16-311: Introduction to Robotics
Spring 2009 Midterm Solutions

Problem 1 (15 pts):

You are given an input signal $[0 \quad 1 \quad 3 \quad -2 \quad 0 \quad 1 \quad 5 \quad 5 \quad -1 \quad 0 \quad 3 \quad -2 \quad 1 \quad 1 \quad 0]$.

(a) Convolve the input signal with the mask $\begin{bmatrix}\frac{1}{2} & \frac{1}{2}\end{bmatrix}$ and then convolve the result again with the same mask $\begin{bmatrix}\frac{1}{2} & \frac{1}{2}\end{bmatrix}$. (4 pts)

Convolved once: $\begin{bmatrix}\frac{1}{2} & 2 & \frac{1}{2} & -1 & \frac{1}{2} & 3 & 5 & 2 & -\frac{1}{2} & \frac{3}{2} & \frac{1}{2} & -\frac{1}{2} & 1 & \frac{1}{2}\end{bmatrix}$

Convolved twice: $\begin{bmatrix}\frac{5}{4} & \frac{5}{4} & -\frac{1}{4} & -\frac{1}{4} & \frac{7}{4} & 4 & \frac{7}{2} & \frac{3}{4} & \frac{1}{2} & 1 & 0 & \frac{1}{4} & \frac{3}{4}\end{bmatrix}$

(b) Convolve the input signal with the mask $\begin{bmatrix}\frac{1}{4} & \frac{1}{2} & \frac{1}{4}\end{bmatrix}$. (2 pts)

Result: $\begin{bmatrix}\frac{5}{4} & \frac{5}{4} & -\frac{1}{4} & -\frac{1}{4} & \frac{7}{4} & 4 & \frac{7}{2} & \frac{3}{4} & \frac{1}{2} & 1 & 0 & \frac{1}{4} & \frac{3}{4}\end{bmatrix}$

(c) Is the result the same or different? (1 pt)

The result is the same.

(d) Why? (5 pts)

Convolution is associative, and $\begin{bmatrix}\frac{1}{2} & \frac{1}{2}\end{bmatrix}$ convolved with itself gives $\begin{bmatrix}\frac{1}{4} & \frac{1}{2} & \frac{1}{4}\end{bmatrix}$.

(e) What does convolving with the mask $\begin{bmatrix}\frac{1}{2} & \frac{1}{2}\end{bmatrix}$ do? (3 pts)

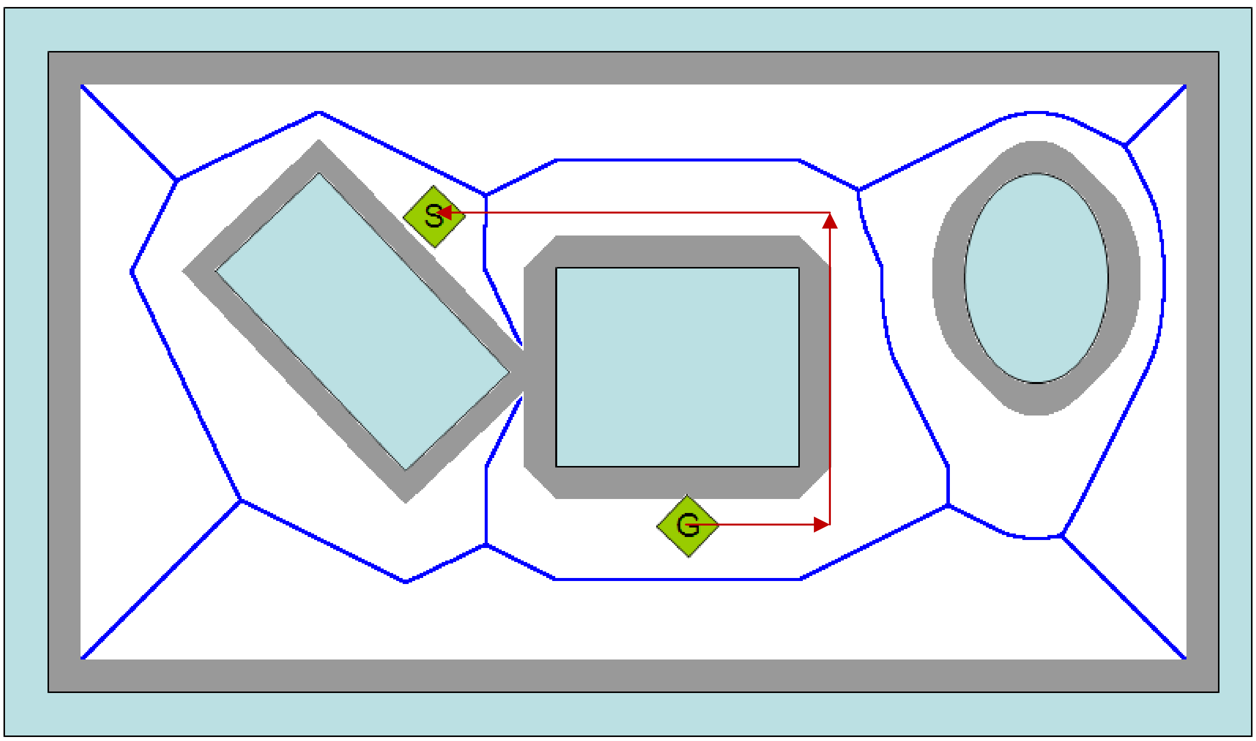
It performs an average (with a window size of 2).

Problem 2 (25 pts):

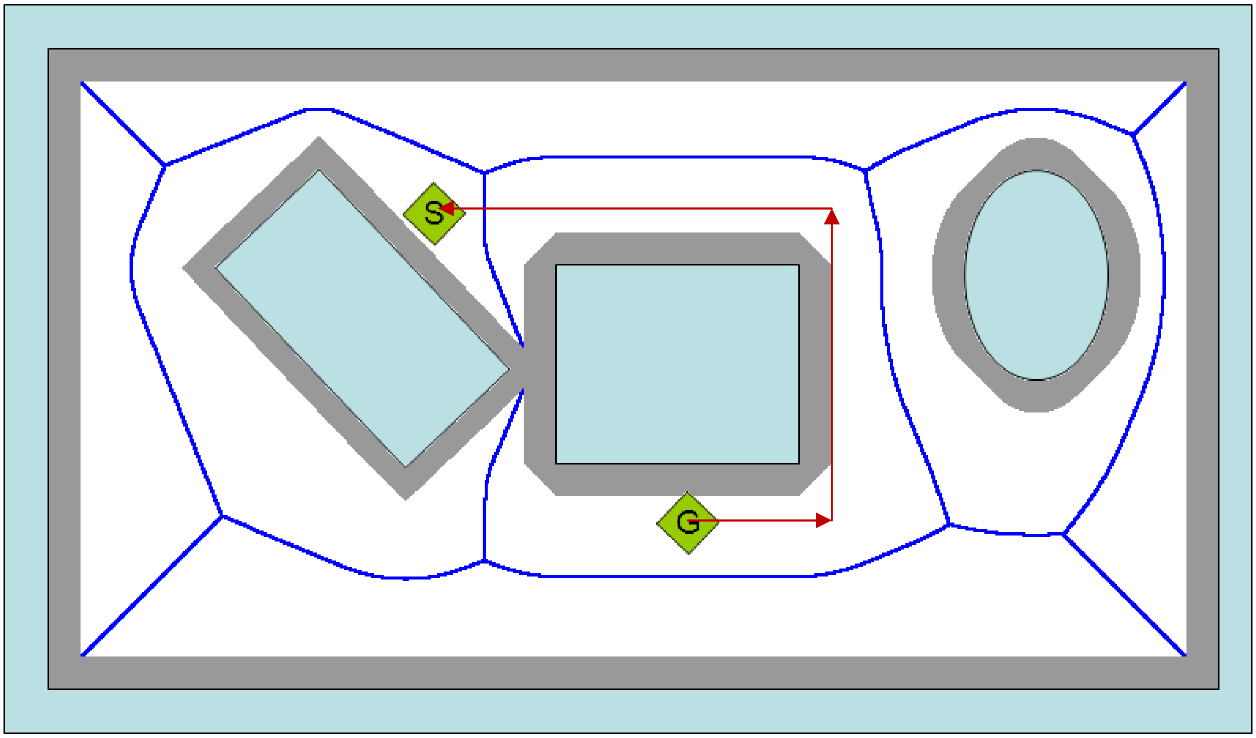
(a) Draw the generalized Voronoi diagram for the configuration space for the square shaped robot in the orientation shown. (20 pts)

(b) Draw the shortest path with respect to the L1 metric between the start and goal locations shown. (5 pts)

Generalized Voronoi diagram using L1 metric:



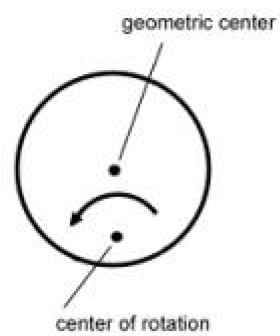
Generalized Voronoi diagram using L2 metric:



Problem 3 (9 pts):

(a) How many DOF does a circular robot which can translate (along a plane) and rotate on some point other than its center have? (3 pts)

3 – 2 translation, 1 rotation



(b) How many DOF does a robot on a track (i.e. it can only go forwards or backwards), with 2 revolute joints have? Think of it as a train with an arm attached to the top of it. (3 pts)

3 – 1 translation, 2 rotation

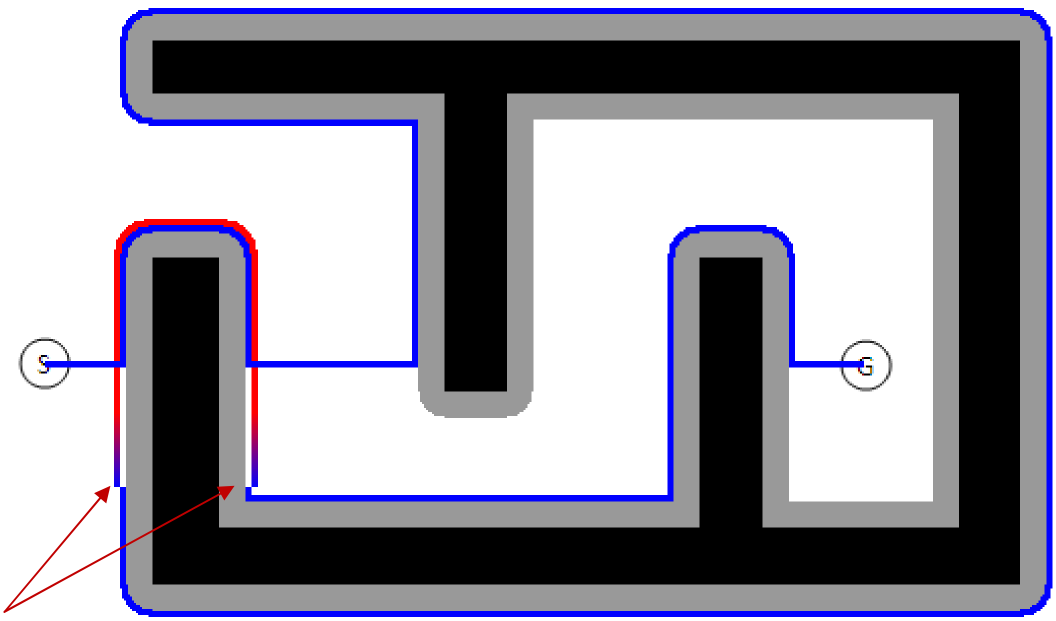
(c) What is the dimension of the configuration space of a robot that has an extensible arm with 2 revolute joints? Think of it as a pan/tilt camera that can be lifted/lowered. (3 pts)

3 – s (extension), θ_1(revolute joint 1), θ_2 (revolute joint 2)

Problem 4 (15 pts):

(a) Draw the path using the BUG2 algorithm in the world shown below: (10 pts)

Suppose the BUG2 algorithm always turns left:



For illustration only, the path actually sticks to the edge

(b) Is this path optimal? (5 pts)

Optimal with respect to what?

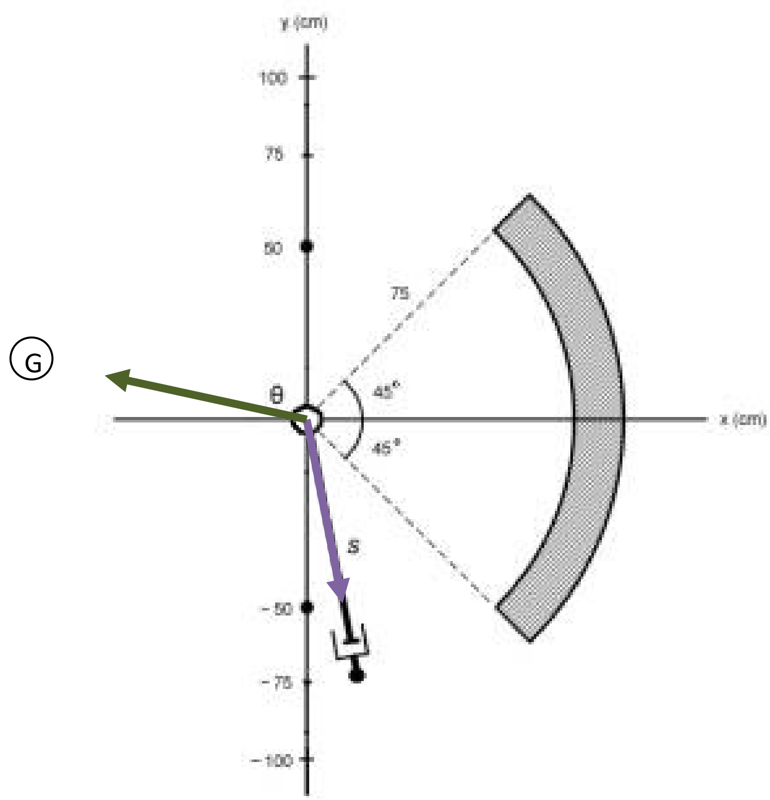
Problem 5 (30 pts):

A 1 DOF prismatic joint is a linear DOF, which as its name suggests, provides motion along a line. Think of it as a telescoping arm. The robot below has a revolute joint with angle θ at the base, which rotates a prismatic joint with length s whose range of motion is 0 to 100 cm. The base joint has no limits. The robot is shown in its initial position.

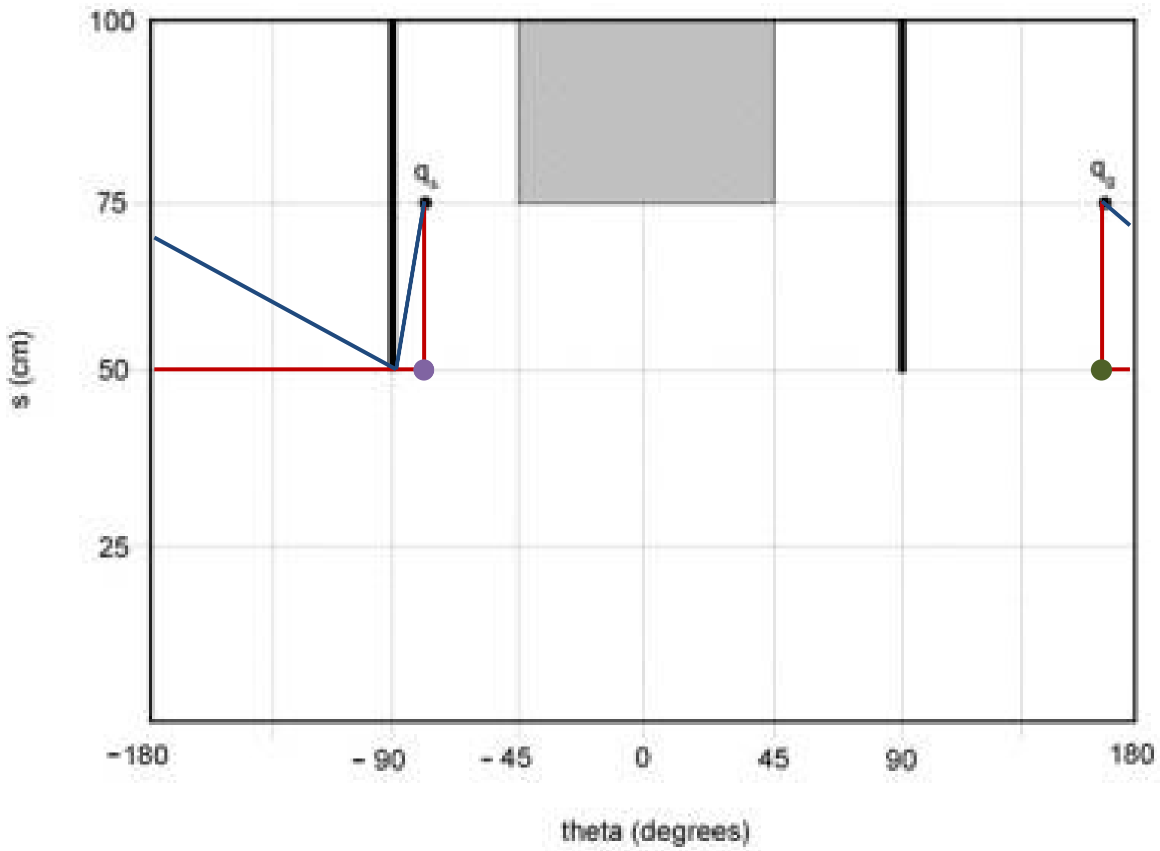
There are 3 obstacles: two point obstacles at (0, 50) and (0, -50), and a curved quarter circular wall with radius 75 cm.

(a) Draw the configuration space of this robot on the next page (20 pts)
(b) Pick a metric and draw the shortest path with respect to that metric. (5 pts)
(c) Draw the end position in the workspace along with 2 intermediate points on the shortest path. (5 pts)

Workspace:



Configuration space (to be filled in):



Metric used for shortest path: L1 or L2

Problem 6 (6 pts):

Answer any 3 of the following 6 questions, clearly crossing out the ones you did not answer.

(a) What is active learning?

You're not handed a data set from the robot. You have to decide what data points to collect, and based on those, you have to learn something from it.

(b) Give an example of how active learning can be used in robotics.

Active learning can be used to teach a robot arm how to throw a tennis ball accurately at a target.

(c) What are the benefits of snake robots, as discussed in class?

Snake robots are able to perform a variety of locomotion that no other single robot can, e.g. climbing a pole, swimming, moving across rubble, moving on flat ground.

(d) True or false: we have two eyes so that we can see in stereo. Why?

False, we have two eyes for redundancy, in case we lose one.

(e) What is Hans Moravac famous for?

Taken from Wikipedia.org, Hans Moravec "is a futurist with many of his publications and predictions focusing on transhumanism," i.e. using technology to "improve human mental and physical characteristics and capacities" (e.g. cyborgs).

(f) In one or two sentences, describe how back propagation on a neural net works.

Based on the error of the output of the neural net, the weights of the output layer are adjusted. The error is then propagated to the next layer, where the weights are adjusted, and so on.