Robotics USI 2018 - Final exam

15 June 2018

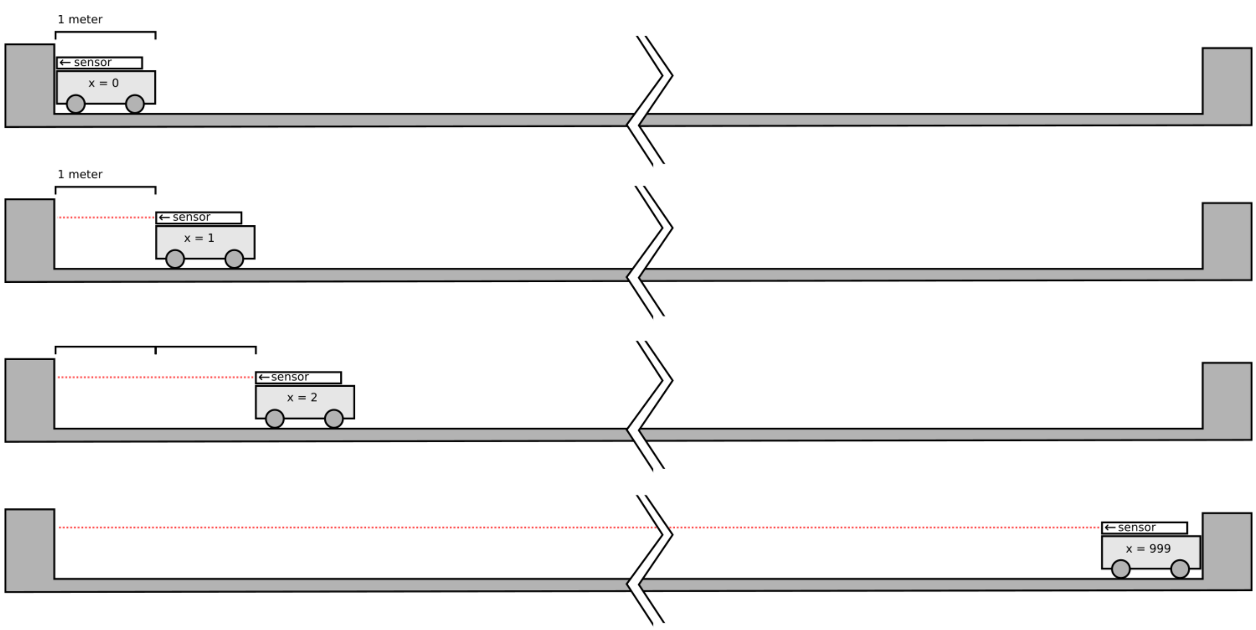
Answer the questions in the spaces provided on the question sheets. If you run out of room for an answer, continue on the back of the page or on the provided extra pages.
Write your name in the header of all pages. The handed-in material must be filled in pen, not pencil.
Clarity is part of the evaluation criteria. If you have doubts about the details of a question, make an assumption that you believe is convenient and reasonable and state it clearly. The exam is evaluated by a human being, not a robot.

Name, surname: ______________________________

1 Exercise (35/100 points)

A robot R moves on a 1D rail that is 1 kilometer long and straight.

The robot can move left or right with great precision, using two possible actions: $o = L$ moves the robot exactly 1m to the left; $o = R$ moves the robot exactly 1m to the right. We model the robot position with a Markov approach, using a 1m-long cell. In the leftmost cell, the robot touches the left wall ($x = 0$).



The robot is equipped with a laser distance sensor, mounted at its left side that measures the distance to the left wall. The sensor is at distance 0 to the wall if the robot touches the left wall. Every time it is used, this sensor returns one of three possible outputs:

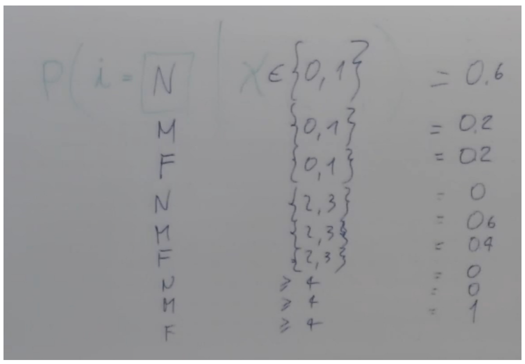
- $i =$ N: the wall is near (0 or 1 meters)
- $i =$ M: the wall is at a medium distance (2 or 3 meters)
- $i =$ F: the wall is far (4 meters or more)

The spec sheet of the sensor states the following:

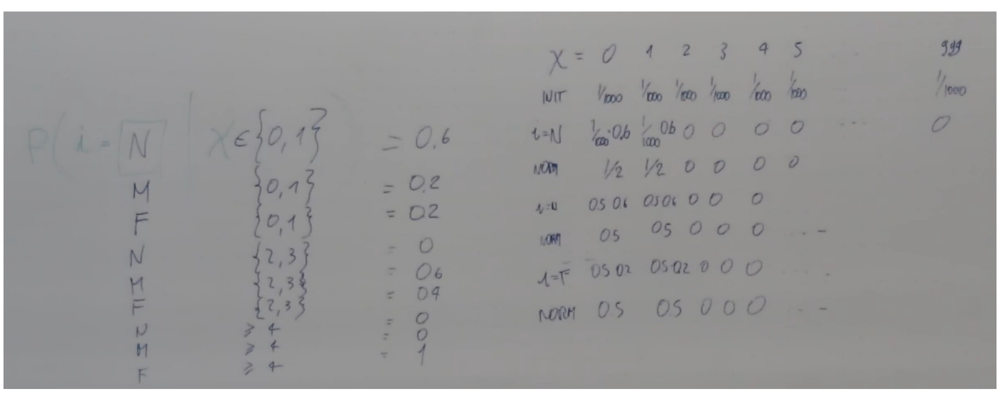
> Our sensor implements our proprietary NeverUnderestimate™ technology. It will never underestimate the true distance, so, for example, it will never return N if the true distance is 2 or more meters. However, 40% of the times, at random, it will overestimate the distance. When it overestimates the distance, all overestimated outputs are equally likely. For example, if the true distance is 0, there is a 40% chance that the sensor will return an overestimated output; this output could be either M or F, with equal probability.

Answer the following questions, which are **independent from each other**.

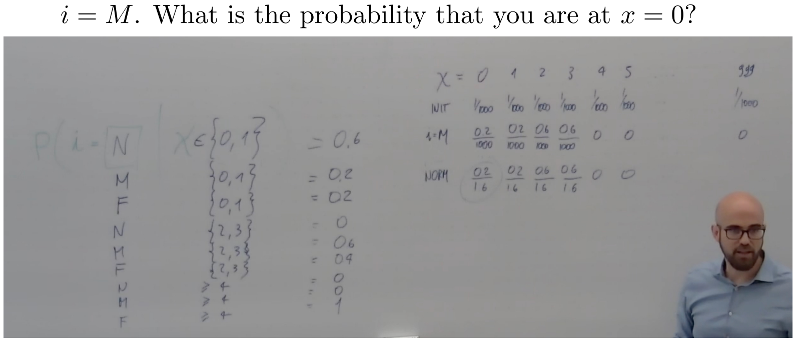
1. (5 points) Formalize the sensor model using probability notation



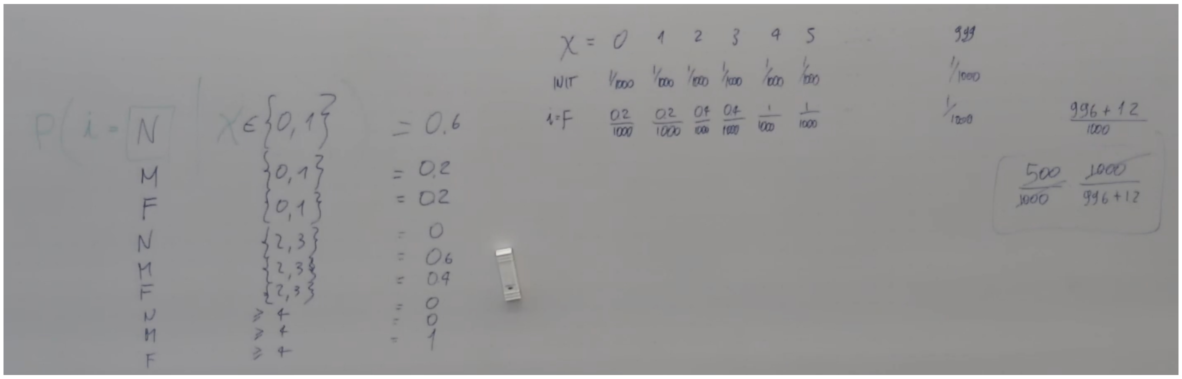
2. (10 points) Describe the belief about the robot location after each of the following sequential steps:
   - The robot is initialized after kidnapping, and has complete ignorance about its location.
   - The robot does not move, then the robot senses $i = N$.
   - The robot does not move, then the robot senses $i = N$.
   - The robot does not move, then the robot senses $i = F$.



3. (5 points) You are the robot and you have been kidnapped, so you don't know where you are. You sense $i = M$. What is the probability that you are at $x = 0$?

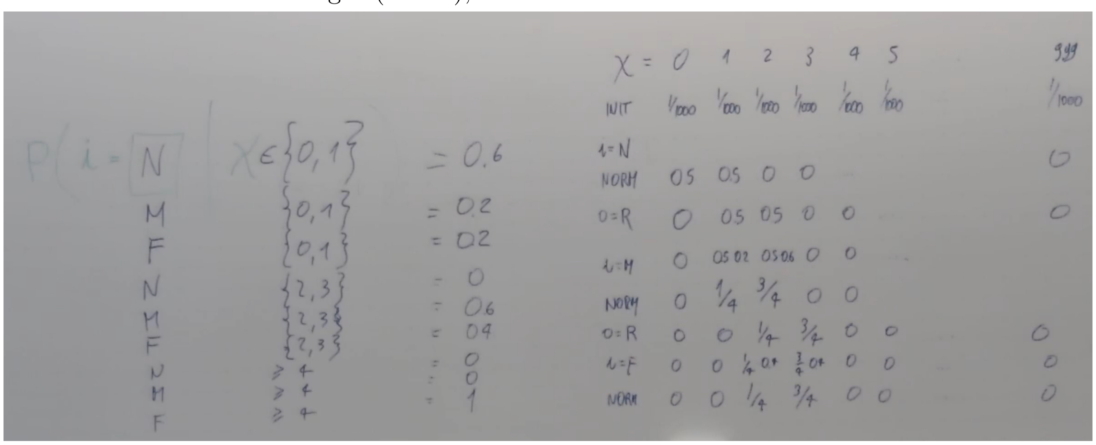


4. (5 points) You are the robot and you have been kidnapped, so you don't know where you are. You sense $i = F$. What is the probability that you are on the right half of the track (i.e., $x \geq 500$)?



5. (10 points) The robot is initialized after kidnapping, and has complete ignorance about its location. Describe the belief about the robot location after each of the following sequential steps:

   - The robot senses $i = N$.
   - The robot moves right ($o = R$), then the robot senses $i = M$.
   - The robot moves right ($o = R$), then the robot senses $i = F$.

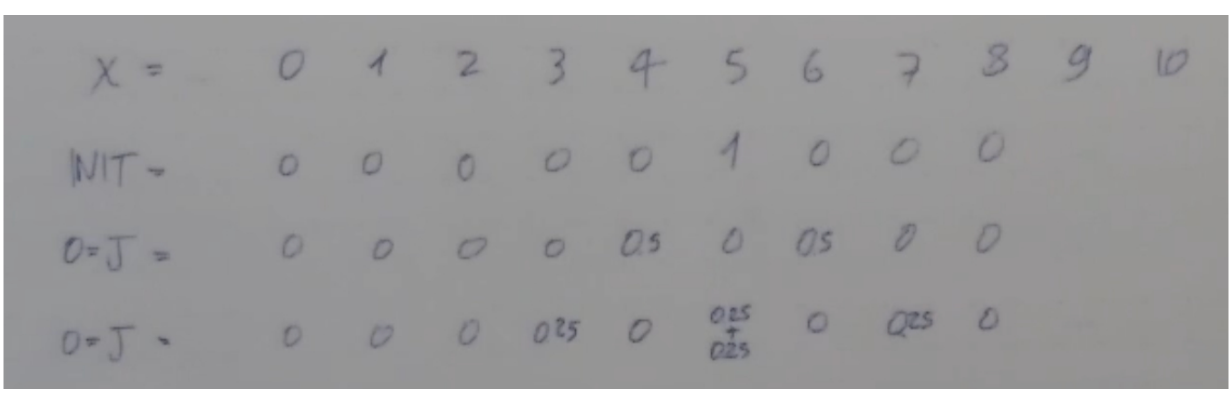


2 Exercise (15/100 points)

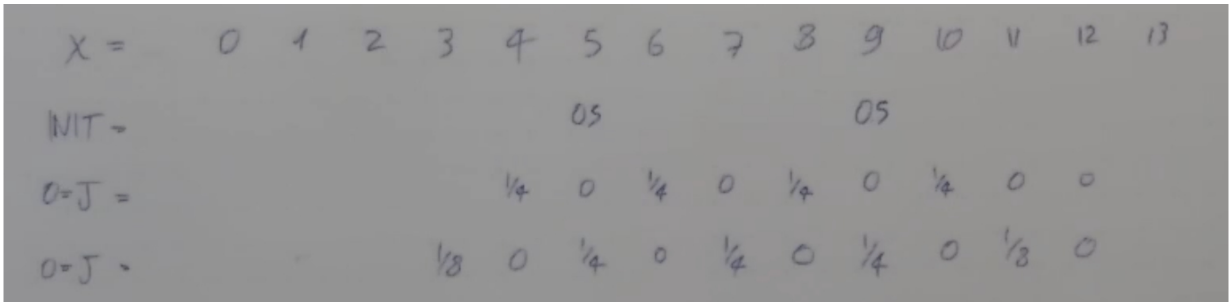
A flea robot lives in an infinite 1D world. It has a peculiar locomotion mode: the only thing it can do is jump. When it jumps ($o = J$), it may land exactly 1m to the right, or 1m to the left. Each of the two outcomes has the same probability.

1. (5 points) Describe the robot's belief about its location after each of the following sequential steps:

   - The robot is sure that it is located at $x = 5$.
   - The robot jumps ($o = J$).
   - The robot jumps again ($o = J$).



2. (10 points) Describe the robot's belief about its location after each of the following sequential steps:
   - The robot is undecided between being at $x = 5$ or $x = 9$, each of the two options being equally likely.
   - The robot jumps ($o = J$).
   - The robot jumps again ($o = J$).

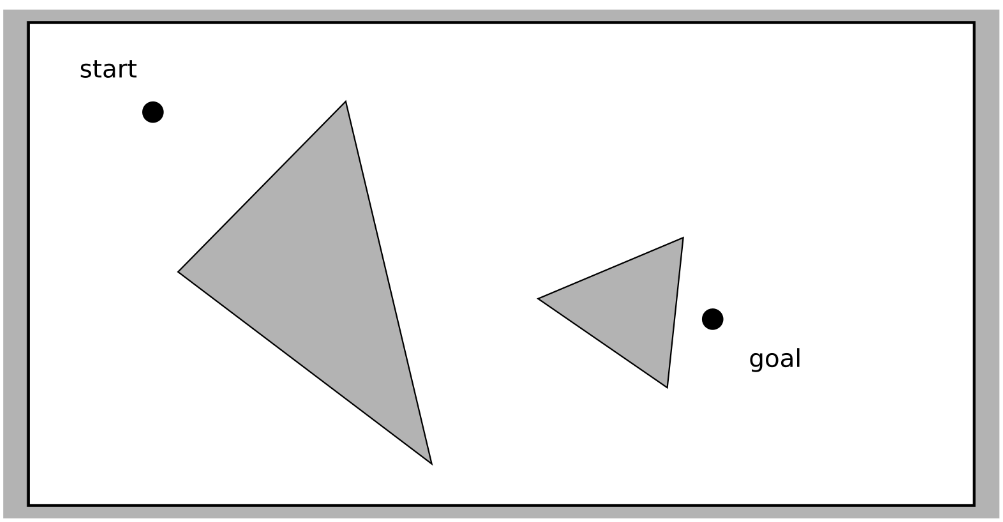


X =	0	1	2	3	4	5	6	7	8	9	10	11	12	13
INIT =						05				05				
O=J =					1/4	0	1/4	0	1/4	0	1/4	0	0	
O=J =				1/8	0	1/4	0	1/4	0	1/4	0	1/8	0	

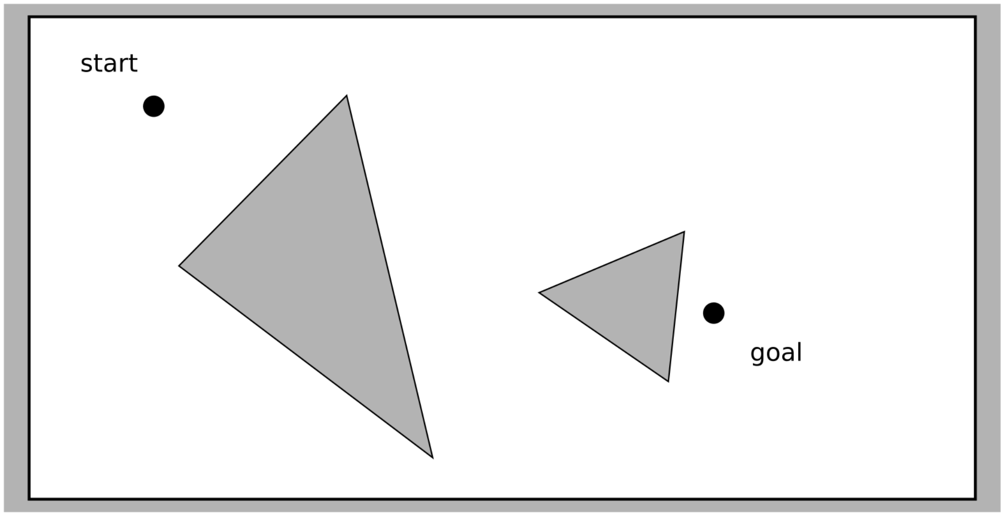
3 Exercise (25/100 points)

Consider the 2D workspace in the figure, in which we need to plan a path from the start pose to the goal pose, for a very small 2D holonomic robot which we can approximate as a point.

1. (3 points) Draw the visibility graph



2. (5 points) For the same environment, draw the voronoi diagram (the boundaries of the environment are to be considered as an impassable obstacle)



3. (3 points) The visibility graph and the voronoi diagram are graphs. In each case, explain how you use the graph for planning a path from the start pose to the goal pose.

4. (3 points) Comment on the optimality of the resulting path in each of the two cases.

5. (4 points) What do we mean when we say that a path planning algorithm is **complete**? Is planning based on the visibility graph complete? Is planning based on the voronoi diagram complete?

6. (5 points) Consider the planning problem we solved above for a pointwise holonomic robot. How would you solve the same problem with a robot that is holonomic but has a circular shape whose size is not insignificant with respect to the workspace size (and therefore, can't be approximated as a point in the workspace)?

7. (2 points) What would change if the robot in the previous question was not holonomic, but a differential drive robot?

4 Questions (10/100 points)

Consider the distance sensor described in the first exercise.

1. (3 points) Discuss and briefly motivate: is it proprioceptive or exteroceptive? Is it active or passive?

Question 4.1

The sensor is active because it uses a laser.

The sensor is exteroceptive because it measures the distance to an object that is outside of the robot (part of its environment).

2. (3 points) Would you say that the sensor's errors are systematic? Briefly discuss.

Question 4.2

The errors are non-systematic: they are not deterministic and can not be modeled in exact terms. However, they can be described in probabilistic terms (which is what we did in exercise 1).

3. (4 points) Consider the localization problem in the first exercise. Discuss and motivate whether the following is true or false: "If you are on the right half of the rail ($x > 500$), sensor aliasing is a big problem for localization.

Question 4.3

Yes, we can say that aliasing is the main problem affecting the sensor on the right half of the rail; in fact, whatever the location of the robot on the right half of the rail, the sensor will always return the same output.

Note that one could also characterize the issue as a limitation in the *resolution* of the sensor.

5 Mixed questions (15/100 points)

1. (5 points) Consider a difficult path planning problem in a cluttered environment. Compare RRT and RRT* in terms of: the probability to find a solution (assuming that a solution exists); the cost of the found solution. Whether it makes sense to wait for a better solution after a first solution has been found.

2. (5 points) Describe in one short but clear paragraph what exact problem the Iterative Closest Points (ICP) algorithm solves, and why solving this problem is useful in robotics.

3. (5 points) Explain in few simple words the role of the Singular Value Decomposition (SVD) in the ICP algorithm

6 Open-ended question (extra points)

1. Consider the problem of localizing a drone that is flying in a small room whose exact 3D map is known; the drone is equipped with an IMU and two laser distance sensors: one pointing forward and one pointing down. Discuss the problem and sketch a solution.

Extra page 1

Extra page 2