Name:
Course: CAP 4601
Semester: Summer 2013
Assignment: Assignment 09
Date: 29 JUL 2013

Assignment 09: 272 Points.

Complete the following written problems:

1. Planning Domain Definition Language (PDDL) (60 Points).

Write a PDDL description (i.e. initial state, goal, and actions) for the Tower of Hanoi puzzle with three disks and three pegs using the following predicates …

- $On(diskX, diskYOrPeg)$: A disk, $diskX$, is on top of a disk or a peg, $diskYOrPeg$.
- $AllowedOn(diskX, diskYOrPeg)$: A disk, $diskX$, is allowed to be on top of a disk or a peg, $diskYOrPeg$.
- $Clear(diskOrPeg)$: A disk or peg, $diskOrPeg$, does not have a disk on top of it.

…, the following objects …

- $D1$: The top (small) disk.
- $D2$: The middle (medium) disk.
- $D3$: The bottom (large) disk.
- $P1$: The (source) peg where all disks are initially located.
- $P2$: The middle peg.
- $P3$: The (destination) peg where all disks will eventually be located.

…, and only one action, $Move(disk, diskOrPegSourceBelow, diskOrPegDestination)$, that takes a disk, $disk$, that is on top of a disk or peg, $diskOrPegSourceBelow$, and moves it on top of another disk or peg, $diskOrPegDestination$.

Note: Descriptions of the Tower of Hanoi puzzle can be found on the following websites:
http://mathworld.wolfram.com/TowerofHanoi.html
http://en.wikipedia.org/wiki/Tower_of_Hanoi

Hint: This will be similar to the PDDL description of the air cargo transportation planning problem on Page 369 and the PDDL description of the blocks world on Page 371.

Hint: As an example, $On(D1, D2) \wedge On(D2, D3) \wedge On(D3, P2)$ should be used to represent that $D1$ is on $D2$, $D2$ is on $D3$, and all these disks are on $P2$. Of course, this isn't the only thing that you would need to specify.

Init (

$On(D1, D2) \wedge On(D2, D3) \wedge On(D3, P1) \wedge$

$Clear(D1) \wedge Clear(P2) \wedge Clear(P3) \wedge$

$AllowedOn(D1, D2) \wedge AllowedOn(D1, D3) \wedge AllowedOn(D2, D3) \wedge$

$AllowedOn(D1, P1) \wedge AllowedOn(D1, P2) \wedge AllowedOn(D1, P3) \wedge$

$AllowedOn(D2, P1) \wedge AllowedOn(D2, P2) \wedge AllowedOn(D2, P3) \wedge$

$AllowedOn(D3, P1) \wedge AllowedOn(D3, P2) \wedge AllowedOn(D3, P3)$

)

Goal (

$On(D1, D2) \wedge On(D2, D3) \wedge On(D3, P3)$

)

Action (

$Move(disk, diskOrPegSourceBelow, diskOrPegDestination)$,

PRECOND: $Clear(disk) \wedge On(disk, diskOrPegSourceBelow) \wedge$

$Clear(diskOrPegDestination) \wedge AllowedOn(disk, diskOrPegDestination)$,

EFFECT: $\neg On(disk, diskOrPegSourceBelow) \wedge Clear(diskOrPegSourceBelow) \wedge$

$\neg Clear(diskOrPegDestination) \wedge On(disk, diskOrPegDestination)$

)

2. Planning (50 Points).

a. (14 Points) For the Tower of Hanoi puzzle above with three disks and three pegs, list the **SEVEN** actions in order that would be necessary to go from the initial state to the goal state. **SEVEN** actions is the optimal plan. Do NOT use more than **SEVEN** actions.

1: $Move(D1, D2, P3)$

2: $Move(D2, D3, P2)$

3: $Move(D1, P3, D2)$

4: $Move(D3, P1, P3)$

5: $Move(D1, D2, P1)$

6: $Move(D2, P2, D3)$

7: $Move(D1, P1, D2)$

b. (36 Points) For the Tower of Hanoi puzzle above with three disks and three pegs, what is the goal state for this problem that passes the goal test? Ensure that you list all of the $On(\ )$, $Clear(\ )$, and $AllowedOn(\ )$ fluents in that conjunction.

$$On(D1,D2) \wedge On(D2,D3) \wedge On(D3,P3) \wedge$$
$$Clear(P1) \wedge Clear(P2) \wedge Clear(D1) \wedge$$
$$AllowedOn(D1,D2) \wedge AllowedOn(D1,D3) \wedge AllowedOn(D2,D3) \wedge$$
$$AllowedOn(D1,P1) \wedge AllowedOn(D1,P2) \wedge AllowedOn(D1,P3) \wedge$$
$$AllowedOn(D2,P1) \wedge AllowedOn(D2,P2) \wedge AllowedOn(D2,P3) \wedge$$
$$AllowedOn(D3,P1) \wedge AllowedOn(D3,P2) \wedge AllowedOn(D3,P3)$$

3. Progression State Space Search (20 Points).

For the Tower of Hanoi puzzle above with three disks and three pegs, list all of the available actions that can occur from the initial state using Progression State Space Search and show that the preconditions of that action are met by the fluents in that initial state.

The initial state is:

$$On(D1,D2) \wedge On(D2,D3) \wedge On(D3,P1) \wedge$$
$$Clear(D1) \wedge Clear(P2) \wedge Clear(P3) \wedge$$
$$AllowedOn(D1,D2) \wedge AllowedOn(D1,D3) \wedge AllowedOn(D2,D3) \wedge$$
$$AllowedOn(D1,P1) \wedge AllowedOn(D1,P2) \wedge AllowedOn(D1,P3) \wedge$$
$$AllowedOn(D2,P1) \wedge AllowedOn(D2,P2) \wedge AllowedOn(D2,P3) \wedge$$
$$AllowedOn(D3,P1) \wedge AllowedOn(D3,P2) \wedge AllowedOn(D3,P3)$$

Since the action $Move(disk, diskOrPegSourceBelow, diskOrPegDestination)$ requires the following preconditions:

$$Clear(disk) \wedge On(disk, diskOrPegSourceBelow) \wedge$$
$$Clear(diskOrPegDestination) \wedge AllowedOn(disk, diskOrPegDestination),$$

then only the following two actions lead out of the initial state:

1: $\boxed{Move(D1,D2,P2)}$ because the initial state has the following fluents that meet the preconditions: $Clear(D1) \wedge On(D1,D2) \wedge Clear(P2) \wedge AllowedOn(D1,P2)$, and

2: $\boxed{Move(D1,D2,P3)}$ because the initial state has the following fluents that meet the preconditions: $Clear(D1) \wedge On(D1,D2) \wedge Clear(P3) \wedge AllowedOn(D1,P3)$

4. Regression State Space Search (20 Points)

For the Tower of Hanoi puzzle above with three disks and three pegs, list all of the available actions that can occur from the goal state using Regression State Space Search and show that the positive effects (i.e. fluents in the effect that don't have a $\neg$ in front) of that action are met by the fluents in that goal state.

The goal state is:

$$\begin{aligned}
&On(D1,D2) \wedge On(D2,D3) \wedge On(D3,P3) \wedge \\
&Clear(P1) \wedge Clear(P2) \wedge Clear(D1) \wedge \\
&AllowedOn(D1,D2) \wedge AllowedOn(D1,D3) \wedge AllowedOn(D2,D3) \wedge \\
&AllowedOn(D1,P1) \wedge AllowedOn(D1,P2) \wedge AllowedOn(D1,P3) \wedge \\
&AllowedOn(D2,P1) \wedge AllowedOn(D2,P2) \wedge AllowedOn(D2,P3) \wedge \\
&AllowedOn(D3,P1) \wedge AllowedOn(D3,P2) \wedge AllowedOn(D3,P3)
\end{aligned}$$

Since the action $Move(disk, diskOrPegSourceBelow, diskOrPegDestination)$ has the following effects:

$$\begin{aligned}
&\neg On(disk, diskOrPegSourceBelow) \wedge Clear(diskOrPegSourceBelow) \wedge \\
&\neg Clear(diskOrPegDestination) \wedge On(disk, diskOrPegDestination),
\end{aligned}$$

then only the following two actions can occur:

1: $\boxed{Move(D1,P1,D2)}$ because the goal state has the following fluents that meet the positive effects: $Clear(P1) \wedge On(D1,D2)$, and

2: $\boxed{Move(D1,P2,D2)}$ because the goal state has the following fluents that meet the positive effects: $Clear(P2) \wedge On(D1,D2)$.

5. Markov Decision Process (26 Points).

Deterministic state transitions. Cost of motion is -5. Terminal state is 100. Actions are Up, Down, Left, or Right (no diagonals). Shaded state cannot be entered.

a. (12 Points) Fill in the final values after Value Iteration.

		(shaded)	100

75	80	(shaded)	100
80	85	90	95

b. (14 Points) Fill in the optimal policy. In other words, write "Up", "Down", "Left", or "Right" in each cell. If cell two or more directions are equally optimal, then include all the optimal directions in that cell.

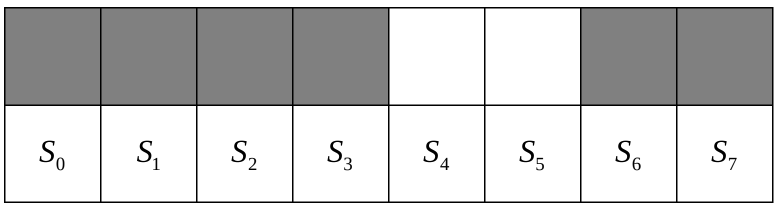
		(shaded)	100

Down or Right	Down	(shaded)	100
Right	Right	Right	Up

6. Particle Filters (60 Points).

A machine is traveling from left to right in a hallway. A map of the hallway is loaded into this machine; however, the machine is not provided with its initial position (i.e. it is not localized). The machine can be in one of eight locations in the hallway. At each location, there is either a wall (the gray squares in the first row) or an open door (the white squares in the first row). The machine can use a depth sensor to determine if it is next to a wall (i.e. close depth measurements) or if it is next to an open door (i.e. far depth measurements). Unfortunately, depth sensors are not perfect and can return close depth measurements when they should return far ones and vice versa. For this machine's depth sensor, the probability of measuring "wall" when the machine is next to a wall is 0.7. The probability of measuring "open door" when it is next to an open door is 0.6. The machine can only measure "wall" or "open door".

To determine its initial position, the machine's internal particle filter algorithm places 8 particles (S_0 through S_7) on its map of the hallway.



Note: "Normalized importance weight" means dividing a probability by the sum of all probabilities. Example: If we had particles A, B, and C and the probabilities for those particles was 0.5, 0.6, and 0.7 respectively, then the "normalized importance weight" for A would be 0.5 / (0.5 + 0.6 + 0.7) = 0.277778

a. (10 Points) What is the "normalized importance weight" of particle S_4 for the measurement "open door" (i.e. a far depth measurement)?

$$\frac{P\left(\text{"open door"} \middle| S_4\right)}{P\left(\text{"open door"} \middle| S_0\right)+P\left(\text{"open door"} \middle| S_1\right)+P\left(\text{"open door"} \middle| S_2\right)+P\left(\text{"open door"} \middle| S_3\right)+P\left(\text{"open door"} \middle| S_4\right)+P\left(\text{"open door"} \middle| S_5\right)+P\left(\text{"open door"} \middle| S_6\right)+P\left(\text{"open door"} \middle| S_7\right)}$$

$$\frac{0.6}{(1-0.7)+(1-0.7)+(1-0.7)+(1-0.7)+0.6+0.6+(1-0.7)+(1-0.7)}$$

$$\frac{0.6}{6(0.3)+2(0.6)}$$

$$\boxed{0.2}$$

b. (10 Points) What is the "normalized importance weight" of a particle S_7 for the measurement "open door" (i.e. a far depth measurement)?

$$\frac{P\left(\text{"open door"} \middle| S_7\right)}{P\left(\text{"open door"} \middle| S_0\right)+P\left(\text{"open door"} \middle| S_1\right)+P\left(\text{"open door"} \middle| S_2\right)+P\left(\text{"open door"} \middle| S_3\right)+P\left(\text{"open door"} \middle| S_4\right)+P\left(\text{"open door"} \middle| S_5\right)+P\left(\text{"open door"} \middle| S_6\right)+P\left(\text{"open door"} \middle| S_7\right)}$$

$$\frac{(1-0.7)}{(1-0.7)+(1-0.7)+(1-0.7)+(1-0.7)+0.6+0.6+(1-0.7)+(1-0.7)}$$

$$\frac{0.3}{6(0.3)+2(0.6)}$$

$$\boxed{0.1}$$

c. (20 Points) What is the probability that the machine is in S_4 given that we measured "open door" (i.e. the depth sensor returned a far depth measurement)? Hint: Bayes Rule, Total Probability, and counting squares.

$$P\left(S_4 \middle| \text{"open door"}\right)=\frac{P\left(\text{"open door"} \middle| S_4\right)P(S_4)}{P\left(\text{"open door"}\right)}$$

$$=\frac{P\left(\text{"open door"} \middle| S_4\right)P(S_4)}{\left(\begin{array}{l}P\left(\text{"open door"} \middle| S_0\right)P(S_0)+P\left(\text{"open door"} \middle| S_1\right)P(S_1)+P\left(\text{"open door"} \middle| S_2\right)P(S_2)+P\left(\text{"open door"} \middle| S_3\right)P(S_3)+\\P\left(\text{"open door"} \middle| S_4\right)P(S_4)+P\left(\text{"open door"} \middle| S_5\right)P(S_5)+P\left(\text{"open door"} \middle| S_6\right)P(S_6)+P\left(\text{"open door"} \middle| S_7\right)P(S_7)\end{array}\right)}$$

$$=\frac{(0.6)\left(\frac{1}{8}\right)}{\left(\begin{array}{l}(1-0.7)\left(\frac{1}{8}\right)+(1-0.7)\left(\frac{1}{8}\right)+(1-0.7)\left(\frac{1}{8}\right)+(1-0.7)\left(\frac{1}{8}\right)+\\(0.6)\left(\frac{1}{8}\right)+(0.6)\left(\frac{1}{8}\right)+(1-0.7)\left(\frac{1}{8}\right)+(1-0.7)\left(\frac{1}{8}\right)\end{array}\right)}$$

$$=\boxed{0.2}$$

d. (20 Points) If particle S_4 has a "normalized importance weight" of 0.2 and we sample 8 new particles with replacement, what is the probability that particle S_4 will be sampled at least once? In other words, what is the probability that at least one particle will remain at the S_4 location on the next iteration of the particle filter?

Sampled "at least once" means sampled one, two, three, …, or eight times. We could find each of these probabilities and then add them all together, or we could find the probability of never being sampled and then subtract by one to get the "at least once" probability. We'll do the later.

Since we are sampling with replacement, then we can use independence and we have:

$$P(Sample_i \neq S_4) = 1 - 0.2 = 0.8$$

$$\begin{aligned} P(S_4 \text{ is never sampled}) &= P(Sample_1 \neq S_4, Sample_2 \neq S_4, \ldots, Sample_8 \neq S_4) \\ &= P(Sample_1 \neq S_4)P(Sample_2 \neq S_4)\cdots P(Sample_8 \neq S_4) \\ &= (0.8)^8 \\ &= 0.167772 \end{aligned}$$

$$\begin{aligned} P(S_4 \text{ is sampled at least once}) &= 1 - P(S_4 \text{ is never sampled}) \\ &= 1 - 0.167772 \\ &= \boxed{0.832228} \end{aligned}$$

This assignment has no programming problems.

After completing Assignment 09, create an `assignment_09_`*`lastname`*`.pdf` file for your written assignment.

Upload your `assignment_09_`*`lastname`*`.pdf` file for your written assignment to the Assignment 08 location on the BlackBoard site: https://campus.fsu.edu.