

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

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Maps for robots

Robots and maps

Sensorial maps

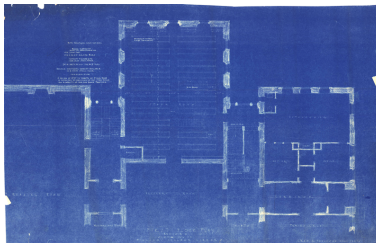
Image based mapping
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Topological Maps

Multiple Robots

Human maps:

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



Maps for robots

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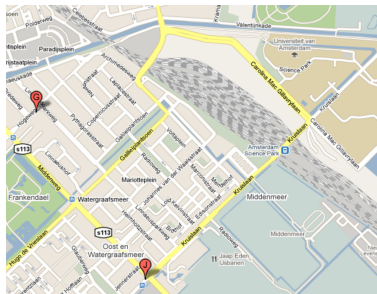
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Human maps:

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



Maps by robots

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- ▶ 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

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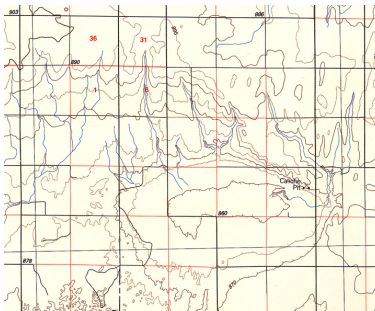
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Multiple Robots

- ▶ Metric
 - ▶ Sensorial
 - ▶ Geometric



Map paradigms: metric vs. topological

Robots and maps

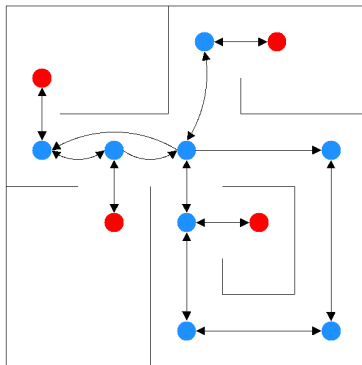
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Topological Maps

Multiple Robots

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



Direction of map hierarchy

Robots and maps

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Multiple Robots

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

Types of data

Robots and maps

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

Sensorial maps

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

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;

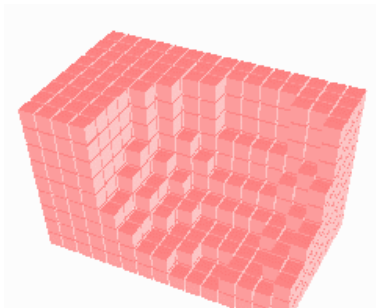
Spatial occupancy grid

Pioneered by Elfes and Moravec

- ▶ Grid of pixels

Spatial occupancy grid

- ▶ Grid of pixels
- ▶ Volume of voxels



Spatial occupancy: data represented

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

Spatial occupancy: probabilistic approach

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

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

Spatial 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.

Spatial 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 "unknown" areas.

Spacial occupancy: Markov models

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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 unknown 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

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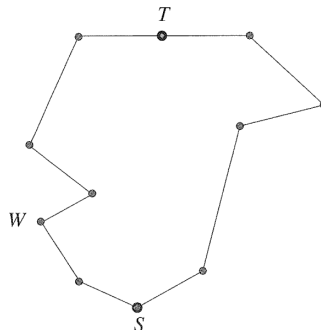
Multiple Robots

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

Geometric maps: Street polygons

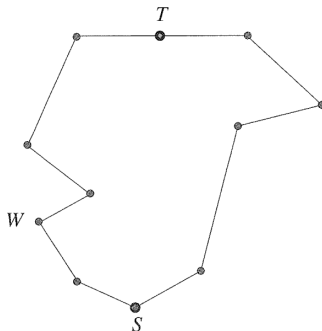
Polygon such that:

- ▶ 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

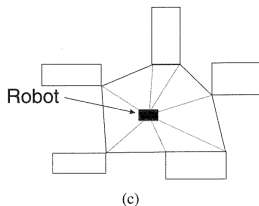
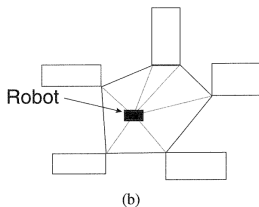
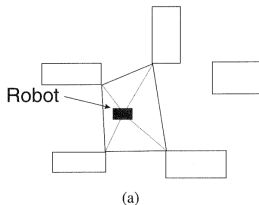
- ▶ Kleinberg developed an algorithm that finds the “*optimal L_1* ” shortest path from S to T .
- ▶ Datta, Icking and Klein developed an algorithm applicable to a generalisation of the street, the “G-street”.



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.



Geometric maps: Spiral search

- ▶ Used to search for object whose location is unknown.
- ▶ For m rays: $\forall i \geq 1 \ f(i) \geq f(i - m)$

Topological Maps

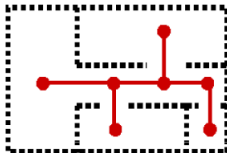
Topological maps: describes the environment as a graph that connects specific locations in the world and represents them as nodes(vertices).

- ▶ Metric representations cost too much memory to maintain in the long run.
- ▶ Easy for us to understand aswell.

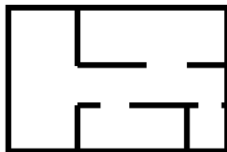
– Qualitative (route):



derived from:



– Quantitative (metric or layout):



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.
- ▶ The graph can be extended by enumerating the edges incident to the node entered.

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

- ▶ Iteratively builds up the known graph by traveling along the incident edges of a node.
- ▶ 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.
- ▶ Using marks to explore has a $O(N^3)$.

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.

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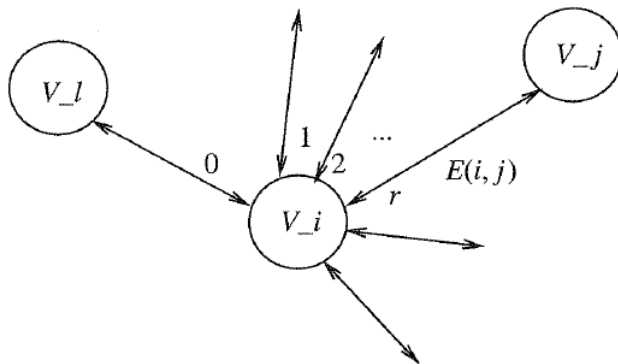
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Marker Based Exploration

Edge Ordering: A correct graph. Edge you traveled along is 0 and enumerate clockwise. This enumeration is local cause it depends on the edge the robot moved over.



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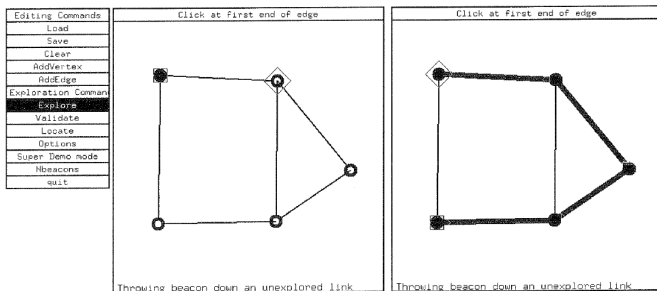
Multiple Robots

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 known 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 , add the edge which was taken aswell and drop a marker.
- ▶ Enumerate all edges incident to the new node and add them to U .
- ▶ Do this till subgraph U is empty.



Why would you use multiple Robots

- ▶ **Improved Robustness:** A multirobot system can, in principle, keep functioning even if one individual robots fail completely.
- ▶ **Improved efficiency:** 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 feasible or guaranteed algorithms to be implemented when no such algorithm is available for a single robot system.

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 individual team members:** Need to be close proximity and Sensor fusion problems.

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 collaboratively without prior knowledge. They need to exchange information while they are still working at the task at hand.
- ▶ If they don't 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 owing 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 different)

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, Odometry error, the fidelity of the sensing and the richness of the environment.
- ▶ Fusing maps is mostly done by cross correlation. This depends on the fact that the individual maps overlap "sufficiently".
- ▶ Cross correlation is done by rotation and translating the given maps till you minimized the difference between them.

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.
- ▶ 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, but still give a decent 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.

[http://www.csupomona.edu/~ftang/courses/CS499/
notes/navigation3.pdf](http://www.csupomona.edu/~ftang/courses/CS499/notes/navigation3.pdf)