Chapter 8: Maps and related tasks

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Robots and maps

Sensorial maps

Image based mapping

Spacial occupancy representations

Geometric maps

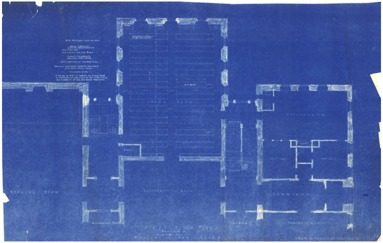
Topological Maps

Multiple Robots

Maps for robots

Human maps:

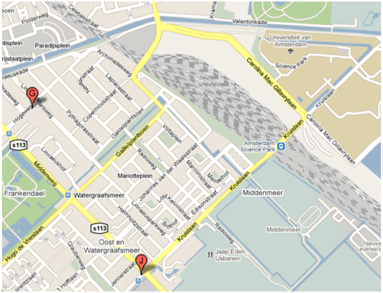
- Often unavailable;
- Often incomplete:
  - human relevant data;
  - robot relevant data;



Maps for robots

Human maps:

- Often unavailable;
- Often incomplete:
  - human relevant data;
  - robot relevant data;
- Wrong level(s) of abstraction: human oriented;



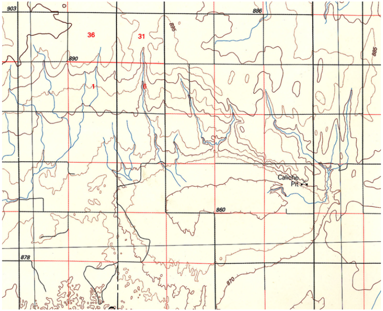
Maps by robots

- Building a robot friendly map is very difficult and tedious.
- Robots are good candidates to build maps with and for their own sensory suite;

Conclusion: Design robots to autonomously construct, update and validate maps destined for robot use.

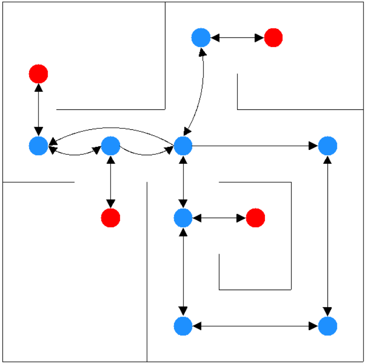
Map paradigms: metric vs. topological

- Metric
  - Sensorial
  - Geometric



Map paradigms: metric vs. topological

- Metric
  - Sensorial
  - Geometric
- Topological
  - Local relational
  - Topological
  - Semantic



Direction of map hierarchy

- Giralt et al.: metric to topological.
- Kuipers and Levitt : topological to metric. Low level topological landmarks as starting point.

Types of data

- (Derived) spacial occupancy;
- (Direct) sensor measurements in relation to position. e.g. olfaction.

Sensorial maps

- Represent sensor measurements against odometry;
- Collection of measurements: $[I_i(x_i, y_i, \theta_i)]$

Image based mapping

The challenge:

- how to sample the set of possible measurements, $\{I_i\}$;
- how to turn the samples into a continuous I.

Li: street panoramas

Li et al.: robots builds graph representing street network:

- edges = streets;
- nodes = intersections;

Robot collects by:

- moving in a closed loop, always turning left;
- recording panoramas of left and right sides of streets;
- concluding a loop by identifying previously recorded street side;

Bourque: robot sightseeing

Bourque et al.: robots builds graph nodes corresponding to panorama shots, in a less constrained environment, by:

- choosing sample (panorama) points based on models of human attention;
- using "alpha backtracking" to make trade-off between distance to next sample point and optimality of next sample point;

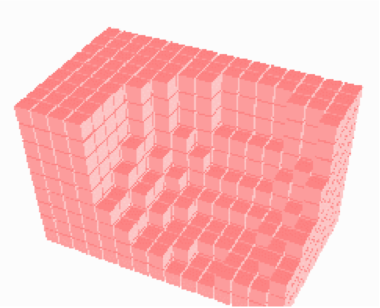
Spacial occupancy grid

Pioneered by Elfes and Moravec

- Grid of pixels

Spacial occupancy grid

- Grid of pixels
- Volume of voxels



Spacial occupancy: data represented

- Fill pixels / voxels with degree of occupancy data.
- More refined: fill pixels / voxels with probability of occupancy data.

Spacial occupancy: probabilistic approach

- Example of a laser sensor: probability of an actual distance z for a given laser reading r computed using Bayes' theorem:

$$P(z|r) = \frac{P(z)P(r|z)}{P(r)}$$

Spacial occupancy: probabilistic approach

- Example of a laser sensor: probability of an actual distance z for a given laser reading r computed using Bayes' theorem:

$$P(z|r) = \frac{P(z)P(r|z)}{P(r)}$$

- Generalised:

$$P(W|R) = \frac{P(W)P(R|W)}{P(R)}$$

with $P(R_i) = \sum_j P(R_i|W_j)P(W_j)$

Spacial occupancy: probabilistic approach

The result: *maximum a posteriori* (MAP). World model that most reasonably estimates environment according to Bayesian approach.

Spacial occupancy: probabilistic approach

The result: *maximum a posteriori* (MAP). World model that most reasonably estimates environment according to Bayesian approach.
Considerations:

- very general: no assumed model, deals with multiple sensors;
- requires accurate probabilistic model of the sensors;
- requires a lot of memory for the occupancy map;
- measurement locations/times discarded: geometric accuracy reduced;
- important to avoid accumulated positional errors - e.g. by iteratively recomputing position;
- needs an exploration policy: e.g. random or towards “unkown’ ’areas.

Spacial occupancy: Markov models

Markov localisation: estimating robot's location based on sensor data by maintaining probability density grid for the robot's environment, with each cell representing a possible robot pose.

Geometric maps

Accurate, with two assumptions:

- sensor data is suitable
- environment is suitable

Geometric maps: exploration

Challenge is exploration. Includes searching for:

- a goal position;
- route with specific properties;
- “covering” a space;
- occupancy.

Geometric maps: reach goal

Papadimitriou and Yannakakis's bug-like algorithm for reaching known goal from known origin in unkown environment with obstacles:

- move "towards" line connecting origin and goal;
- if not possible, move in arbitrary direction;

Useful in certain simple types of environment, notably where obstacles are:

- rectilinear;
- nonintersecting;
- aligned with world coordinates.

In more general environments no bound is possible.

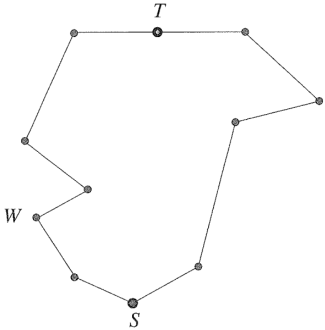
Geometric maps: geometric representations

Chosen geometric representation influences applicable algorithms. Important representation is that of “street polygons”.

Geometric maps: Street polygons

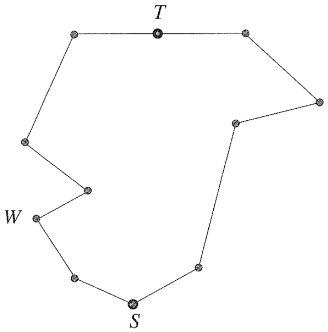
Polygon such that:

- there is a start vertex S and end vertex T
- vertices and lines categorised as "left" or "right" with respect to line segment from S to T;
- every vertex on either side is visible to some vertex on the other



Geometric maps: Street polygons

- Kleinberg developed an algorithm that finds the "*optimal* L_1 " shortest path from S to T.
- Datta, Icking and Klein developed an algorithm applicable to a generalisation of the street, the "G-street".



Geometric maps: exploring occupancy

Exploring for occupancy. Has limitations:

- difficult to know if all space explored;
- can't describe complex open spaces;
- external operator decides on next location.

occupancy.png

Geometric maps: Spiral search

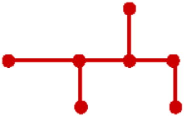
Used to search for object whose location is unknown.

Topolgical Maps

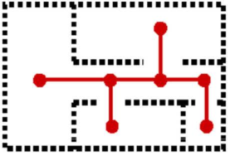
Topological maps: describes the environment as a graph that connects specific locations in the world and represents them as nodes(vertices).

- Because metric representations cost too much memory to maintain in the long run.
- Easy to understand for humans.

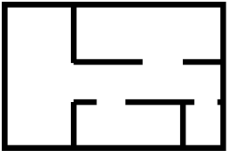
– Qualitative (route):



derived from:



– Quantitative (metric or layout):



The Graph

Landmarks and Edges

- The nodes on the graphs are landmarks or features of the environment.
- The edges are paths between the landmarks.
- Landmarks need to be unique to be good landmarks.
- Landmarks can be artificial or natural.(junctions, signs)
- The graph can be extended by enumerating the edges incident to the node entered. Edge you traveled along is 0 and enumerate clockwise. This enumeration is local cause it depends on the edge the robot moved over.

Marker Based Exploration

Marker Based Exploration: can be used when no prior information about the environment available and there aren't enough unique landmarks.

- The robot needs to have something to mark where it has already been.(spray paint, bread crumbs)
- Here we choose marks which it can pick up, drop and recognize.
- Iteratively builds up the known graph by traveling along the incident edges of a node.
- Using marks to explore has a $O(N^3)$. They say.

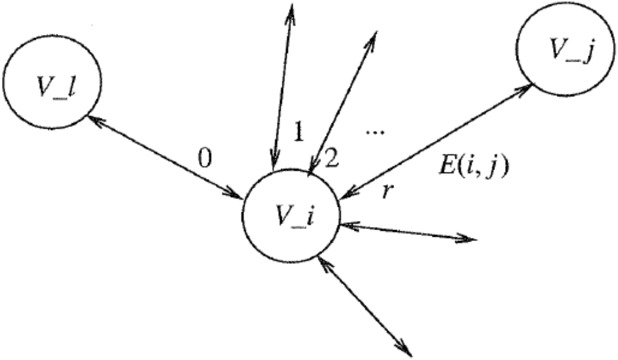
Marker Based Exploration

Conventions and Restrictions

- v_i is the node where the robot is currently at. v_j is the node where the robot is moving to. $E_{i,j}$ is the edge between the two nodes.
- In the transition function r stands is the edge number from the perspective of the last edge it came from.
- Transition function need to follow these properties. If $(v_i, E_{i,j}, r) = v_j$ and $(v_j, E_{i,j}, s) = v_k$, then $v_j, E_{i,j}, -s) = v_i$
  Moves are invertible and can be retraced.
- $t \neq -s$ then $v_j, E_{i,j}, -s) = v_i$ and $(v_j, E_{i,k}, s) = v_j$ are not valid. To avoid redundant and degenerate paths.
- Subgraph S for explored edges and Nodes. U is the for unexplored sub graph.

Marker Based Exploration

Edge Ordering: A correct graph.



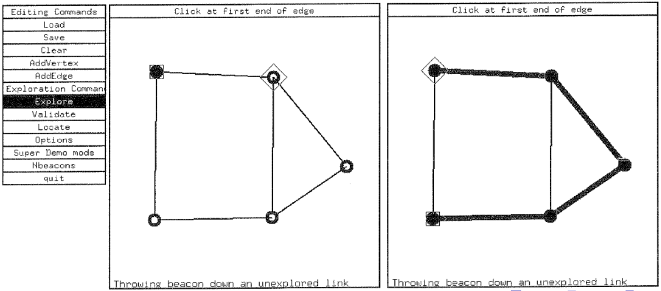
Marker Based Exploration

Operations of the robot

- Move along edge r.
- Each marker can be in 3 different states[pickup,putdown,null]
- At each vertex the robot can see two things [present, not-present]
- Robot must be able to order the edges each time it enters a node. So if a robot enters the same vertex from a different it can make a global ordering.

Marker Based Exploration Algorithm and Example

- First validate all explored nodes. So all nodes in graph S. Make sure there aren't any doubles by looking for markers.
- Explore new nodes. If there is no marker found at a certain node v add it the subgraph S and add the edge which was taken aswell.
- Enumerate all edges incident to the new node and add them to U.
- Do this till subgraph U is empty.



Multiple Robots

Why would you use multiple Robots

- **Improved Robustness**: A multirobot can, in principle, keep functioning even if one indiviudual robots dail completely.
- **Improved effiency**: It is possible for a group of robots to accomplish a search or exploration task faster than an equivalent single robot.
- **Alternative Algorithms**: For some tasks, the availability of multiple robots allows feadible or guaranteed algorithms to be implemented when no such algorithm is available for a single robot system.

Multiple Robots in Practice

Problems

- **Where are the other robots?**: Rendezvous with other robots
- **Partitioning**: Finding a good way to distribute the work amongst the robots.
- **Multi-robot planning**: Prevent the trajectories of the robots to collide.
- **Merging the data from the indivual team members**: Need to be close proximity and Sensor fusion problems.

Rendezvous

Rendezvous: Is a having two or more robots meet at an appointed place and time.

- A rendezvous is needed for robots that can only communicate in close proximities, but may also be needed to exchange objects between robots.
- When Multiple robots try to complete a task collaboratately without prior knowledge. They need to to exchange information while they are still working at the task at hand.
- If they dont meet they cannot benefit from what others have already learned.

Too many rendezvous

Problems:Robots mustn't devote too much energy to rendezvous to stay efficient.

- The extent to which the two robots agree on their perceptions of the environment.
- The degree of synchronization of the robots can attain expressed as the likelihood that an appointed rendezvous at a common location will fail owning to a failure to arrive at the same time
- The extent of the commonality between the region of space the robots have explored.(Can't share if the parts are completely diffent)

Map Fusion

Map Fusion: is needed to make the collaborative efforts worthwhile when the problem needs a long term map.

- Complexity of the map-merging depends on the, Odemetry error, the fidelity of the sensing and the richness of the evironment.
- Fusing maps is mostly done by cross correlation. This depends on the fact that the individual maps overlap "sufficiently'.
- Done by rotation and translating the given maps to minimize the difference between them.

Exploration with Multiple robots

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The basic idea of the algorithm: Given Robots are only allowed to communicate when they are in the same node.

- Split all the work between all the robots and have them explore their own part of the graph. tem Plan rendezvous, to harmonize the information they got till then and make a single consistent representation of the environment they are in.
- Redivide the work and repeat this till everything is known.

Conclusion

- Topological Maps are low cost and still give a good representation of the environment
- Marker Based exploration is nice to use when you want to make a good topological map.
- Using multiple robots can make exploration faster and more robust, but needs coordination.

links

http://www.csupomona.edu/~ftang/courses/CS499/notes/navigation3.pdf