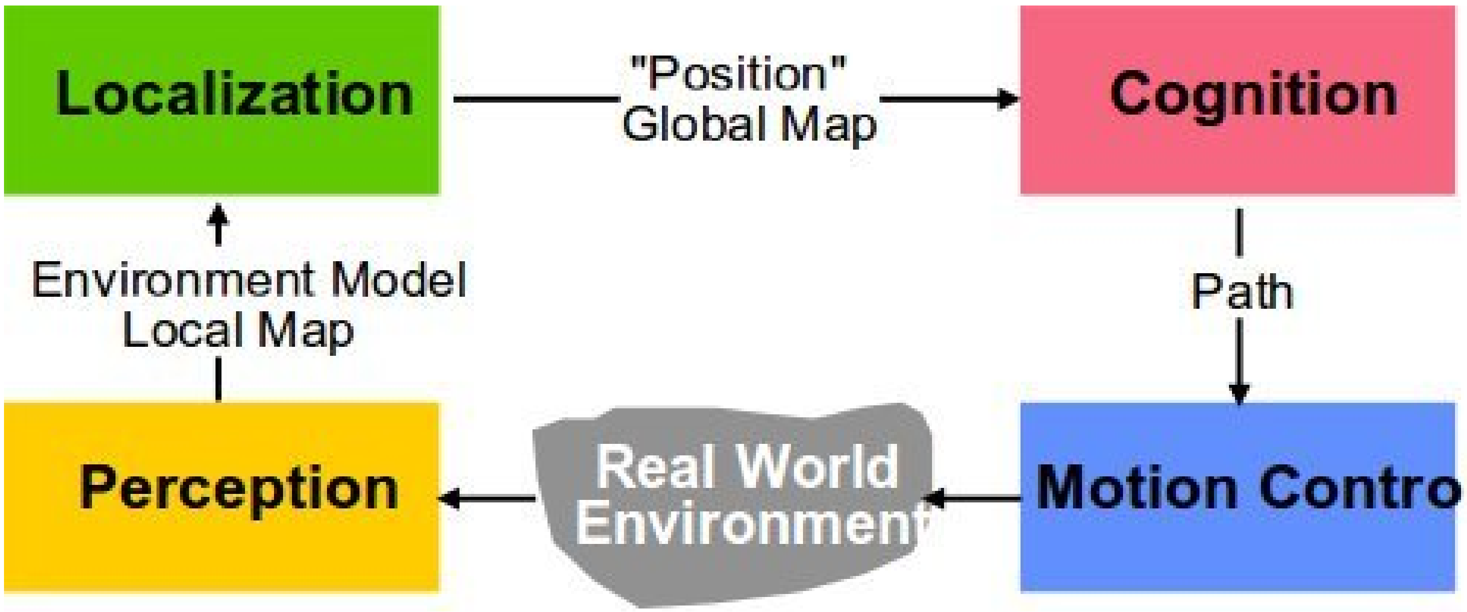
NAVIGATION

Today



- Today we will finish up the material for the course.
- We'll be looking at navigation.
  - How a robot gets around the world.

What counts as navigation

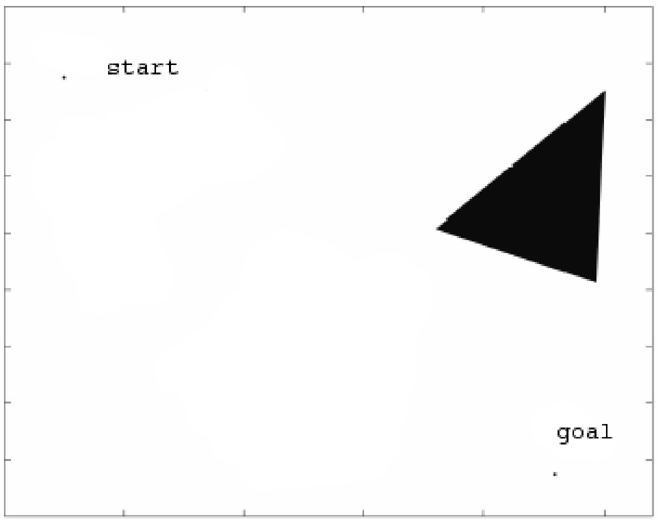
- Navigation is concerned with how a robot gets around the world.
  - So what is new?
- More than just blundering about using dead reckoning.
- Assume that the robot:
  - Knows where it is.
  - Knows where it is going.
- Concerned with getting from one place to another.

- Distinguish two kinds of navigation
  - Global navigation
  - Local navigation

- *Global* navigation is about deciding how to get from some start point to a goal point.
- The robot *plans* in some sense.
- We will look at methods for *path planning*.
- In short, the robot comes up with something like the "plan" you used in the last lab.
  - A sequence of *way points*
- We'll look at a couple of different methods that are appropriate for different map representations.
  - Remember them?

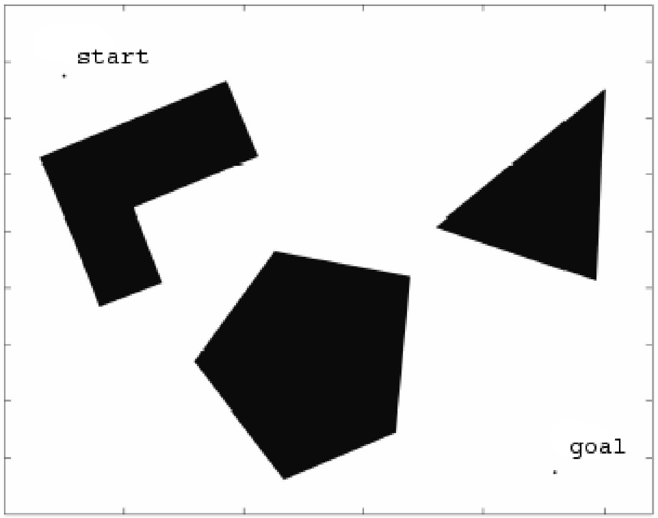
- *Local* navigation is about obstacle avoidance.
  - If there are objects in the way, make sure you don't hit them.
- Range of different approaches depending on what kind of information we have about the world.
  - Depends on sensors

- One way to think about the difference between the two is in terms of the relationship between the robot's `start` point and the `goal` point.



- If there is a clear *line of sight* between the start point and the goal then we are into obstacle avoidance.
  - Just avoiding some debris that isn't on the map

- However, if there is no line of sight from `start` to `goal`:

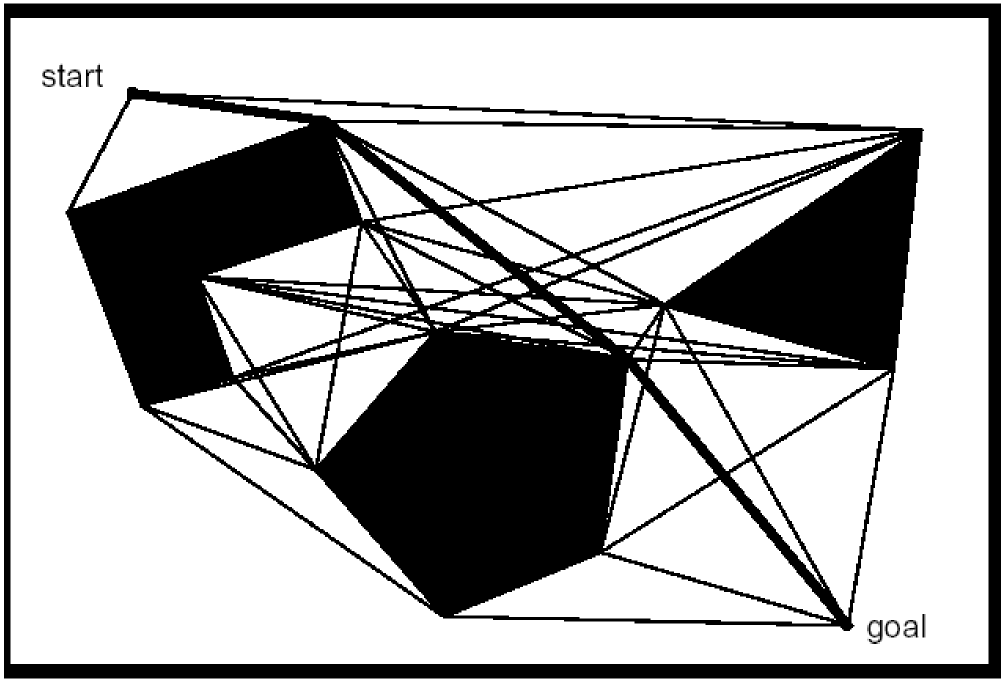


then we have to find a path.

- Typically path segments will be between two points between which there is a line of sight.
  - Waypoints

Visibility graph

- Direct implementation of line-of-sight.



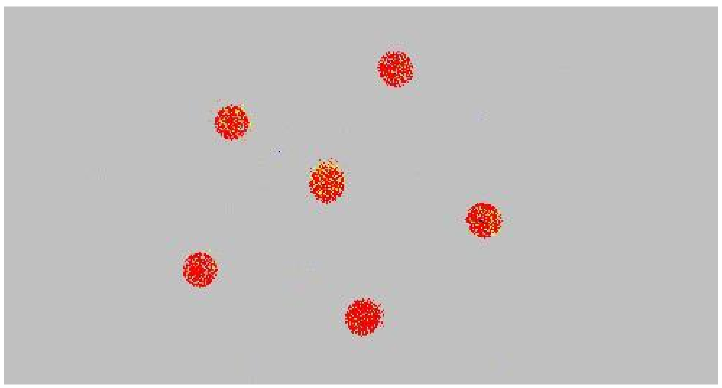
- Connect up all the vertices in the map.

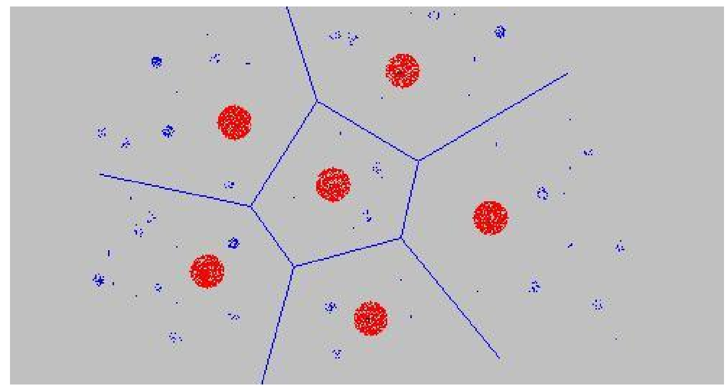
- Given the line segments, we can find the shortest path from `start` to `goal`.
- Can then translate the path into a series of waypoints.
  - Waypoints are the end points of the line segments.
- Given the visibility graph above, there is an obvious problem with using the lines as a guide for where the robot should go.
- What is it?

- Routes at the moment run arbitrarily close to the vertices of objects.
  - Problems with collisions
- Fix this by expanding objects by enough that the robot will still clear them.
  - More than half the diameter of the robot.

Voronoi diagram

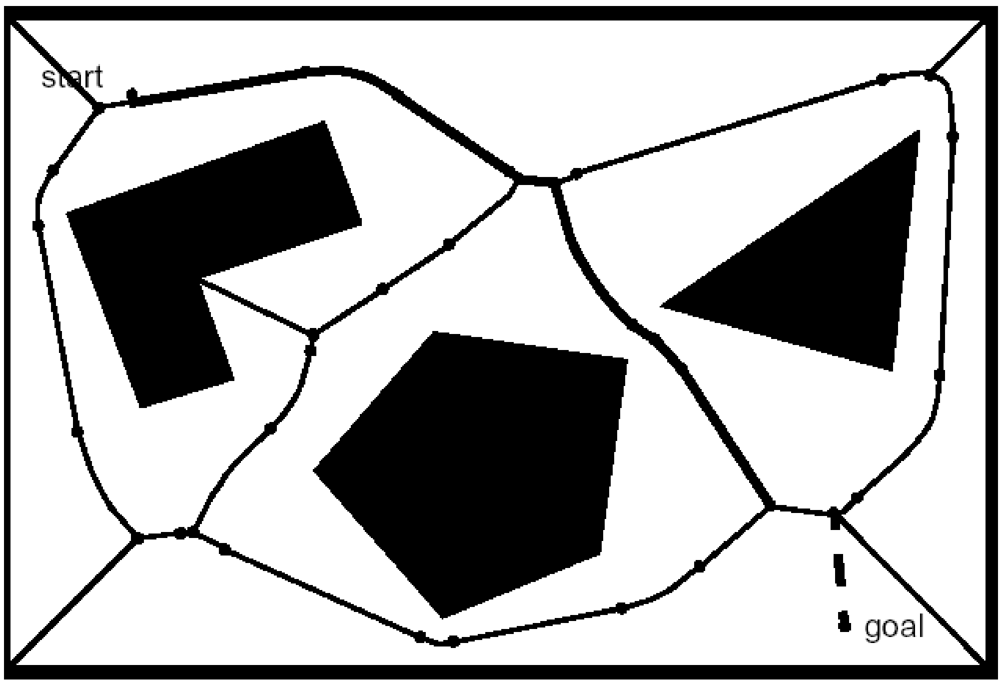
- A Voronoi diagram is a way to divide up a plane (a map).





- Given a set of points P, a Voronoi diagram is a set of polygons such that the points inside each polygon are closer to one member of P than any other.

- Can extend this to cases where P is a set of objects.



- Treat the line segments exactly like the edges in the visibility graph.

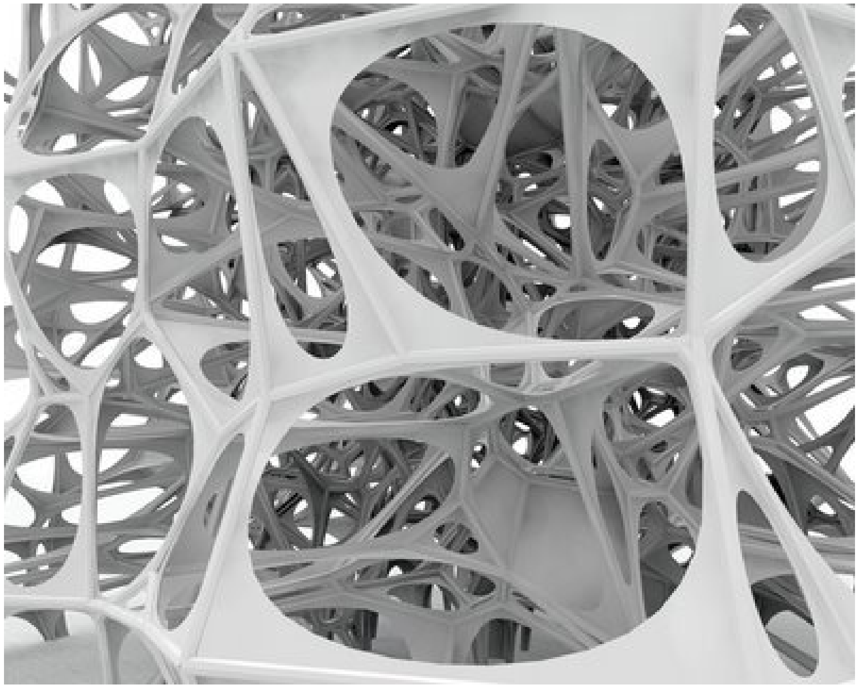
- The lines are not necessarily lines of sight
  - As above they may bend.
- However, they *are* object free, and so can be followed just like lines of sight can.

- Voronoi diagrams also have a nice property in terms of path-following
  - That is when you get the robot to follow the "plan".
- A robot that is maximising its distance from objects will follow the lines in the Voronoi diagram.

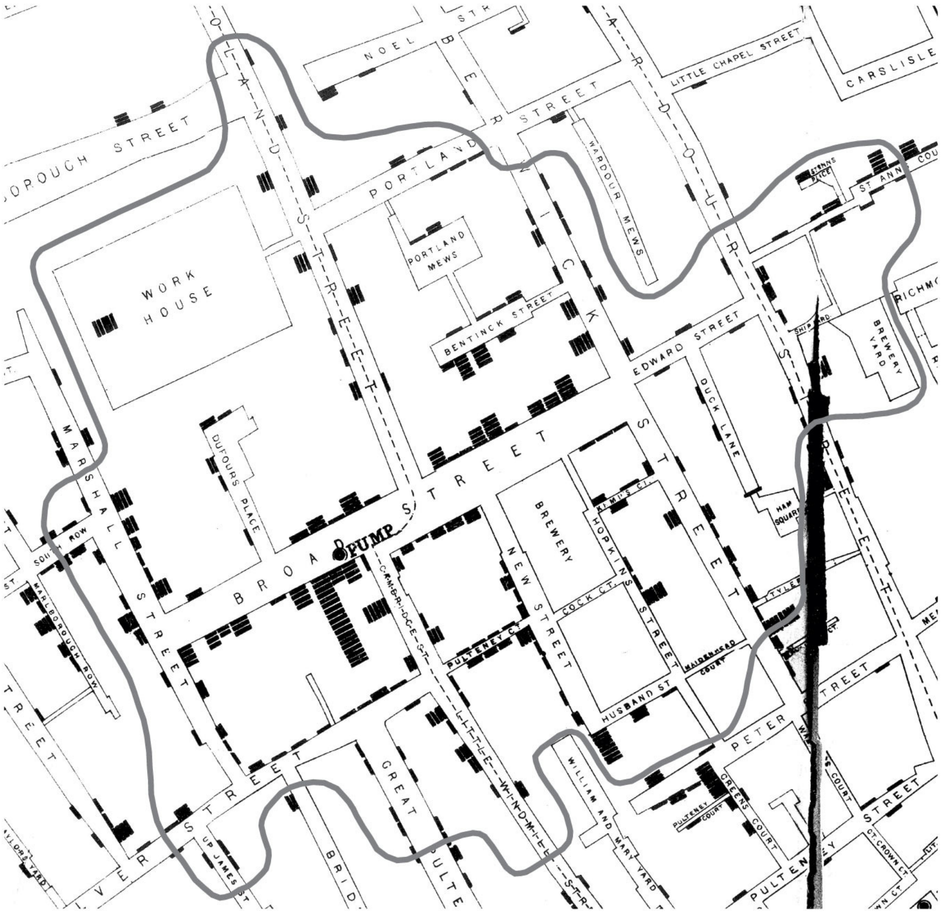
  Exactly what you did in the corridor following example.
- Means that we can again reduce the path to a set of waypoints.
  - Head to the next waypoint while maximising distance from objects.

Asides

- Voronoi diagrams work in 3D also:



- They were also famously used by John Snow to identify the source of the 1854 cholera epidemic in London



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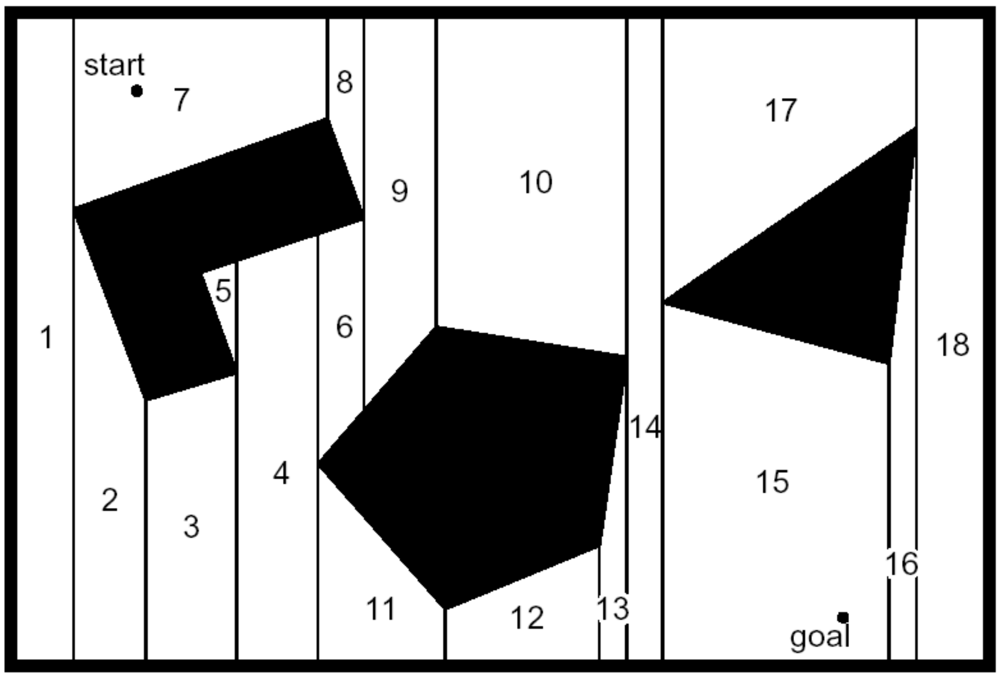
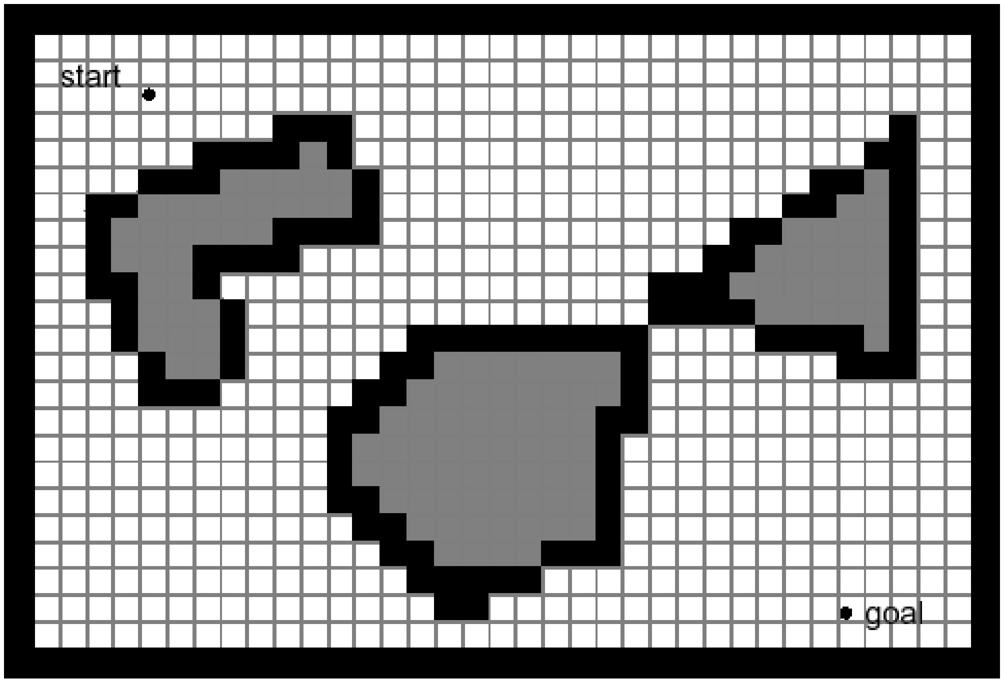
Cell-based maps

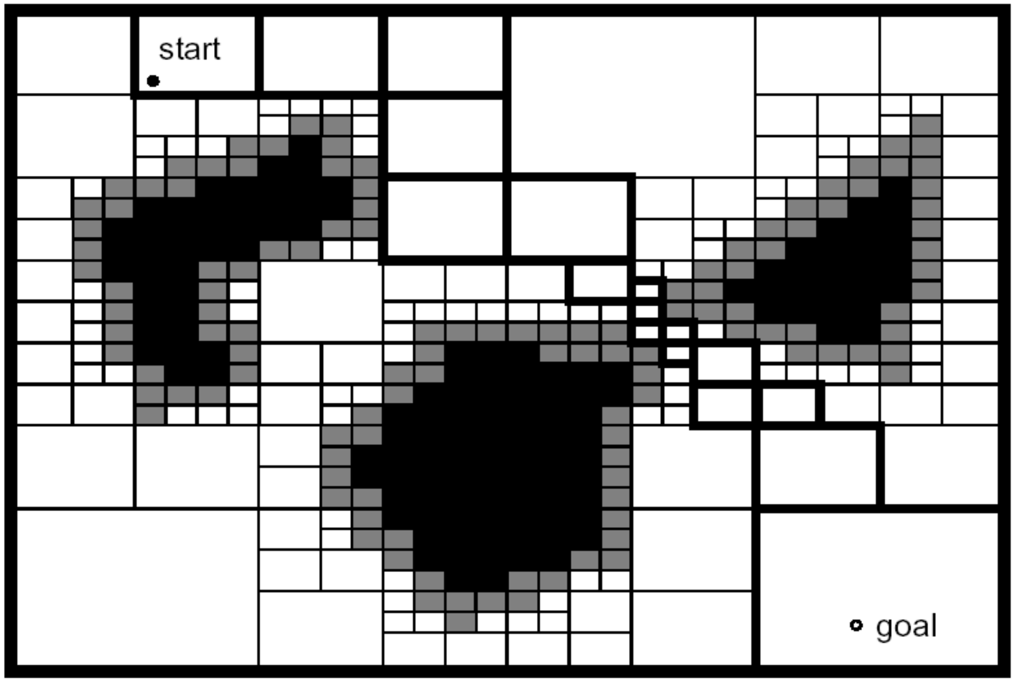
- Last time we saw a variety of different cell-based maps.



- Exact cell decomposition



- Fixed cell decomposition

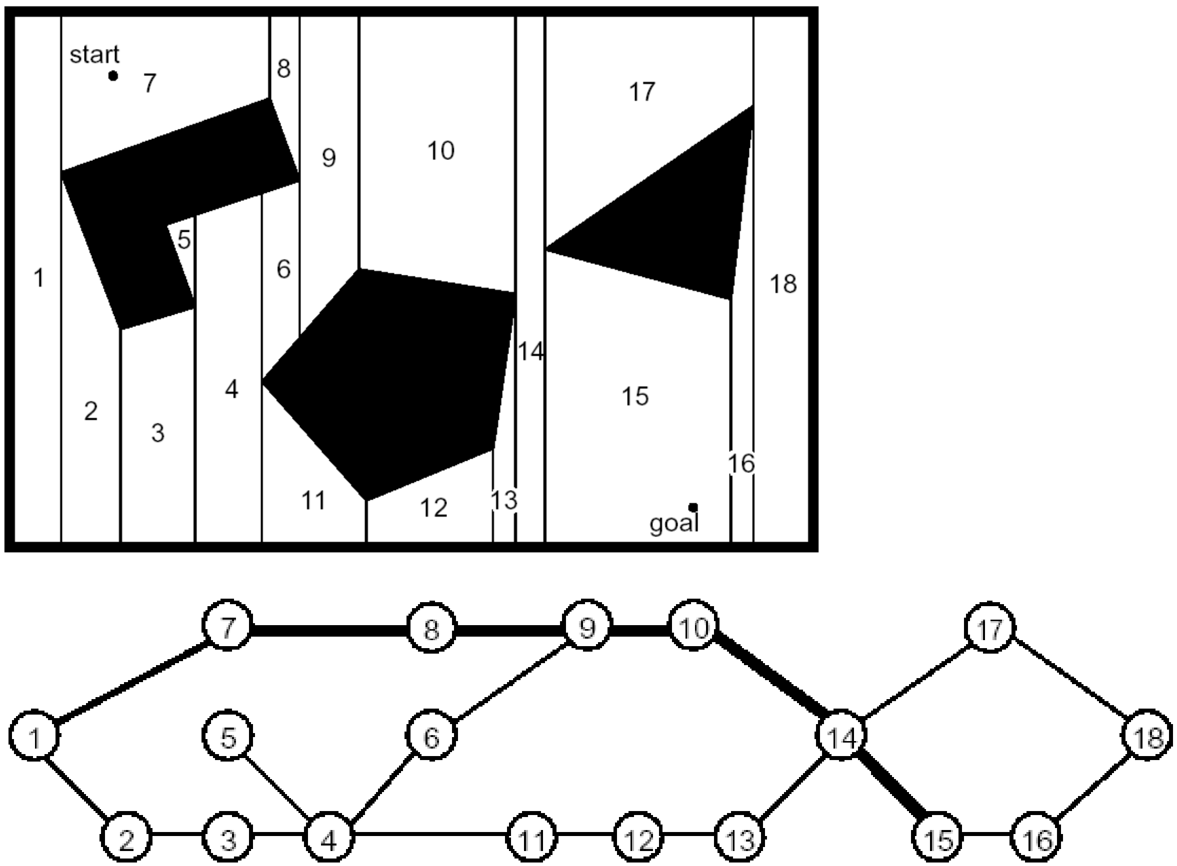


- Adaptive cell decomposition.

- Given the maps, we still want to figure out a sequence of line segments.
- Not quite so straightforward for cell-based maps.
- We will look at two general approaches to do path-finding:
  - Explicit search of a connectivity graph.
  - Wavefront planning
- These are really the same thing in different guises.

Connectivity graph

- Identify which cells are next to which other cells.



- The question is how to figure out a path from the graph.
- When the graph is complex, we need to use *search* techniques.
- This is also the case for the connectivity graphs we get automatically from the visibility graph or Voronoi diagram approaches.
- Standard approaches to search:
  - Breath first
  - Depth first
  - A*
- Plus there are robotics-specific approaches like D*.

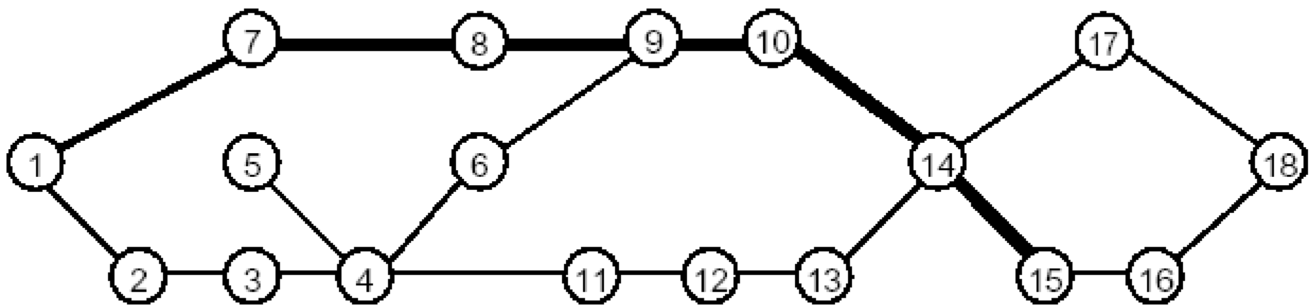
Search

- A general algorithm for search is:

```
agenda = initial node;
while agenda not empty do{
   state <- node from agenda;
   new nodes = nodes connected to state;
   if goal in new nodes
   then {
          return solution;
      }
   add new nodes to agenda;
}
```

- Note that this doesn't generate a set of waypoints, it just looks for the goal state.

- Let's think about how this would work on the connectivity graph:



- To use the algorithm we need to decide how to do the selection in

```
state <- node from agenda;
```

and how to do the addition in:

```
add new nodes to agenda;
```

- Depth-first search:
  - Takes the first node on the agenda;
  - Adds new nodes to the front of the agenda.
- Leads to a search that explores "vertically".

- Breadth-first search
  - Takes the first node on the agenda;
  - Adds new nodes to the back of the agenda.
- Explores all the nodes at one "level" before looking at the next level.

- A* search focuses the search by giving each node a pair of weights:
  - How far it is from the start; and
  - How close it is to the goal.
- The *cost* of the node is then the sum of the weights.
- We pick from the agenda by choosing the node with the lowest cost.

  (Choosing like this means we don't have to worry about what order we put nodes onto the agenda).

- In some domains we have to design clever functions to determine what "far" is.
- In robotics we can just use Euclidean or Manhattan distance between points:
  - Euclidean distance

$$d^e_{s,g} = \sqrt{(x_g - x_s)^2 + (y_g - y_s)^2}$$

  - Manhattan distance

$$d^m_{s,g} = |(x_g - x_s)| + |(y_g - y_s)|$$

- Of course the distance to t he goal may be an underestimate (may be no route through), but it turns out that this is a good thing for A*.

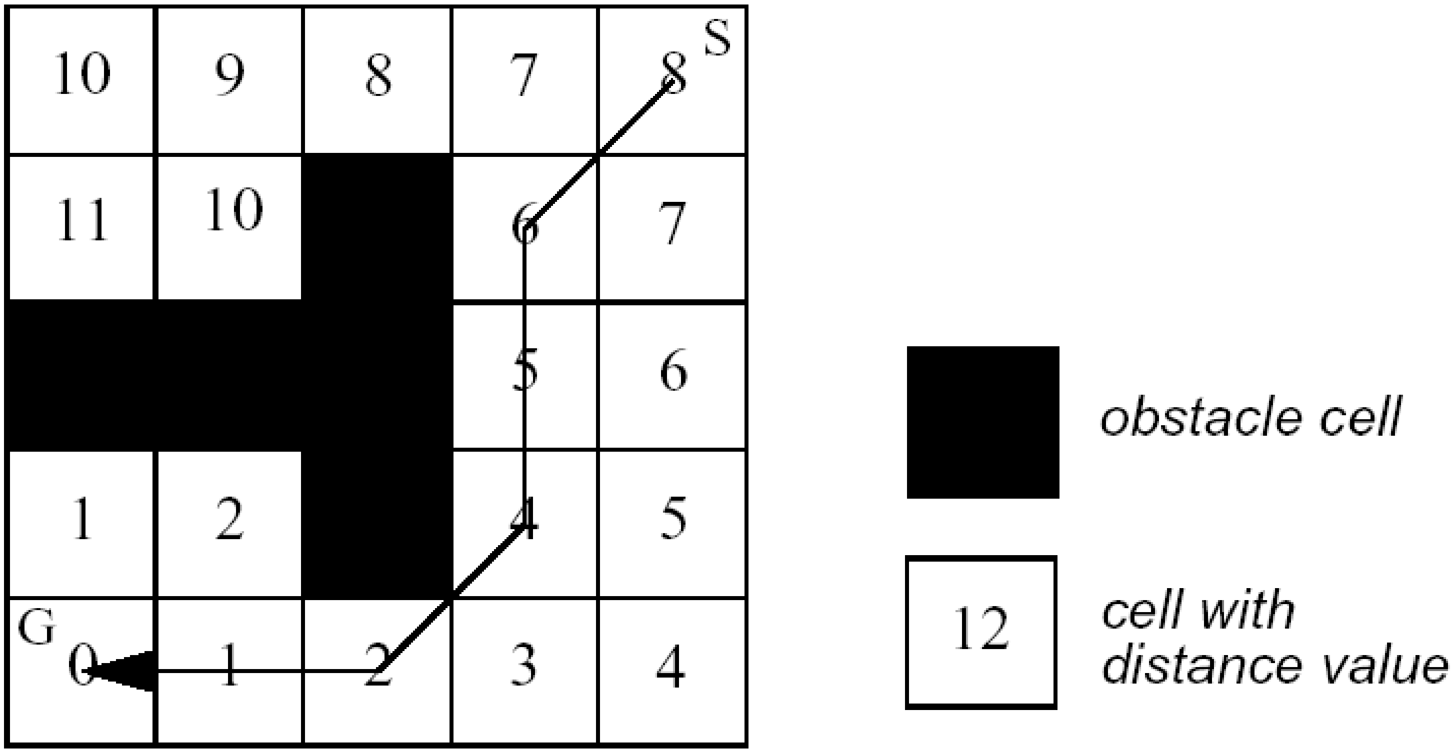
- Often in robotics we need to *replan*
- D* is a version of A* that keeps track of the search that led to a plan and just fixes the bits that need to be fixed.
- Quicker than replanning from scratch.
  - Usually have to replan from the robot to the goal and the only change is near the robot.
  - That is where the robot senses failure.

- In all these approaches we have to extract the waypoints after we find the goal.
- First we identify the sequence of cells.
  - As we search we can build a plan for each node we visit.
  - The plan for each node is the route to its parent plus the step to the node.
  - When we get to the goal we have the plan.
- Then we build a waypoint from each grid cell.
  - Typically the center of gravity of the cell.

Wavefront planning

- Also known as Grassfire, wildfire or NF1.
- Essentially breadfirst search in a convenient form for application to grid-based maps.
- Works like this:
  1. Start at the cell containing the `goal` and label it 0.
  2. Take every unlabelled cell that is next to a cell labelled n and label it $n+1$.
  3. Repeat until the cell containing the `start` is labelled.
- Then read the sequence of cells to traverse by following the labels down from the `start`.

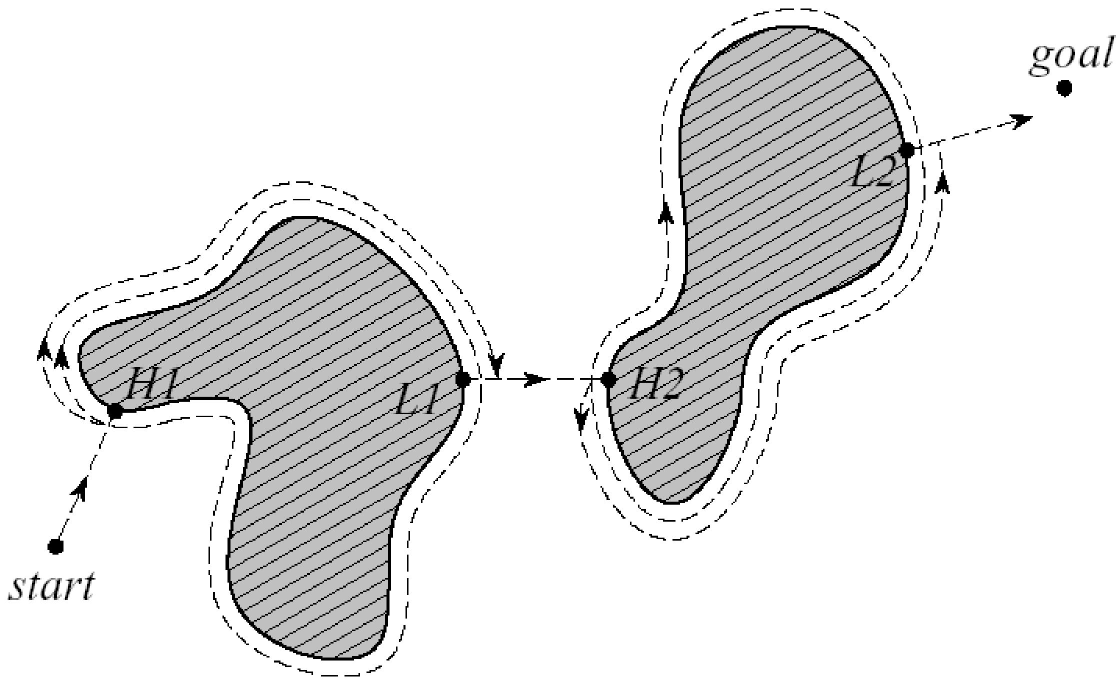
- Here's an example:



- Works especially well with occupancy grids, where the obstacles are already factored into the map.

Bug algorithms

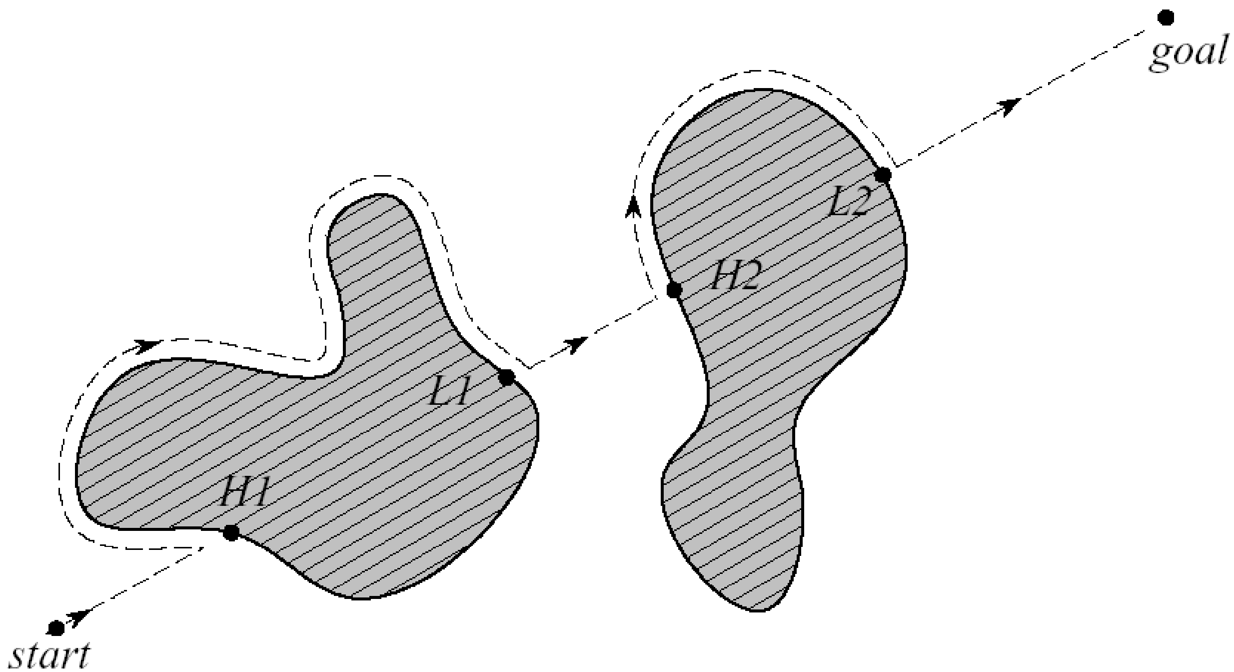
- The bug algorithms assume localization but no map.



- Here we see the first such algorithm, bug 1, working.

- When you meet an obstacle you follow around the edge.
- Leave the obstacle at the point closest to the goal.
- Circle the obstacle to be sure that you know where this point is.

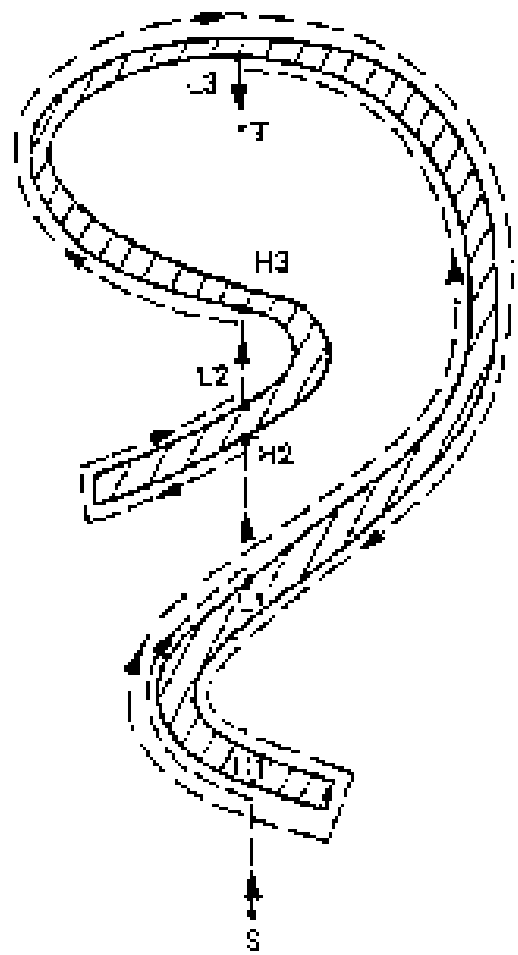
- Here's the second bug algorithm in action.



- Improves on the performance of bug 1

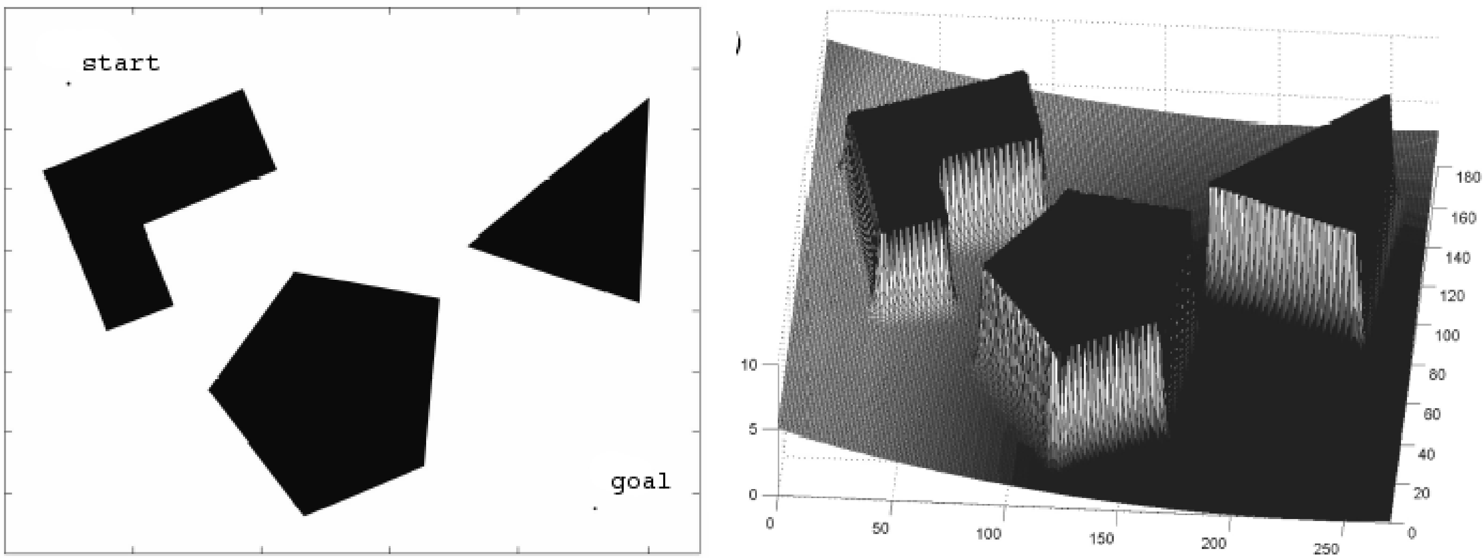
- Follow the obstacle always on the left or right side.
- Leave the obstacle if you cross the direct (line of sight) connection between start and goal.

Works even on very complex obstacles



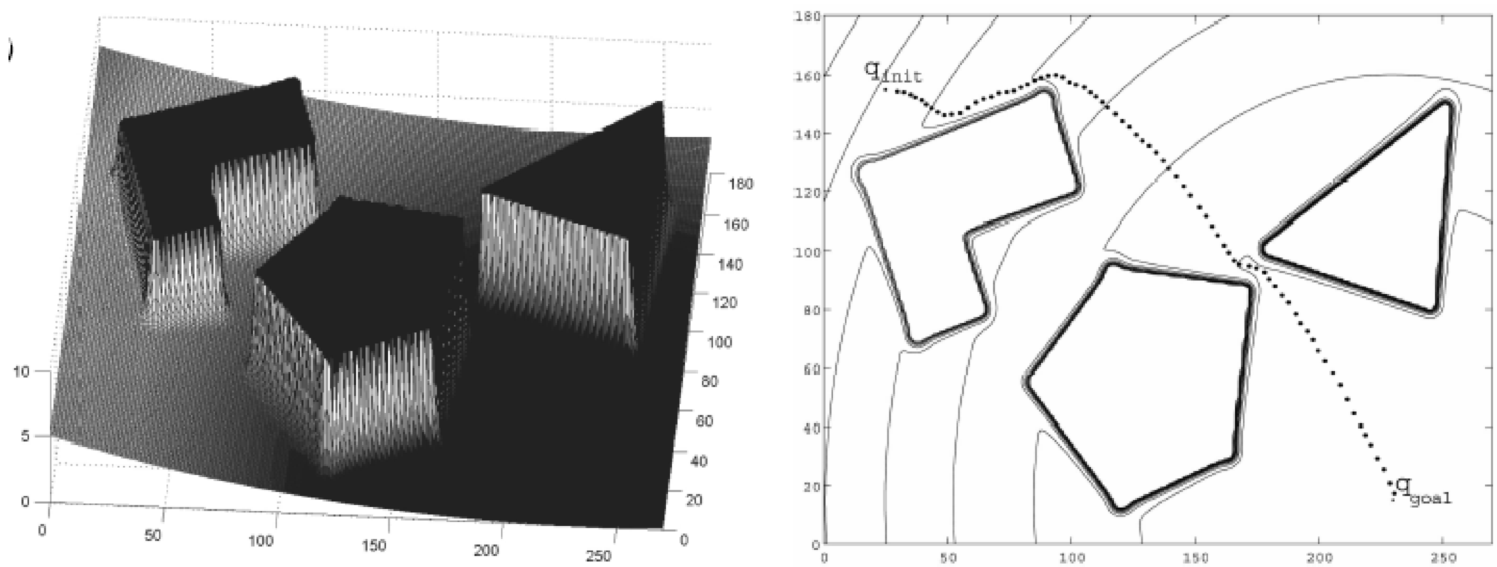
Potential field

- Robot is treated as a point under the influence of an artificial potential field.



- The `goal` attracts it and obstacles repel it.

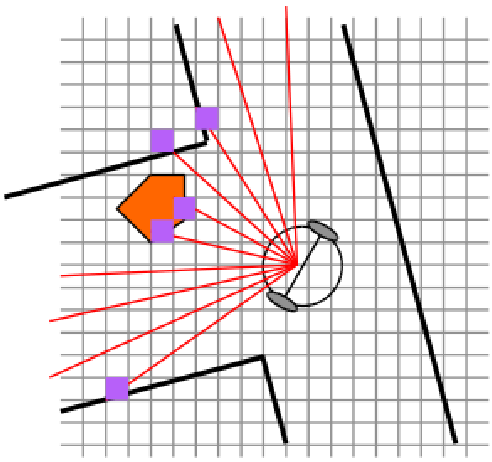
- Generated robot movement is similar to a ball rolling down the hill



- Lots of possibilities to get stuck in local minima.

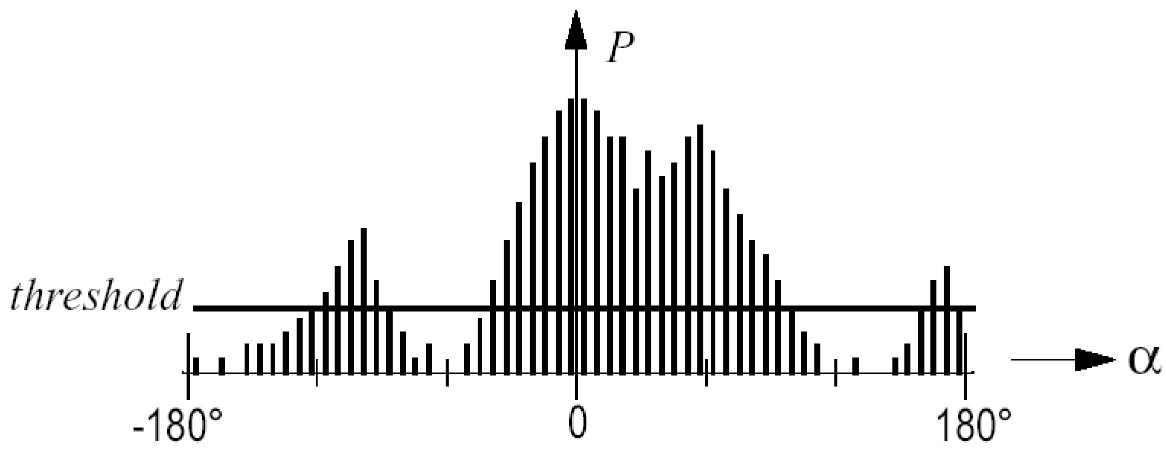
Vector field histogram

- Approach that uses sensor readings to tell the robot how to avoid obstacles.



- Representing the area around the robot as a grid, compute the probability that any square has an obstacle.
- Provides a local map to decide how the robot should move.

- The local map is reduced to a 1 DOF histogram:

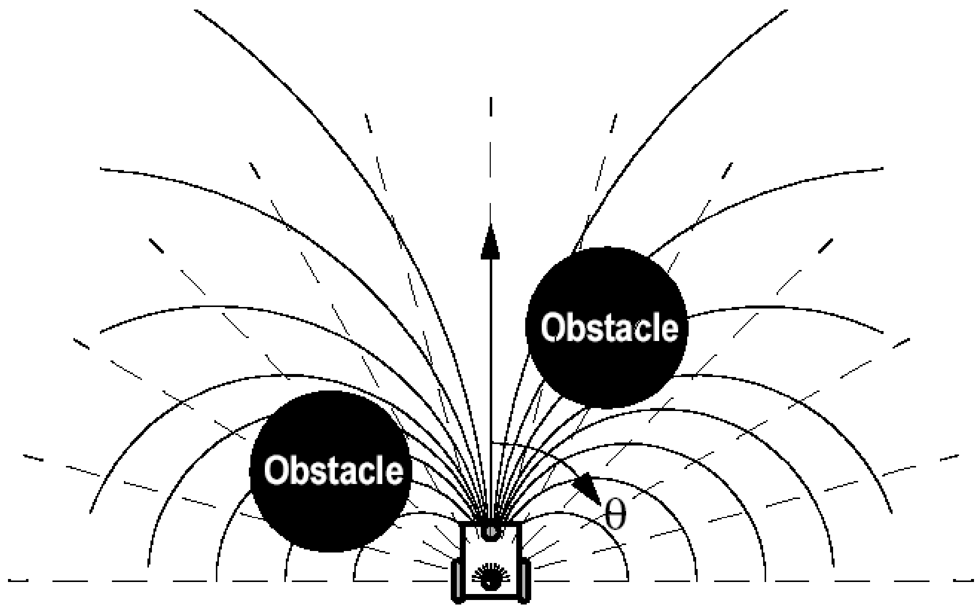


- Then compute the steering angle for the best gap.
- Best selected using function G which combines:

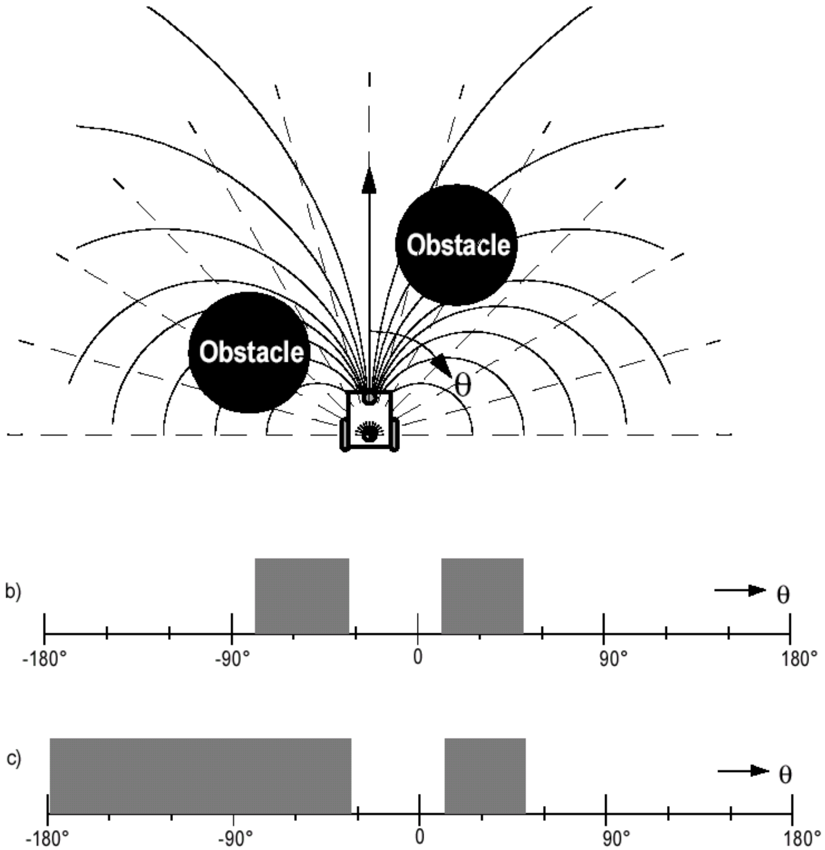
$$G = a.\,\texttt{target-direction} + b.\,\texttt{wheel-orientation} + c.\,\texttt{previous-direction}$$

VFH+

- An issue with VFH is that it doesn't take account of how the robot can really move.

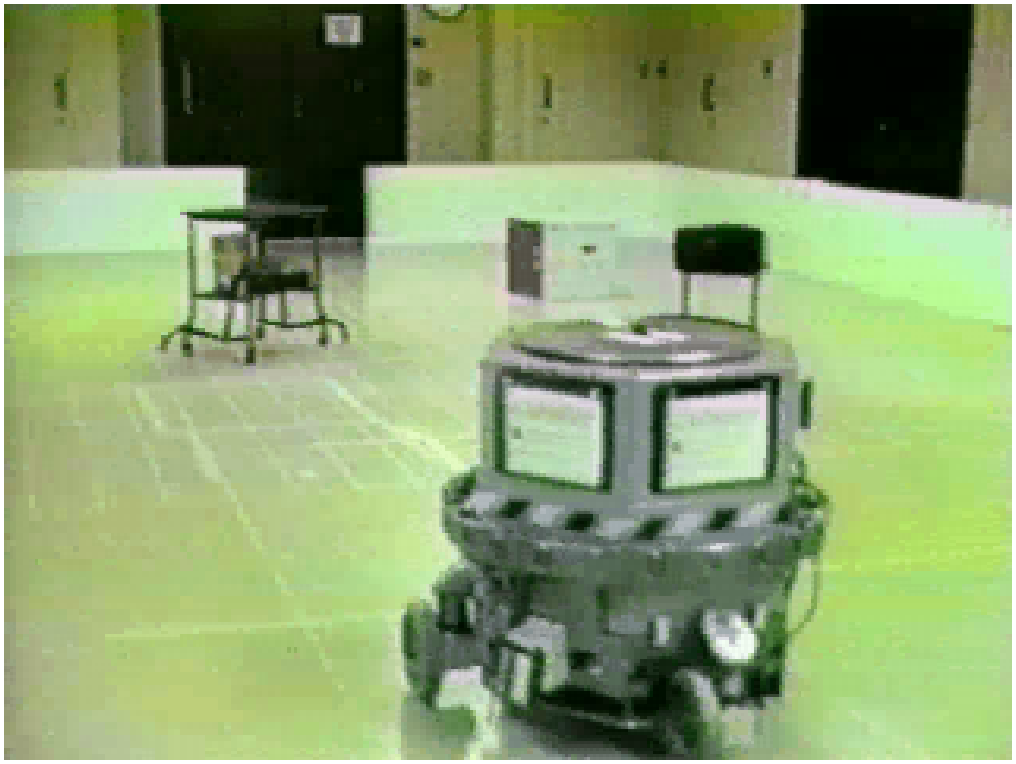


- The best gap could be one that the robot has to stop and do some complex maneuver to go through.



- VFH+ considers motion on trajectories.
- Any turn that has a trajectory that intersects an obstacle is blocked

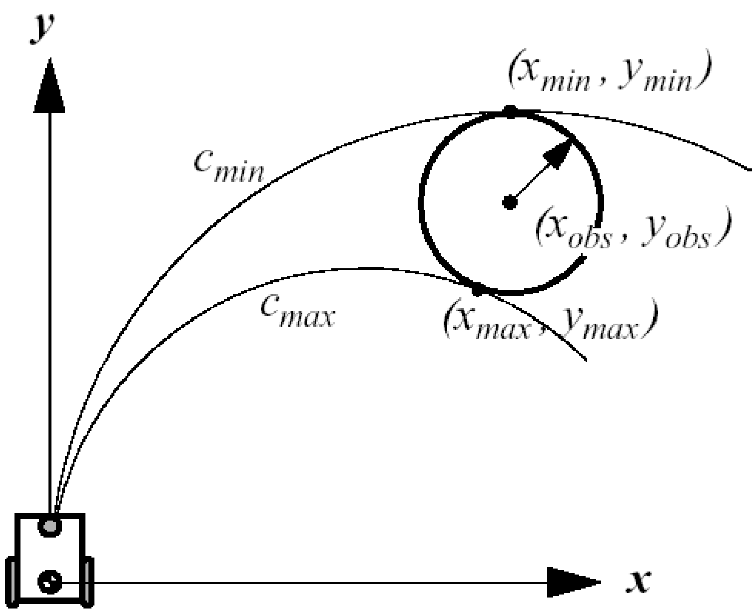
- VFH in action.



- VFH and VFH+ are limited if narrow areas (e.g. doors) have to be traversed.
- Local minima might not be avoided.
- Reaching the goal can not be guaranteed.
- Dynamics of the robot not really considered.

Curvature velocity methods

- Go further than VFH+ in modelling the motion of the robot.



- Transform obstacles into the velocity space of the robot.
- Apply acceleration constraints to determine possible velocities.

Summary

- In this final lecture we looked at issues to do with navigation.
  - Global navigation is about finding a path.
  - Local navigation is about avoiding obstacles.
- We looked at several examples of both.
- In the final labs we will look at path-planning, building on the path following code you have already written.