ME 449 Robotic Manipulation
Fall 2014
Problem Set 5
Due Wednesday December 10 at noon. Bring your laptops for your final computer demo in the classroom at noon.

1. Implement an A^* path planner. The planner takes a graph G as input, with N nodes and E edges. Edge e_i is just a specification of the two nodes (i, j) it connects as well as the distance between the two nodes, d_{ij}. One possible representation of G is as a symmetric matrix, where $G_{ij} = G_{ji} = 0$ if there is no edge between i and j, and $G_{ij} = G_{ji} = d_{ij}$ if there is an edge. Your A^* planner should return the sequence of nodes visited, $\{n_1, n_2, \ldots, n_k\}$, in the shortest path, where n_1 is the start node and n_k is the goal node. If there is no solution, your code should indicate so. Turn in your well-commented code.

2. Now test your A^* code on the case of a circular mobile robot moving among N circular obstacles in a 100×100 planar region.
Input:

(i) the radius r of the robot

(ii) a list of radii r_i and (x_i, y_i) coordinates of the centers of the obstacles

(iii) a list of (x, y) coordinates (the configuration of the center of the robot) for potential nodes of the graph

(iv) the start and goal nodes

Your code should then discard potential nodes that are in collision, construct the graph consisting of nodes that can be connected by straight-line paths without hitting an obstacle (you should come up with an exact method to determine whether two nodes are connected by a straight line, no sampling), invoke your A^* planner, and give the result as a list of nodes in the shortest path as well as a graphical representation of the solution, as in Figure 1.

You may find it helpful, for testing your code, to create another program that invokes this program using a random set of obstacles and a random set of nodes.

Turn in your well-commented code, as well as the graphical output for one example, of similar complexity to what you see in Figure 1. You are also welcome to submit a more complicated example, for example generated by a random set of nodes and obstacles.

3. (a) For the stationary contacts in Figure 2, draw the rotation centers that correspond to feasible motion of the planar object and label them with the appropriate contact modes. Put the contact label for the uppermost finger first,

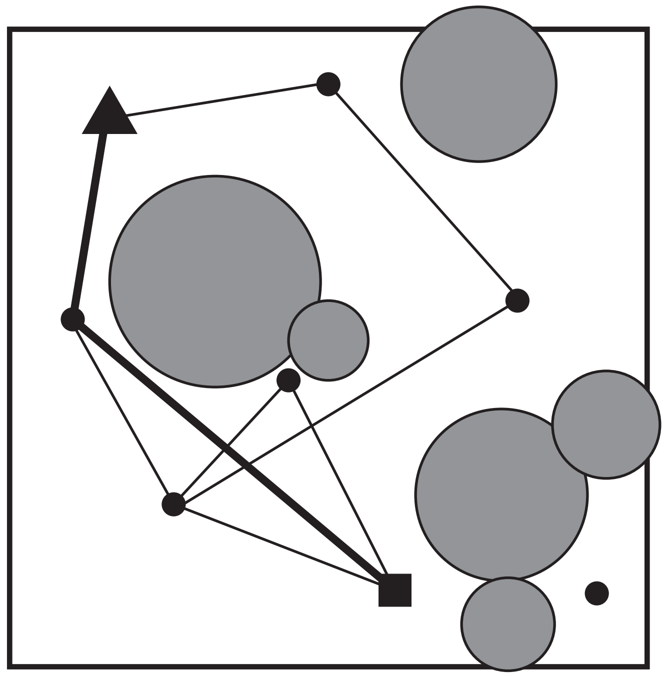

Figure 1: An example of what your final graphical represeentation might look like. The nodes of the graph are represented as filled circles, with the start node represented as a triangle and the goal node as a square. Edges in the graph are given in thin lines while edges in the optimal solution are given by thick lines.

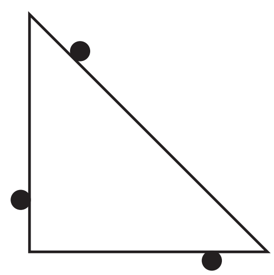

Figure 2: Three point fingers contacting a triangle.

then the middle finger, then the bottom finger. (b) Add a fourth "finger" that puts the object in form closure.

4. (a) For the friction cones in Figure 3, draw the moment-labeling represen-

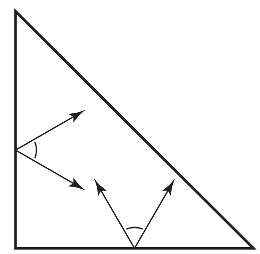

Figure 3: Two friction cones.

tation of all forces that can be applied to the object through the contacts. (b) Draw a force that cannot be resisted by the contacts and explain why in terms of the moment labeling regions.

5. In Figure 4, body 1, of mass m_1 with center of mass at (x_1, y_1), leans on body 2, of mass m_2 with center of mass at (x_2, y_2). Both are supported by a horizontal line, and gravity acts downward. The friction coefficient at all four contacts (one at $(0, 0)$, one at (x_L, y), one at $(x_L, 0)$, and one at $(x_R, 0)$) is $\mu > 0$. We want to know if it is possible for the assembly to stay standing by some choice of contact forces within the friction cones. Write the six equations of force-balance for the two bodies in terms of the gravitational forces and the contact forces, like we did in class, and express the conditions that must be satisfied for it to be possible for this assembly to stay standing. (All your conditions should be specified mathematically, so if we plugged in specific values for m_1, (x_1, y_1), etc., the problem could be solved immediately using Matlab, Mathematica, or similar software.)

6. What is the minimum friction coefficient needed for two-fingered force-closure grasping of a regular pentagon (all sides equal length) if you cannot grasp a corner? How about a regular hexagon? What if you can grasp corners?

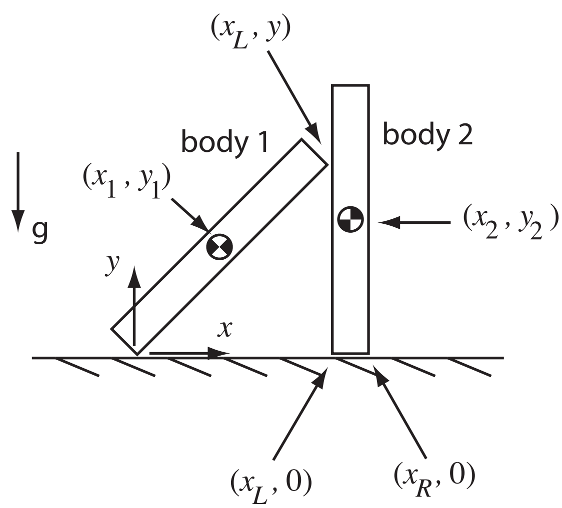

Figure 4: One body leaning on another.