CSE-490DF
Robotics Capstone

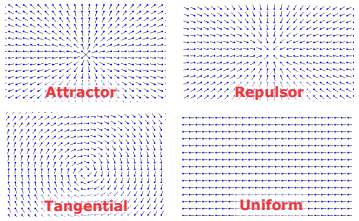
Motion planning

Behavior-based Control

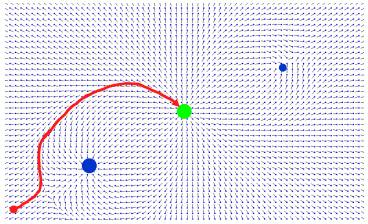
Potential Field Methodologies

- Treat robot as particle acting under the influence of a potential field
- Robot travels along the derivative of the potential
- Field depends on obstacles, desired travel directions and targets
- Resulting field (vector) is given by the summation of primitive fields
- Strength of field may change with distance to obstacle/target

Four Primitive Motion Fields



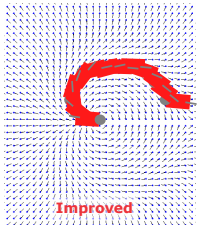
Combined Motion Fields (Goal with Obstacles)



Docking Fields

- Complex motion field
- Used to approach a position from a particular direction
  - Approaching the ball
  - Taking a specific field position and facing
- Combines
  - Attractor field to guide robot near target
  - Tangential field to guide robot around target
  - Docking "cone" to attract robot when it is in the correct position

Docking Field



- Difficult to find good parameters
- Smooth transitions are important

Characteristics of Potential Fields

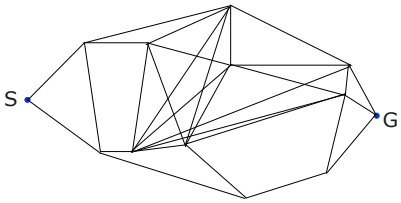
- Easy to visualize
- Easy to combine different fields
- High update rates necessary
- Parameter tuning important
- Difficult to generate complex motion
- No optimality

Path Planning Techniques

Discretization of Continuous Space

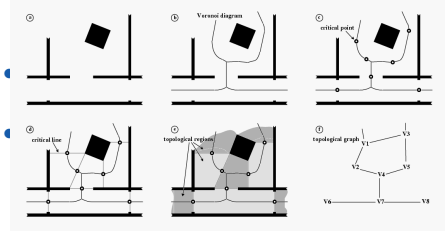
- Extract a discrete search space / graph from the continuous map.
- Redcuce path planning to graph search
  - Visibility graphs / roadmaps
  - Voronoi diagrams
  - Discrete grids

Visibility Graph / Roadmap

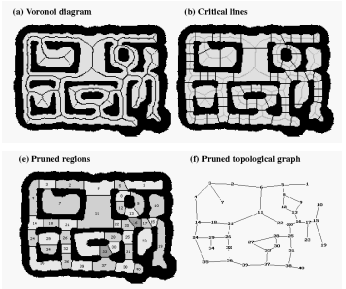


Voronoi Diagrams

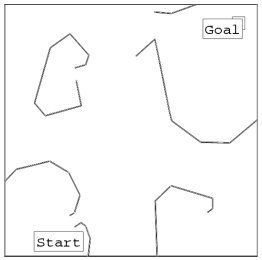
- Generalized Voronoi Diagram is locus



Voronoi Example



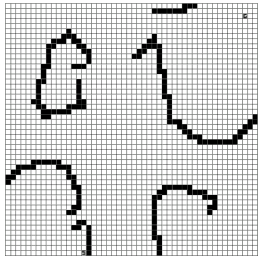
Continuous Environments



From: A Moore & C.G. Atkeson "The Parti-Game Algorithm for Variable Resolution Reinforcement Learning in Continuous State spaces," Machine Learning 1995

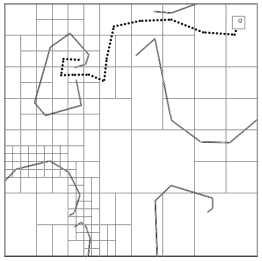
Approximate Cell Decomposition

[Latombe 91]



Parti-Game

[Moore 96]



Search on the Graph

- Can apply A* to find optimal path to goal.
- Only expands nodes needed to find optimal path.
- Not sufficient if motion is uncertain.
- In some cases, replanning is efficient enough.
- D* extends A* to efficient re-planning.

Gradient Method (Konolige)

- Path is list of points $P=\{p_1, p_2, \ldots p_k\}$
- p_k is only point in goal set
- Cost of path is separable into intrinsic cost at each point along with adjacency cost of moving from one point to the next

$$F(P) = \sum_i I(p_i) + \sum_i A(p_i, p_{i+1})$$

  - Adjacency cost typically Euclidean distance
  - Intrinsic cost typically occupancy, distance to obstacle

Navigation Function

- Assignment of potential field value to every element in configuration space [Latombe].
- Goal set is always downhill, no local minima.
- Navigation function of a point is cost of minimal cost path that starts at that point.

$$N_k = \min_{P_k} F(P_k)$$

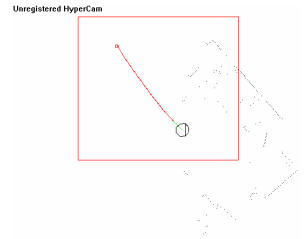
Computation of Navigation Function

- Initialization
  - Points in goal set ← 0 cost
  - All other points ← infinite cost
  - Active list ← goal set
- Repeat
  - Take point from active list and update neighbors
  - If cost changes, add the point to the active list
- Until active list is empty

Further Details

- Keep paths away from obstacles by setting intrinsic cost dependent on distance from obstacles.
- Local perceptual space depends on quality of sensors and odometry.
- Can easily achieve 10Hz update rate on low-end PC (10 x 10m LPS, 10cm resol.).
- Performs superior to human operator.

Example Run



Combination of Reactive Behaviors

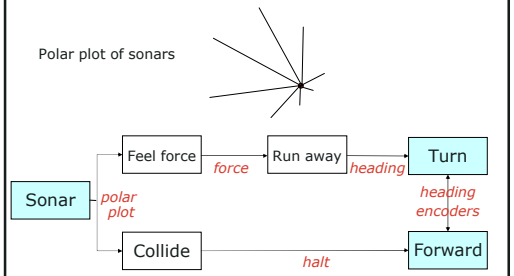
Combining Reactive Behaviors

- Reactive behaviors don't scale well.
- Need to find a way to combine reactive behaviors into a larger behavior system.
- Three ideas (other methods possible):
  - Competition - reactive behaviors compete for control of the robot.
  - Subsumption - reactive behaviors selectively take control of the robot.
  - Sequencing - reactive behaviors are sequenced by a higher level controller.

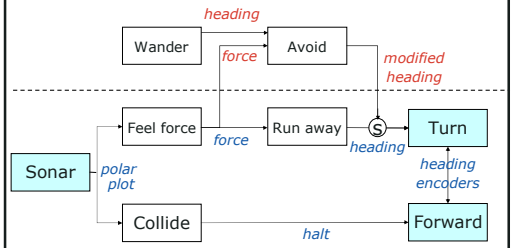
Subsumption Architecture

- Introduced by Rodney Brooks '86.
- Behaviors are networks of sensing and acting modules (augmented finite state machines AFSM).
- Modules are grouped into layers of competence.
- Layers can subsume lower layers.
- No internal state!

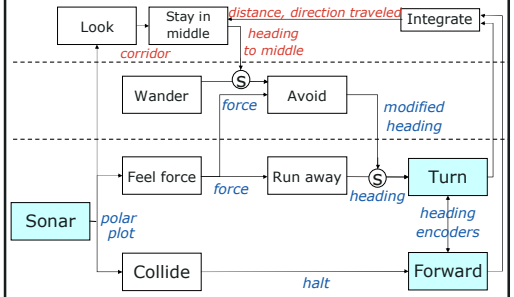
Level 0: Avoid



Level 1: Wander



Level 2: Follow Corridor



Sequencing

- Run only one reactive behavior at a time and switch the active behavior from time to time.
- Convenient method for sequencing the reactive behaviors is to use a finite state machine (FSM).
- Each state of the FSM has an associated reactive behavior.
- Each transition of the FSM has a transition rule that must be satisfied before the transition can happen.

Advantages of Sequencing

- Problems with oscillation are greatly reduced because transitions are gated by transition rules. Oscillation occurs by switching rapidly between states.
- Reactive to environment.
- Can select different actions from same perceptual state using context.
- Easy to create macro actions.
- Easy to chain together actions into larger behavior.
- Works well in practice.

Sequencing: Adding Scale

- In order to scale to larger problems, we would like to be able to reuse collections of reactive behaviors that together perform a task.
- We can simply allow each state of FSM to either be a reactive behavior or a collection of behaviors controlled by its own FSM.
- Can also allow reactive FSM behaviors to take parameters that control details of the actions they perform. For instance, a speed for going to a point or an object id for finding an object.

Behaviors Design

- Behavior design is more of an art form than a science.
- Good behaviors produce smoothly varying control signals.
- Control signals that oscillate or otherwise jump around lead to poor control performance.
- Oscillation amongst behaviors needs to be avoided because it leads to oscillatory control signals.

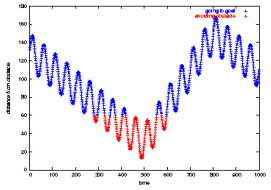
Avoiding Oscillation

- Oscillation can occur any time there is a transition path among a set of states.
- It usually happens at the boundary between states.
- There are two basic ways to reduce oscillation:
  - Merge 2 similar states together.
  - Add hysteresis to the transition rules.
- Oscillation can also occur if there are states where the robot fails to make progress towards the goal.

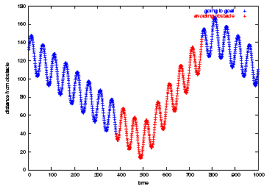
Hysteresis

- A system is said to exhibit hysteresis when the behavior of the system depends not only on its current state, but also on its history.
- In the context of behaviors, hysteresis refers to the creation of a buffer zone between two states.
- Within the buffer zone, the robot simply uses whatever state it was using when it entered the buffer zone.
- This is sometimes called a dual threshold because there are 2 thresholds involved instead of one.

No Hysteresis



Hysteresis



Behavior Design Principles

- Design the behavior in stages. Only work on one stage of the behavior at a time.
- Start with the state the robot should execute first. Working on later stages first tends to fail because the later states depend on the way in which the earlier states transition to them.
- As each state is completed, add the next state to be executed in the chain.
- Make one change at a time. The extra time spent compiling/booting will be saved by not wasting time trying to figure out which change you just made messed things up.