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Task 1: Does a unifier exist for these pairs of predicates. If they do, give the unifier

i. Taller(x, John); Taller(Bob, y)
ii. Taller(y, Mother(x)); Taller(Bob, Mother(Bob))
iii. Taller(Sam, Mary); Shorter(x, Sam)
iv. Shorter(x, Bob); Shorter(y, z)
v. Shorter(Bob, John); Shorter(x, Mary)

Solution:

(i.) Taller(x, John) Taller(Bob, y) ∴ Unifier θ can be → $\{x / Bob, y / John\}$

(ii.) Taller(y, Mother(x)) Taller(Bob, Mother(Bob))

Here y can be Bob so that 1^{st} part is same.

for 2^{nd} part, Mother(x) = Mother(Bob)

∴ x = Bob or x = Sibling(Bob)

∴ Unifier θ can be $\{x / Bob, y / Bob\}$ or $\{x / sibling(Bob), y / Bob\}$

(iii.) Taller(Sam, Mary) Shorter(x, Sam)

Assuming that Shorter(x, Sam) means x is shorter than Sam &

Taller(Sam, Mary) means Sam is taller than Mary.

Here 2^{nd} predicate implies that Sam is taller than x.

∴ We can say that Taller(Sam, x) is true.

∴ Taller(Sam, Mary) & Taller(Sam, x) have a unifier $\theta = \{x / Mary\}$

(iv.) Shorter(x, Bob) Shorter(y, z)

An unifier exists for above two predicates

$\theta = \{x / y, z / Bob\}$

(v.) Shorter(Bob, John) Shorter(x, Mary)

Here even if we substitute x as Bob, we would still end up with two different predicates.

∴ We can say that no unifier exists for these 2 predicates.

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Task 2: Two adults and two children are on the left side of the river. They all want to cross to the right side of the river. However, the only means of transportation they can use is a boat (also initially on the left bank) which can carry either just one adult or one adult and one child or just one child or two children from one bank to the other bank. Any adult or child can operate the boat, but the boat cannot be operated without having at least one person on the boat. The goal is to come up with a plan for moving everyone from the left side to the right side using multiple boat trips.

Describe the initial state and the goal, using PDDL. Define appropriate actions for this planning problem, in the PDDL language. For each action, provide a name, arguments, preconditions, and effects.

Extra Credit (5 pts): Also, give a complete plan (using the actions described) for getting from the start to the goal state

Solution:

Constants:

P_1, P_2, P_3, P_4, B, Left, Right

Predicates:

On(x, y): x is on y bank

IsBoat(x): x is boat

IsChild(x): x is child

Initial state:

On(P_1, Left) ∧ On(P_2, Left) ∧ On(P_3, Left) ∧ On(P_4, Left) ∧ On(B, Left) ∧ IsBoat(B) ∧ IsChild(P_3) ∧ IsChild(P_4).

Goal state:

On(P_1, Right) ∧ On(P_2, Right) ∧ On(P_3, Right) ∧ On(P_4, Right)

Actions:

1. Move_one_left2right(x,y):

Move_one_Left2right(x,y) → move one person x from Left to right using boat y.

PRE: On(x, Left) ∧ On(y, Left) ∧ IsBoat(y)

EFF: On(x, Right) ∧ On(y, Right) ∧ ¬ On(x, Left) ∧ ¬ On(y, Left)

2. Move_one_right2left(x,y):

Move_one_right2left(x,y) → move one person x from right to left using boat y.

PRE: $On(x, Right) \land on(y, Right) \land IsBoat(y)$

EFF: $On(x, Left) \land on(y, Left) \land \neg On(x, Right) \land \neg On(y, Right)$

3. Move_two_left2right(x,y,z):

Move_two_Left2right(x, y, z) → Move adult/child x & child y from left to right using boat z

PRE: $On(x, Left) \land on(y, Left) \land on(z, Left) \land IsBoat(z) \land IsChild(y)$

EFF: $On(x, Right) \land On(y, Right) \land On(z, Right) \land \neg On(x, Left) \land \neg On(y, Left) \land \neg On(z, Left)$

4. Move_two_right2left(x,y,z):

Move_two_right2left(x, y, z) → Move adult/child x & child y from right to left using boat z

PRE: $On(x, Right \land on(y, Right) \land on(z, Right) \land IsBoat(z) \land IsChild(y)$

EFF: $On(x, Left) \land On(y, Left) \land On(z, Left) \land \neg On(x, Right) \land \neg On(y, Right) \land \neg On(z, Right)$

One of the possible plans:

PLAN:

Status after taking action

Plan	Left side	Right side	
	P_1, P_2, P_3, P_4, B		→ (initial state)
Move_two_Left2right(P_1, P_2, B)	P_3, P_4	P_1, P_2, B	
Move_one_right2left(P_2, B)	P_2, P_3, P_4, B	P_1	
Move_two_left2right(P_3, P_2, B)	P_4	P_1, P_2, P_3, B	
Move_one_right2left(P_2, B)	P_2, P_4, B	P_1, P_3	
Move_two_left2right(P_4, P_2, B)		$\boxed{P_1, P_2, P_3, P_4, B}$	→ goal achieved

Task 3: Suppose that we are using PDDL to describe facts and actions in a certain world called JUNGLE. In the JUNGLE world there are 3 predicates, each predicate takes at most 4 arguments, and there are 5 constants. Give a reasonably tight bound on the number of unique states in the JUNGLE world. Justify your answer.

Solution:

Given: No. of predicates, $n = 3$; each predicate takes max 4 arguments

i.e. No. of arguments $a \Rightarrow 1 \leq a \leq 4$.

No. of constants, $m = 5$.

From given information,

if no. of constants are 5 & no. of arguments a are

$$1 \leq a \leq 4$$

then no. of possible arguments for 1 predicate can be given as,

$$5^1 \leq poss\_args \leq 5^4$$

As it is given that no. of predicates $= 3$ $\therefore$ we can find no. of possible arguments for 3 predicates as follows,

$$(3 \times 5^1) \leq poss\_args\_3 \leq (3 \times 5^4)$$

$$15 \leq poss\_args\_3 \leq 1875$$

Now, to find possible no. of states, we know that a predicate can be either true or false i.e. it can have 2 possible values

$\therefore$ no of states $= 2^{poss\_args\_3}$.

And thus, no. of possible states is,

$$\boxed{\begin{array}{c} 2^{15} \leq \text{no. of states} \leq 2^{1875} \\ \text{i.e. } 32768 \leq \text{no. of states} \leq 2.64 \times 10^{564} \end{array}}$$

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Task 4: Consider the problem in Task 2. Let us say that, if there is only one person in the boat, the boat can be blown off course and end up back on the side it originally started from. How would you modify the actions you described in Task 2 to account for this if you were going to try and handle this scenario by

- Execution Monitoring/Online Replanning
- Conditional Planning

In both cases, show what the modifications are (If no modification is necessary, Justify).

Solution:

Execution Monitoring/ Online replanning:
In this type of planning we do not need to modify the action definitions. We can keep them as they were in the deterministic case.
Justification: In this type of planning, instead of modifying the action definitions we do a few additional things before performing any action to check if the state of the environment is same as it is expected to perform the action.
There are 3 ways to do so i.e. Action monitoring, Plan monitoring and Goal monitoring. In the given scenario, there is an unexpected environment change happening i.e. the boat can be blown off course if there is one person in the boat which can be used as an advantage to come up with a better plan. So the best way to monitor the world would be **Goal monitoring**.

Conditional Planning: In this type of planning we need to consider the unexpected changes in the world in the action definitions. Following are the only required changes in the two action definitions.

Move_one_left2right(x,y):

Move_one_left2right(x,y) move one person x from left to right using boat y.
PRE: $On(x, Left) \wedge On(y, Left) \wedge IsBoat(y)$
EFF: $[On(x, Right) \wedge On(y, Right) \wedge \neg On(x, Left) \wedge \neg On(y, Left)] \vee [On(x, Left) \wedge On(y, Left)]$

Move_one_right2left(x,y):

Move_one_right2left(x,y) move one person x from right to left using boat y.
PRE: $On(x, Right) \wedge On(y, Right) \wedge IsBoat(y)$
EFF: $[On(x, Left) \wedge On(y, Left) \wedge \neg On(x, Right) \wedge \neg On(y, Right)] \vee [On(x, Right) \wedge On(y, Right)]$

Here, these were the only two action definitions that required change because the effects of the other two actions won't be affected considering the given information about the uncertain world changes (i.e. "if there is only one person in the boat, the boat can be blown off course and end up back on the side it originally started from").