Name:

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Dept.:
e.g. CSE

Instructions:

Total: **40 marks**

1. This question paper contains a total of 14 pages (14 sides of paper). Please verify.
2. Write your name, roll number, department on **every side of every sheet** of this booklet

Problem 1. SAT-based motion planning (20 points)

Let us assume that a 2D workspace is divided into small rectangular blocks using a grid. The size of the workspace is 5×5. The lower left grid block has the ID $(0,0)$, and the upper right grid block has the ID $(4,4)$. The blocks $(2,0)$, $(3,0)$, $(1,2)$, $(3,2)$, $(1,4)$, and $(2,4)$ are covered with obstacles. We have two robots whose initial locations are $(0,0)$ and $(4,4)$, respectively. The robots have to move to the blocks $(4,4)$ and $(0,0)$, respectively. The robots have four motion primitives: L, R, U, D that can take the robot from its current block location to the left, right, upper and lower block respectively. Each robot has a motion primitive that keeps it in the same grid block for one time unit.

Write a SAT query whose solution will give the trajectories of the robots as the sequences of their motion primitives. Generate the trajectories using MiniSAT solver. To find the solution iteratively, you should write a script to generate the Boolean formulas for a specific length of the trajectory automatically.

Submit the following:

- The SAT formula for which you get a satisfiable solution.

- A snapshot of the terminal showing the execution of the SAT solver.

- Provide a visual representation of the trajectories synthesized from the solution obtained from the SAT solver.

MiniSAT webpage: `http://minisat.se`

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Problem 2. SMT-based optimal LTL motion planning (20 points)

Let us assume that a 2D workspace is divided into small rectangular blocks using a grid. The size of the workspace is 5×5. The lower left grid block has the ID $(0,0)$, and the upper right grid block has the ID $(4,4)$. The blocks $(2,0)$, $(3,0)$, $(1,2)$, $(3,2)$, $(1,4)$, and $(2,4)$ are covered with obstacles. The robots have motion primitives to perform one-step vertical, horizontal and diagonal movement. A vertical movement and a horizontal movement incur a cost of 1 unit, and a diagonal movement incurs a cost of 1.5. Each robot has a motion primitive that keeps it in the same grid block for one time unit. This primitive incurs a cost of 0.5.

Consider the following requirement. The robots have to explore the whole workspace and reach their final destinations. For a successful exploration, each obstacle-free grid cell should be visited by at least one robot for at least once. Suppose that the initial location of the robots are $(0,0)$, $(0,1)$, $(1,0)$ and $(1,1)$ and the final location of the robots are $(0,0)$, $(0,4)$, $(4,0)$ and $(4,4)$. The final locations are not assigned to individual robots. Any robot can go to any of the final locations. Provide an LTL formula that captures the requirement stated above. A plan for this multi-robot system will be optimal if the total cost for all the movements involved in the plan is minimal. Formulate the optimal plan generation problem as an SMT-solving problem and generate a motion plan using Z3 SMT solver. To find the solution iteratively, you should write a script to generate the Boolean formulas for a specific length of the trajectory automatically.

Submit the following:

- The LTL formula.

- The SMT formula for which you get a satisfiable solution.

- A snapshot of the terminal showing the execution of the SMT solver.

- Provide a visual representation of the trajectories synthesized from the solution obtained from the SMT solver.

Z3 Wbdpage: `https://rise4fun.com/Z3/tutorial/guide`

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Indian Institute of Technology, Kanpur
CS638 Formal Methods in Robotics
and Automation
Homework Assignment 2
Deadline: March 15, 2020