Student Name: ______________________ Student ID # ______________________

Question 1: Sensor Models for Mapping. 20 points.

Jim wants to have his robot map the hallways and rooms in his building. However, he isn't convinced that the sonar model given in chapter 11 of his textbook is accurate and he thinks that constructing his own sonar model, either empirically or analytically, would be too difficult. So, Jim considers using a simple laser sensor instead. This laser sensor sends out a short pulse of narrowly focused light (a laser pulse) in whatever direction it is pointing and measures the time it takes for the pulse to be reflected and return. Under normal operating conditions, this sensor has a maximum range of about 25 feet.

Jim thinks that it would be easier to empirically construct and use (integrate into mapping code) a model for this sensor than it is to empirically construct and use a model for a sonar sensor.

List and **explain** *two* reasons that Jim is right.

Question 2: Bayesian Mapping. 20 points.

Unlike Jim, Osama decides to use the sonar model given in the textbook. He implements it on his robot, which uses a standard Polaroid "lab grade" ultrasonic transducer with a maximum range of 25 feet. He uses the common assumption that P(Occupied) = P(Empty) = 0.5 and initializes his robot's occupancy grid accordingly. Then he positions the robot 24 1/2 feet from a wall in a big, open room and takes a reading. Sure enough, the sonar returns a reading of 24.5 feet. Osama is quite pleased until he sees that, in the map that his robot is using, the grid element corresponding to the wall directly in front of the sonar at a range of 24.5 feet has been updated to have a probability of being occupied of 0.4998 and a probability of being empty of 0.5002 whereas all the grid elements directly between the one corresponding to the robot's position and the one corresponding to the wall have been updated to have a probability of being occupied of 0.51 and a probability of being empty of 0.49.

[Math help: 0.51 * 0.98 = .4998]

A. Why is Osama bothered by these updated values?

B. Where is the problem in the system?

Question 3: Dempster-Shafer Theory. 10 points.

Charlie decides to use Dempster-Shafer Theory for his robot's mapping. His robot gets a reading for a particular grid element that indicates a belief mass of 0.9 for that element to be occupied and 0.1 for a "don't know" mass for that element. Because this was the first reading that his robot took, he calculates that after updating from the initial state, the new values for this grid element should be m(Occupied) = 0.9, m(Empty) = 0.0, and m(don't know) = 0.1. He checks his robot's readings for that grid element and the numbers match. So far, so good.

Then Charlie's robot moves and gets another reading for that same cell but this time the new reading indicates a belief mass of 0.9 for that element to be *empty* and 0.1 for "don't know." Charlie reasons that these two conflicting readings should put the robot in a state with a large belief mass for "don't know." Using pen and paper, he calculates that the overlap for the conflict should be 0.9 * 0.9 = 0.81 and the overlap for the two "don't know" beliefs should be 0.1 * 0.1 = 0.01. He adds these up and gets 0.82 for the total "don't know" belief mass after two readings, and gets 0.9 * 0.1 = 0.09 for the belief mass for occupied and 0.9 * 0.1 = 0.09 for the belief mass for empty. These values add up nicely to a total belief mass of 1.0 and Charlie is happy.

However, when Charlie checks the values returned by his robot for this grid cell, he's confused. The robot's updated values after two readings are m(Occupied) $\approx$ 0.47, m(Empty) $\approx$ 0.47, and m(don't know) $\approx$ 0.05.

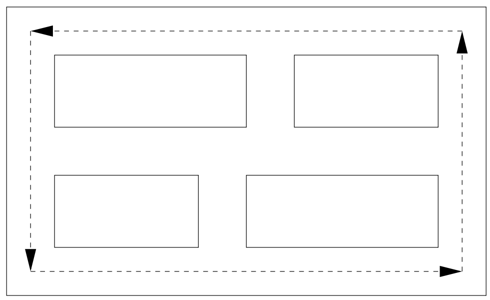
[Math help: 0.09 / 0.19 $\approx$ 0.47 and 0.01 / 0.19 $\approx$ 0.05]

Is Charlie's problem on paper, in his code, both, or neither? **Explain your answer.**

Question 4: Localization and Map Making. 10 points.

Chris has a robot equipped with a laser rangefinder (for which he has figured out appropriate sensor models and correctly implemented code for updating the occupancy grid on his robot) and shaft encoders. He moves his robot around to several known locations, has it take readings, has it update its occupancy grid, and checks the results. Everything checks out.

Now he believes that his robot is ready to run around his building and build a map of the hallways. He knows that the basic layout of the halls is as shown below, so he decides to have it run around and around the outer hallway loop (as also shown below) until the values in the map stop changing much (converge within some tolerance), then have it map the other halls.



Chris starts up his robot and it moves around the loop once, twice, three times, four, ... and just keeps on going. Not only do the values not converge but they are still changing just as much the hundredth time around the loop as they did the second.

Explain what might be going on and how Chris could address this problem.

Question 5: Heterogeneity in Multiple Robot Systems. 10 points.

According to Balch's social entropy measure, which is the more heterogeneous collection of robots?

1. A group of 50 small, ball-shaped, sensor robots that can roll around and detect radiation teamed with a humanoid robot that communicates with the sensor robots and instructs nearby people what to do if radiation is detected, or
2. The 10 robots built by the 10 teams in this class for project 2.

Explain your answer.

Question 6: Cooperation in Multiple Robot Systems. 10 points.

A. Can ALLIANCE be used for active cooperation? **Explain your answer.**

B. Can ALLIANCE be used for non-active cooperation? **Explain your answer.**

Question 7: Multi-Robot Localization and Mapping. 20 points.

You want a team of robots to construct a map of this building (Sarkeys Energy Center) but you have no *a priori* reason to care if this map is metric or topological.

Your team consists of 10 identical mobile robots, each equipped with a color camera and shaft encoders. Each is able to communicate with all of the others using a wireless Ethernet system. They have no other sensing or communication systems. They avoid bumping into obstacles by using optic flow to estimate distance.

You want to be able to place them at random locations around the building, turn them on, and have each one construct a local map of what it finds as it explores. Further, you want them to be able to merge their local maps to create a global map when overlapping regions are found.

Given the multi-robot system available to you, would you choose to have your robots create a metric or topological map. **Explain your answer.**