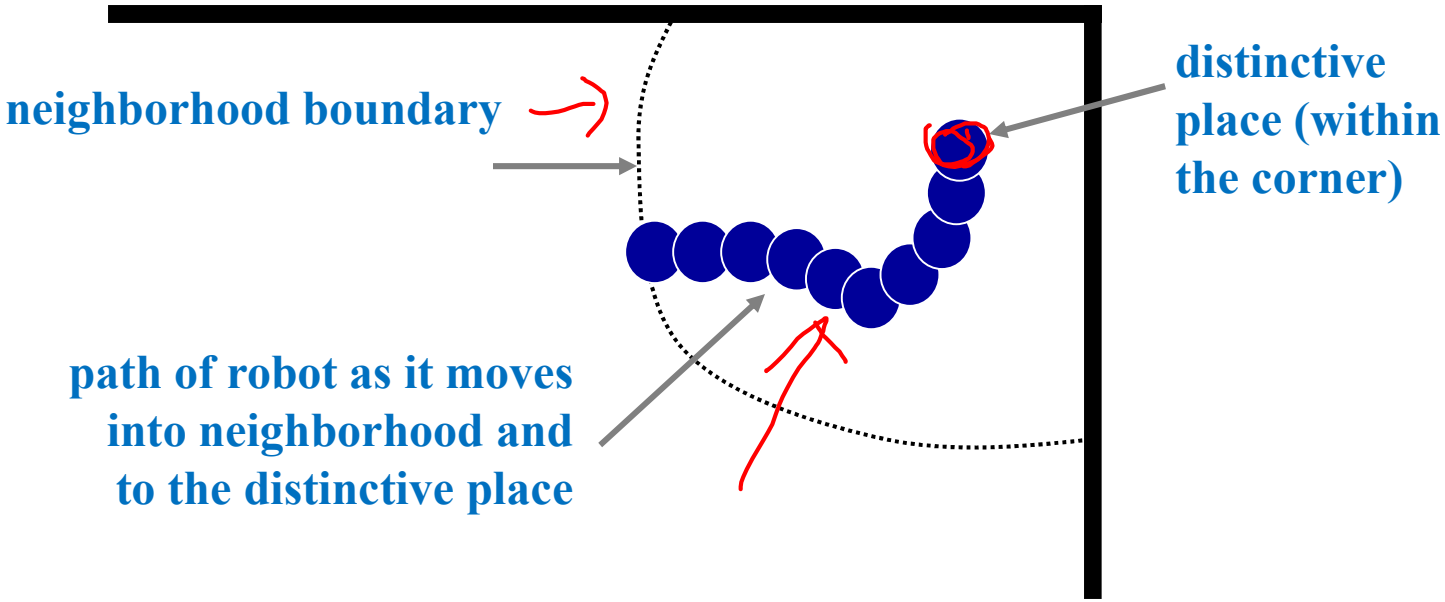


13 Distinctive Place (DP) Approach

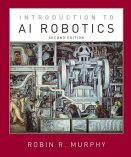
- Distinctive place: landmark that robot can detect from nearby region called "neighborhood"
- Once robot in the neighborhood, it uses sensors to position itself relative to the landmark
- Edge in the relational graph: local control strategy (lcs)
  - Procedure (behavior) for getting from current node to next node
- When landmark sensed, "hill-climbing" used to direct robot around in the neighborhood.
- The feature values are maximum at distinctive place



Example of Distinctive Place



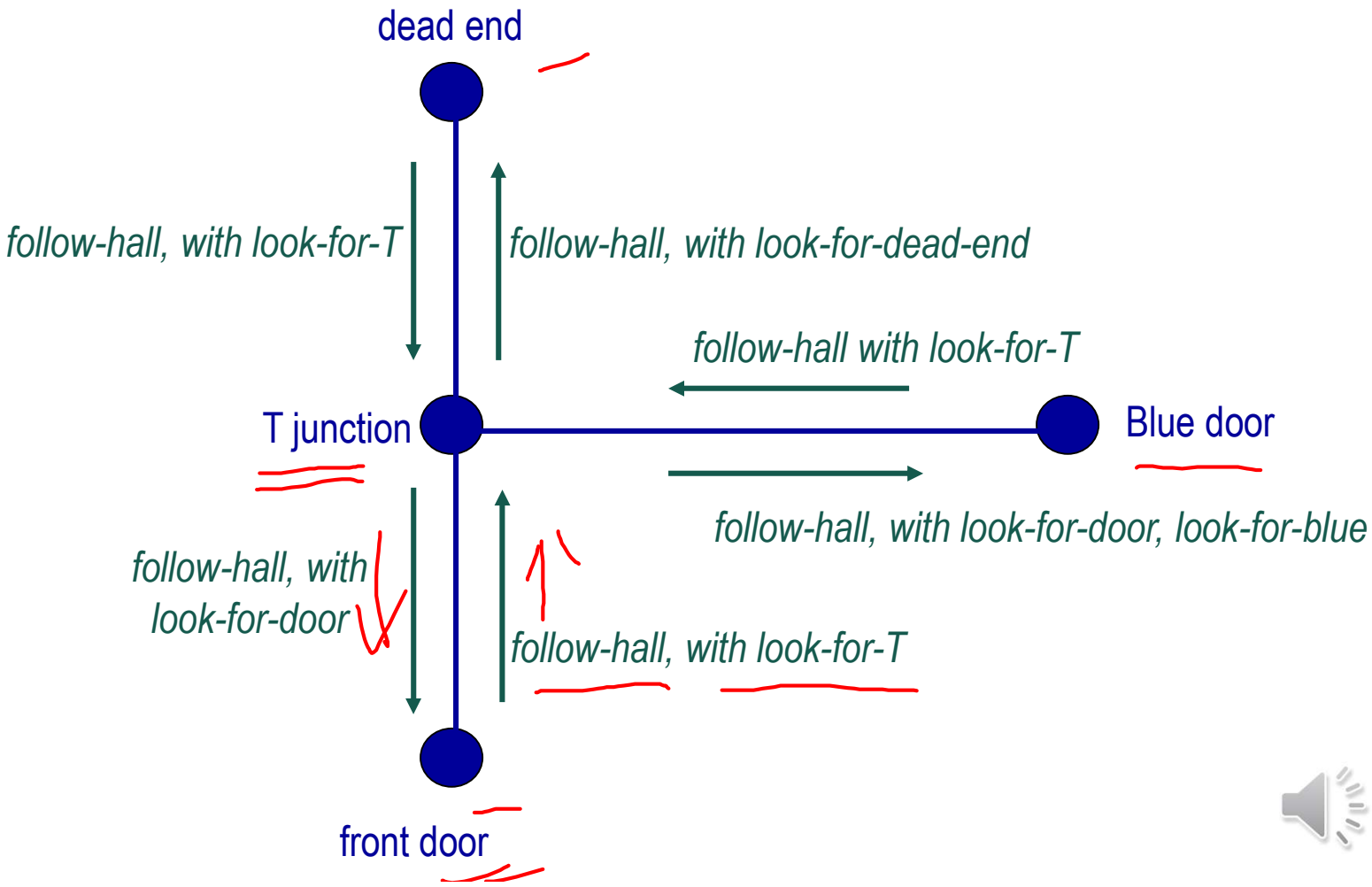
Robot moves to distinctive place using sensor-based local control strategy and hill-climbing



Example of Local Control Strategies

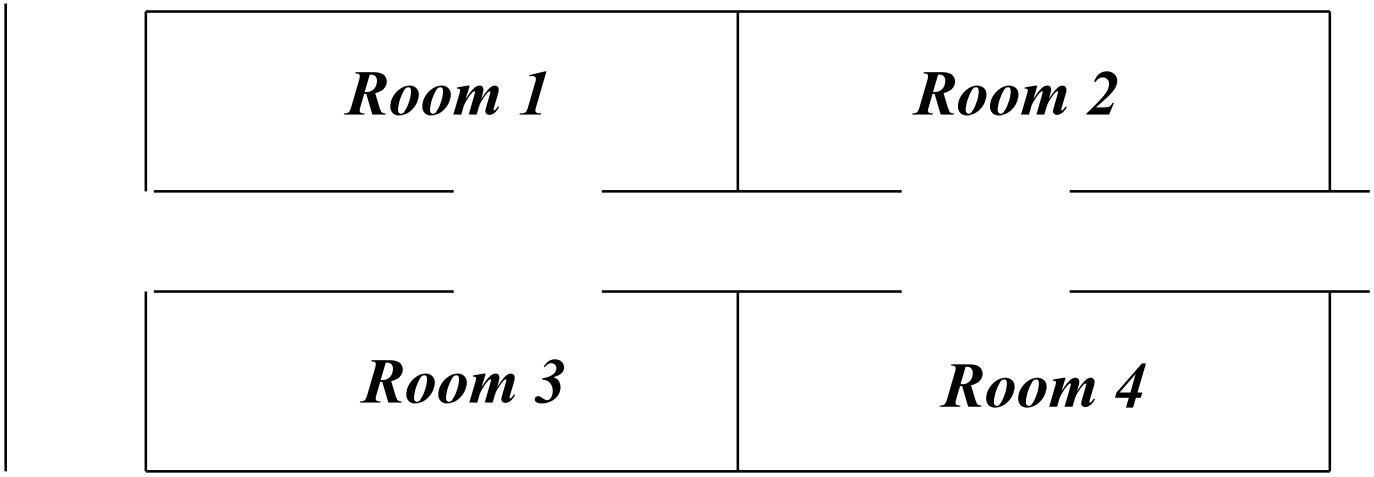
Basic behavior: *follow-hall*

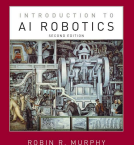
Releasers: *look-for-T, look-for-dead-end, look-for-door, look-for-blue*



Example

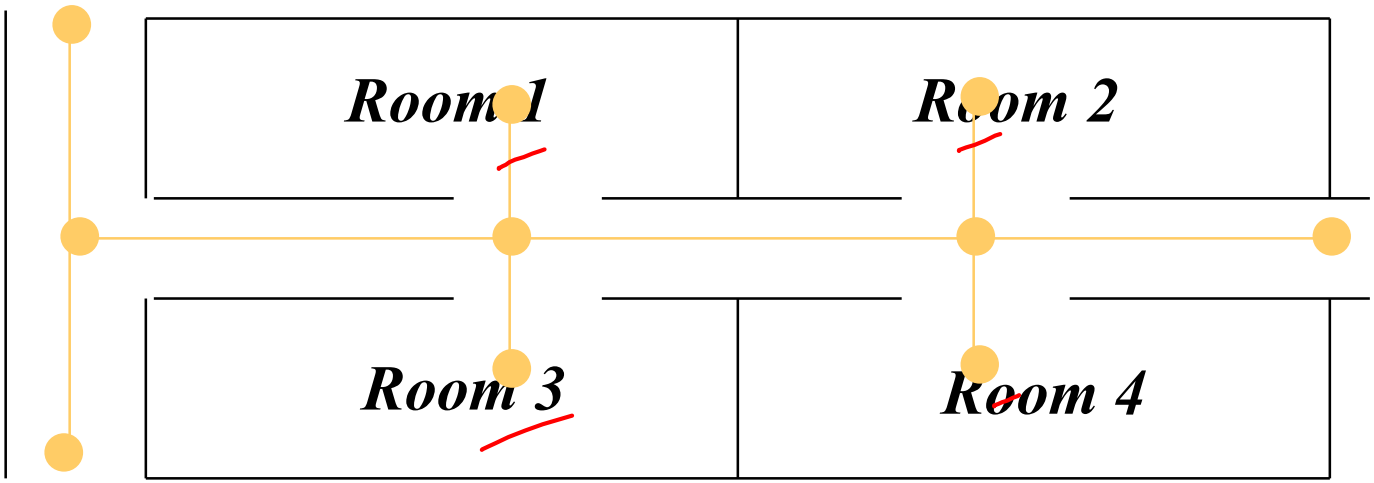
- Create a relational graph for this floorplan
- Label each edge with the appropriate LCS:
  - Mtd = move-thru-door, fh = follow-hall
- Label each node with the type of gateway:
  - De = deadend, t = turn, r = room

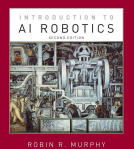




Example

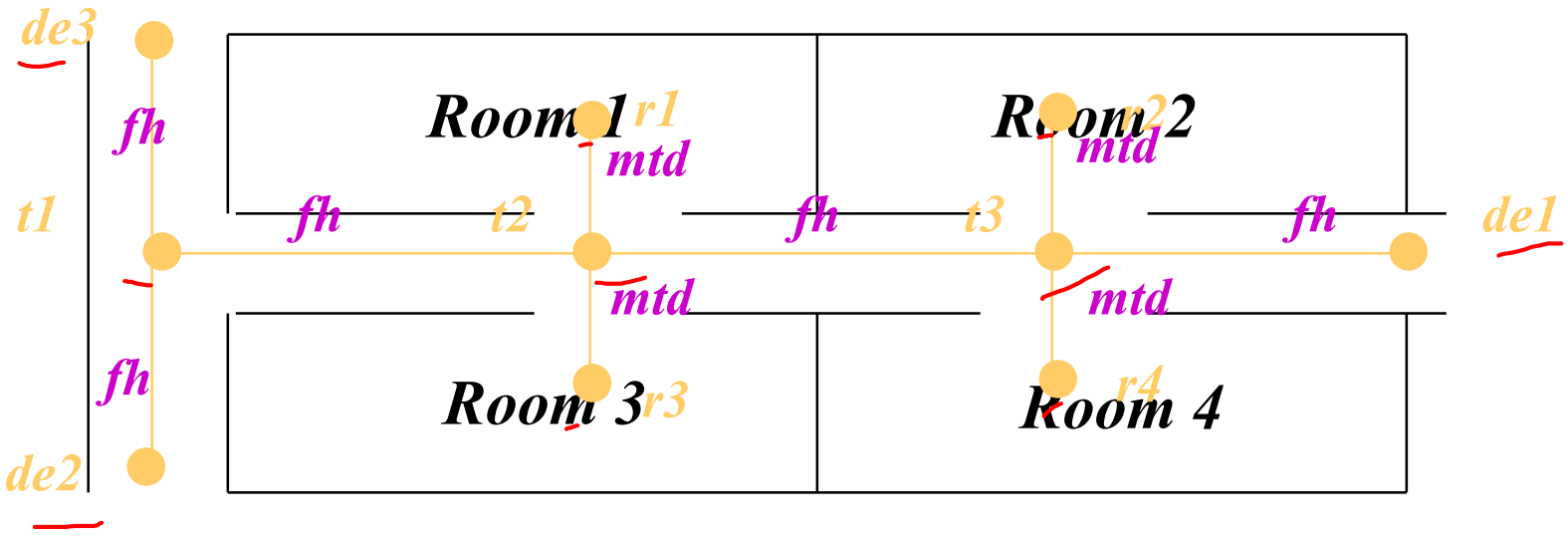
- Create a relational graph for this floorplan

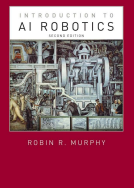




Example

- Create a relational graph for this floorplan
- Label each edge with the appropriate LCS: mtd, fh
- Label each node with the type of gateway: de, t, r





Distinctive Places: Advantages and Disadvantages

- Advantages:
  - Eliminates concern over navigational errors at each node
  - Robot can build up metric information over multiple trips, since error will average out
  - Supports discovery of new landmarks
- Disadvantages:
  - Difficult to find good distinctive places
    - Either too numerous, and thus not locally unique
    - Or, too few, and thus hard to find
  - Difficult to define and learn local control strategies

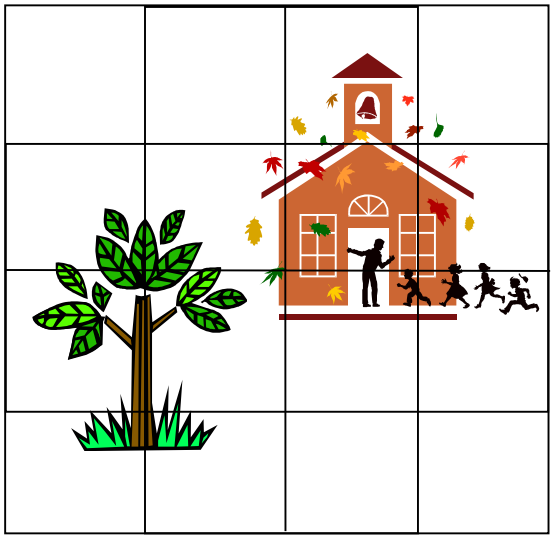
Associative Methods

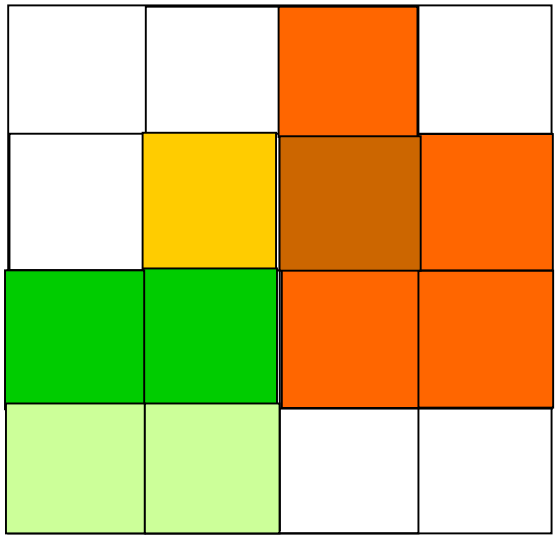
- Create a behavior that converts sensor observations into direction to go to reach a particular landmark
- Assumption: location or landmark has:
  - Perceptual stability: views from nearby locations look similar
  - Perceptual distinguishability: views far away should look different
- Associative methods are similar to distinctive place neighborhoods
- Difference: associative methods use coarse computer vision

Visual Homing

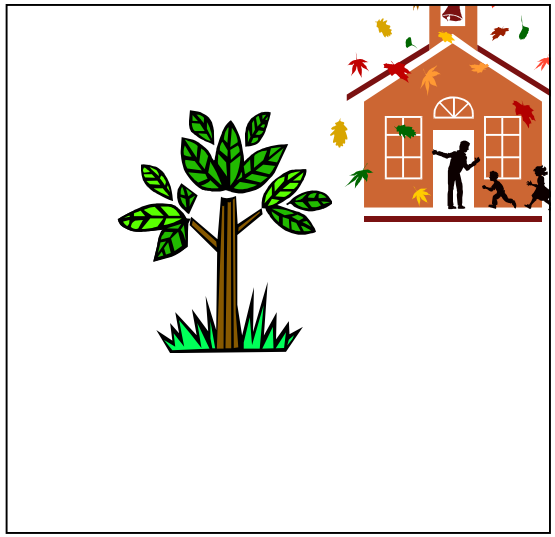
- Partition image into coarse subsections (e.g., 16)
- Each section measured based on some attribute
  - e.g., edge density, dominant edge orientation, average intensity, etc.
- Resulting measurements yield image signature
- Image signature forms a pattern
- If robot nearby, should be able to determine direction of motion to localize itself relative to the location
- Visual homing: the use of image signatures to direct robot to specific location

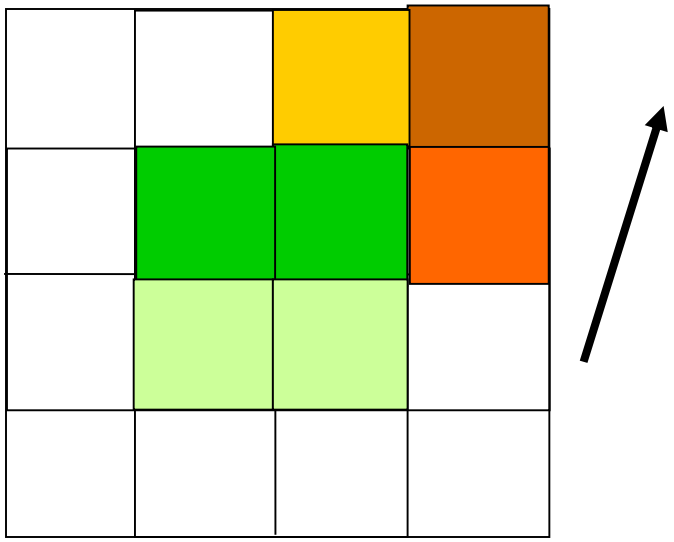
Example of Visual Homing





Example of Visual Homing (cont.)





QualNav – Levitt and Lawton

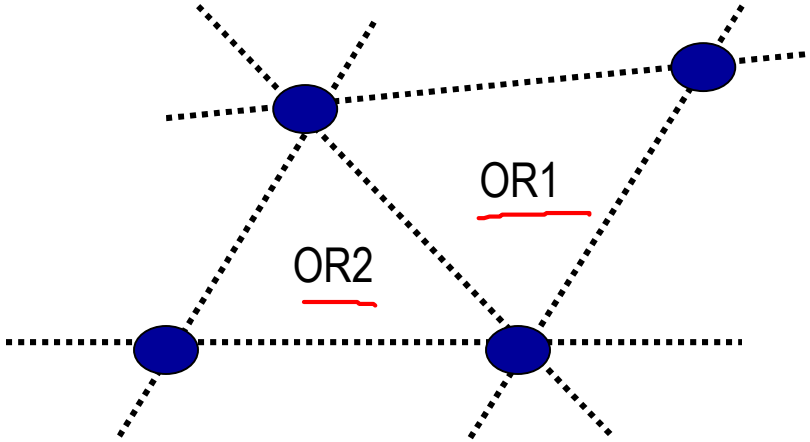
- Basic idea: localize robot relative to particular orientation region, or patch of the world

- Orientation region:
  - Defined by landmark pair boundaries
  - Similar to neighborhood
  - Within an orientation region, all landmarks appear in same relationship

- Vehicle can directly perceive when it has entered a new orientation region

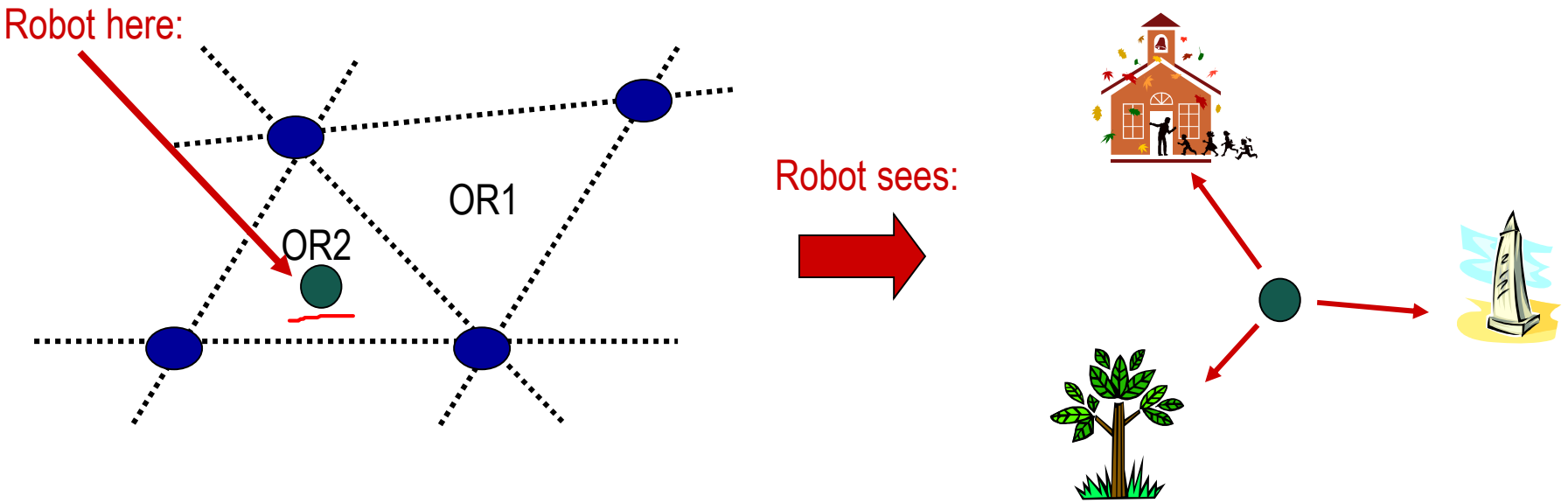
Example of Orientation Regions

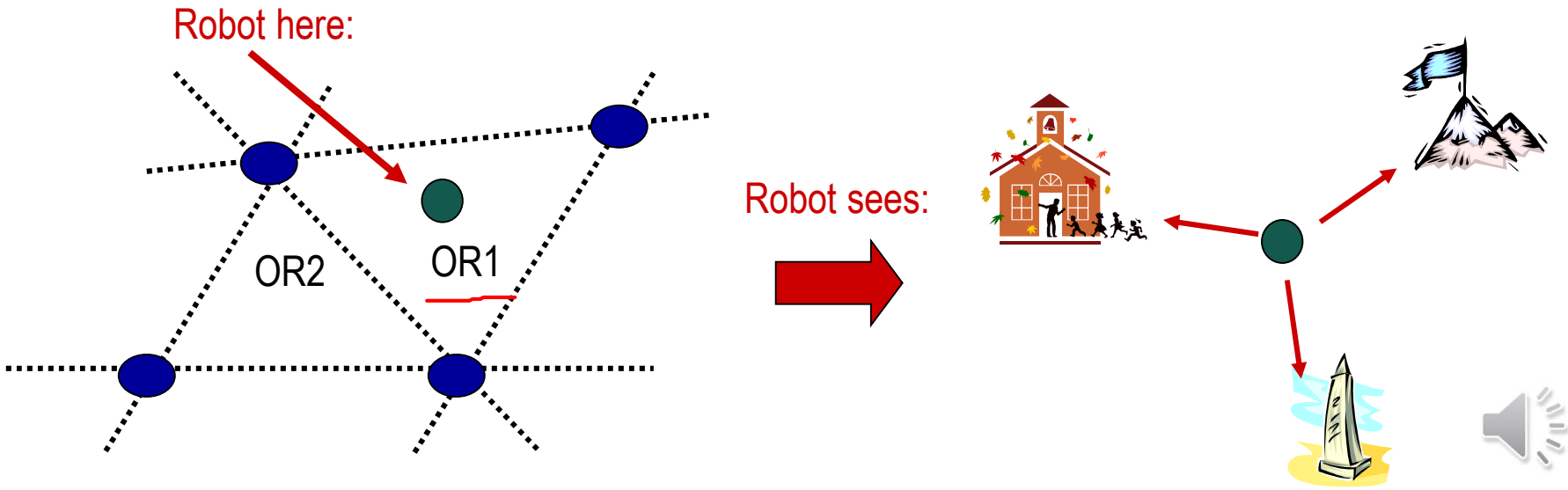
Topological representation as orientation regions:



Metric Map:

Example of Orientation Regions (cont.)





Orientation Regions (cont.)

- Allows robot to create outdoor topological map as it explores the world
- Allows robot to coarsely localize itself
- Robot does not have to estimate range to landmarks
- Using angles to each landmark, it can move to follow desired angles

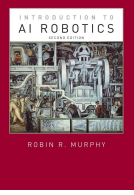
Associative Methods: Advantages and Disadvantages

- Advantages:
  - Tight coupling of sensing to homing
  - Robot does not need to explicitly recognize what a landmark is
  - Enables robots to build up maps as it explores

- Disadvantages:
  - Require massive storage
  - Brittle in presence of dynamic world when landmarks may be occluded or change

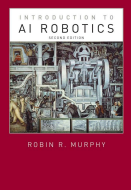
Summary

- Route, qualitative, and topological navigation all refer to navigating by detecting and responding to landmarks.
- Landmarks may be natural or artificial; roboticists prefer natural but may have to use artificial to compensate for robot sensors
- There are two type of qualitative navigation: *relational* and *associative*



Summary (cont.)

- Relational methods use graphs (good for planning) and landmarks
  - The best known relational method is distinctive places
  - Distinctive places are often gateways
  - Local control strategies are behaviors
- Associative methods remember places as image signature or a viewframe extracted from a signature
  - can't really plan a path, just retrace it
  - direct stimulus-response coupling by matching signature to current perception



13

Return to Questions

- **What is navigation?**
  - About getting to a specific location
  - Where am I going? *Mission planning*
  - What's the best way there? *Path planning*
  - Where have I been? *Map making*
  - Where am I? *Localization*
- **How do animals navigate?**
  - Topologically
- **Are there different types of navigation?**
  - Yes, topological and metric
- **Which one is best?**
  - It depends!
  - Topological is directly tied to the environment