DD2380

ARTIFICIAL INTELLIGENCE

ASSIGNMENT 3

KNOWLEDGE, REASONING, AND PLANNING

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1 Maze Runner

2 Student Einstein Puzzle

2.1 E-level 10 points

- S1: $Commute(John) = Bike$
- S2: $Commute(Carol) = Bike$
- S3: $Company(Carol) = W$
- S4: $Commute(Mary) = Subway$
- S5: $Coworkers(Mary, Carol)$
- S6: $\neg Classmates(Mary, Carol)$
- S7: $\forall x.\ Commute(x) = Bike \implies University(x) = KTH$
- S8: $\forall x.\ University(x) = KTH \implies Classmates(Sofie, x)$
- S9: $\forall x.\ Classmates(Carol, x) \wedge \neg x = Carol \implies Comany(x) = Z$
- S10: $\forall x.\ Commute(x) = Subway \wedge Company(x) = W \implies University(x) = SU$
- S11: $\forall x.\ Coworkers(John, x) \implies Commute(x) = Walk$

2.2 E-level 5 points

Let $\theta = \{x/John\}$, and first take premises S1 and S7 into consideration. We would have

$$\frac{X1 : Commute(John) = Bike,\ X2 : Commute(x) = Bike \implies University(x) = KTH}{X3 : University(John) = KTH},$$

where $\theta = \{x/John\}$. Let **T1**: $University(John) = KTH$.

Then take T1 and S7 into consideration. We would have

$$\frac{X1 : University(John) = KTH,\ X2 : University(x) = KTH \implies Classmates(Sofie, x)}{X3 : Classmates(Sofie, John)},$$

where $\theta = \{x/John\}$. Thus, $Classmates(Sofie, John)$ is inferred.

2.3 D-level 10 points

- C1: $Commute(John) = Bike$
- C2: $Commute(Carol) = Bike$
- C3: $Company(Carol) = W$

- C4: $Commute(Mary) = Subway$
- C5: $Coworkers(Mary, Carol)$
- C6: $\neg Classmates(Mary, Carol)$
- C7: $\neg Commute(x) = Bike \vee University(x) = KTH$
- C8: $\neg University(x) = KTH \vee Classmates(Sofie, x)$
- C9: $\neg Classmates(Carol, x) \vee x = Carol \vee Comany(x) = Z$
- C10: $\neg Commute(x) = Subway \vee \neg Company(x) = W \vee University(x) = SU$
- C11: $\neg Coworkers(John, x) \vee Commute(x) = Walk$

2.4 C-level 15 points

- C12: If two students are co-workers, then they work at the same company.
- C13: If two students work at the same company, then they are co-workers.
- C14: If this student is the co-worker of that student, then that student is also the co-worker of this student.
- C15: If this student is the classmate of that student, then that student is also the classmate of this student.
- C16: If two students are classmates, then they study at the same university.
- C17: If two students study at the same university, then they are classmates.

To infer the information of each students:

- From C1, C2, C3, and C4, we can get

$$\begin{aligned}&Commute(John) = Bike\\&Commute(Carol) = Bike\\&Company(Carol) = W\\&Commute(Mary) = Subway\end{aligned}$$

- From C1 and C7, we can have l_1 is $Commute(John) = Bike$, m_1 is $\neg Commute(x) = Bike$, m_2 is $University(x) = KTH$, and $UNIFY(l_1, \neg m_1) = \theta = \{x/John\}$. The resolvent clause is $University(John) = KTH$. The resolution is

$$\frac{X1 : Commute(John) = Bike, X2 : \neg Commute(x) = Bike \vee University(x) = KTH}{X3 : University(John) = KTH},$$

where $\theta = \{x/John\}$. Let **A1**: $University(John) = KTH$.

- From C2 and C7, we can have l_1 is $Commute(Carol) = Bike$, m_1 is $\neg Commute(x) = Bike$, m_2 is $University(x) = KTH$, and $UNIFY(l_1, \neg m_1) = \theta = \{x/Carol\}$. The resolvent clause is $University(Carol) = KTH$. The resolution is

$$\frac{X1: Commute(Carol) = Bike, X2: \neg Commute(x) = Bike \vee University(x) = KTH}{X3: University(Carol) = KTH},$$

  where $\theta = \{x/Carol\}$. Let **A2**: $University(Carol) = KTH$.

- From A1 and C8, we can have l_1 is $University(John) = KTH$, m_1 is $\neg University(x) = KTH$, m_2 is $Classmates(Sofie, x)$, and $UNIFY(l_1, \neg m_1) = \theta = \{x/John\}$. The resolvent clause is $Classmates(Sofie, John)$. The resolution is

$$\frac{X1: University(John) = KTH, X2: \neg University(x) = KTH \vee Classmates(Sofie, x)}{X3: Classmates(Sofie, John)},$$

  where $\theta = \{x/John\}$. Let **A3**: $Classmates(Sofie, John)$.

- From A1 and C15, we can have the resolution

$$\frac{X1: Classmates(Sofie, John), X2: \neg Classmates(x, y) \vee Classmates(y, x)}{X3: Classmates(John, Sofie)},$$

  where $\theta = \{x/Sofie,\ y/John\}$. Let **A4**: $Classmates(John, Sofie)$.

- From A1, A4, and C16, we can have the resolution

$$\frac{X1: A1, X2: A4, X3: \neg Classmates(x, y) \vee \neg University(x) = z \vee University(y) = z}{X4: University(Sofie) = KTH},$$

  where $\theta = \{x/John,\ y/Sofie,\ z/KTH\}$. Let **A5**: $University(Sofie) = KTH$.

- From A1, A2 and C17, we can have the resolution

$$\frac{X1: A1, X2: A2, X3: Classmates(x, y) \vee \neg University(x) = z \vee \neg University(y) = z}{X4: Classmates(Carol, John)},$$

  where $\theta = \{x/Carol,\ y/John,\ z/KTH\}$. Let **A6**: $Classmates(Carol, John)$.

- From A2, A5, and C17, we can have **A7**: $Classmates(Carol, Sofie)$, which is similar to how we get A6.

- From A6, C9, and C19, we can have l_1 is $Classmates(Carol, John)$, l_2 is $\neg Carol = John$, m_1 is $\neg Classmates(Carol, x)$, m_2 is $x = Carol$, m_3 is $Company(x) = Z$, and $UNIFY(l_1, \neg m_1) = \theta = \{x/John\}$. The resolvent clause is $Company(John) = Z$. The resolution is

$$\frac{X1: A1, X2: C19, X3: \neg Classmates(Carol, x) \vee x = Carol \vee Comany(x) = Z}{X4: Company(John) = Z},$$

  where $\theta = \{x/John\}$. Let **A8**: $Company(John) = Z$.

- From A7, C9, and C21, we can have **A9**: $Company(Sofie) = Z$, which is similar to how we get A8.

- From A8, A9, and C13, we can have the resolution

$$\frac{X1: A8, X2: A9, X3: \neg Company(x) = z \vee \neg Company(y) = z \vee Coworkers(x, y)}{X4: Coworkers(John, Sofie)},$$

  where $\theta = \{x/John, y/Sofie, z/Z\}$. Let **A10**: $Coworkers(John, Sofie)$.

- A10 and C11, we can have l_1 is $Coworkers(John, Sofie)$, m_1 is $\neg Coworkers(John, x)$, m_2 is $Commute(x) = Walk$, and $UNIFY(l_1, \neg m_1) = \theta = \{x/Sofie\}$. The resolvent clause is $Commute(Sofie) = Walk$. The resolution is

  $$\frac{X1 : Coworkers(John, Sofie), X2 : \neg Coworkers(John, x) \vee Commute(x) = Walk}{X3 : Commute(Sofie) = Walk},$$

  where $\theta = \{x/Sofie\}$. Let **A11**: $Commute(Sofie) = Walk$.

- From C5 and C14, we can have **A12**: $Coworkers(Carol, Marry)$, which is similar to how we get A4.

- From A12, C3, and C12, we can have the resolution

  $$\frac{X1 : A12, X2 : C3, X3 : \neg Coworkers(x, y) \vee \neg Company(x) = z \vee Company(y) = z}{X4 : Company(Marry) = W},$$

  where $\theta = \{x/Carol, y/Marry, z/W\}$. Let **A13**: $Company(Marry) = W$.

- From A13, C4, and C10, we can have the resolution

  $$\frac{X1 : Commute(Marry) = Subway, X2 : Company(Marry) = W, X3 : C10}{X4 : University(Marry) = SU}$$

  where $\theta = \{x/Marry\}$. Let **A14**: $University(Marry) = SU$.

In all, we would get

Table 1: The information of each students.

Name	Commute	Company	University
Carol	Bike	W	KTH
John	Bike	Z	KTH
Mary	Subway	W	SU
Sofie	Walk	Z	KTH

2.5 C-level 5 points

Assume we have two grounded clauses: $A \wedge \neg B$, $\neg A \wedge B$. What we can get are $A \wedge \neg A$ and $B \wedge \neg B$.

3 Florence + The Machine at Ericsson Globe

3.1 E-level 10 points

A part of the reachable space of all states containing 10 different states is illustrated in fig 1.

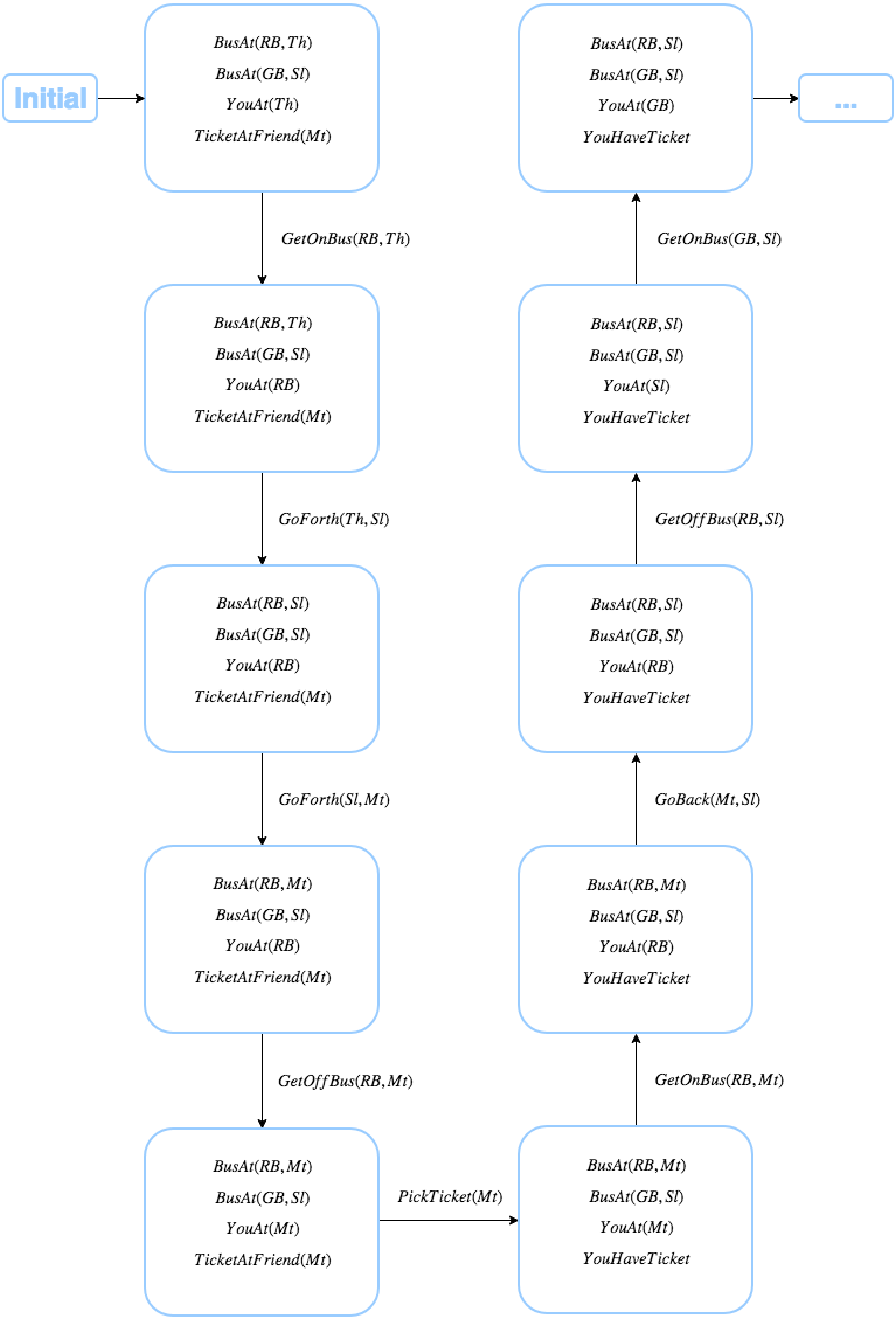

Figure 1: A part of the reachable space of all states.

3.2 E-level 5 points

- Infinity. One can keep travelling between two stations by taking actions $GoForth(x, y)$ and $GoBack(y, x)$, where x and y are two different stations.
- Infinity. The reason is same with above question even though $Travel(Gp, Gp, GB)$ is removed.
- 12 actions: $GetOnBus(RB, Th) \rightarrow GoForth(Th, Sl) \rightarrow GoForth(Sl, Mt) \rightarrow$ $GetOffBus(RB, Mt) \rightarrow PickTicket(Mt) \rightarrow GetOnBus(RB, Mt) \rightarrow GoBack(Mt, Sl) \rightarrow$ $GetOffBus(RB, Sl) \rightarrow GetOnBus(GB, Sl) \rightarrow GoForth(Sl, Gp) \rightarrow GoForth(Gp, Gl) \rightarrow$ $GetOffBus(GB, Gl)$.

3.3 E-level 10 points

The space of all belief states that are reachable from the initial one is illustrated in fig 2.

Figure 2: The space of all belief states that are reachable from the initial one.

- Always true:
  (1) $Travel(Th, Sl, RB)$;
  (2) $Travel(Sl, Mt, RB)$;
  (3) $Travel(Sl, Gp, GB)$.

  Always false:
  (1) $BusAt(RB, Gp)$;
  (2) $BusAt(RB, Gl)$;
  (3) $BusAt(GB, Th)$.
- 5 actual physical states. We don't know whether we are at Th, Sl, Mt, Gp, or Gl, but we know we are not at on the bus, so the initial belief state contains 5 actual physical states which is illustrated in fig 2.
- 0. There's no feasible actions can be applied to the initial belief state, not to say finding the plans that lead to the satisfaction of the goal.
- There is no plan that lead to the satisfaction of the goal.

3.4 D-level 10 points

A part of the reachable belief state space containing 5 states with their outgoing edges labelled with ground actions is illustrated in fig 3.

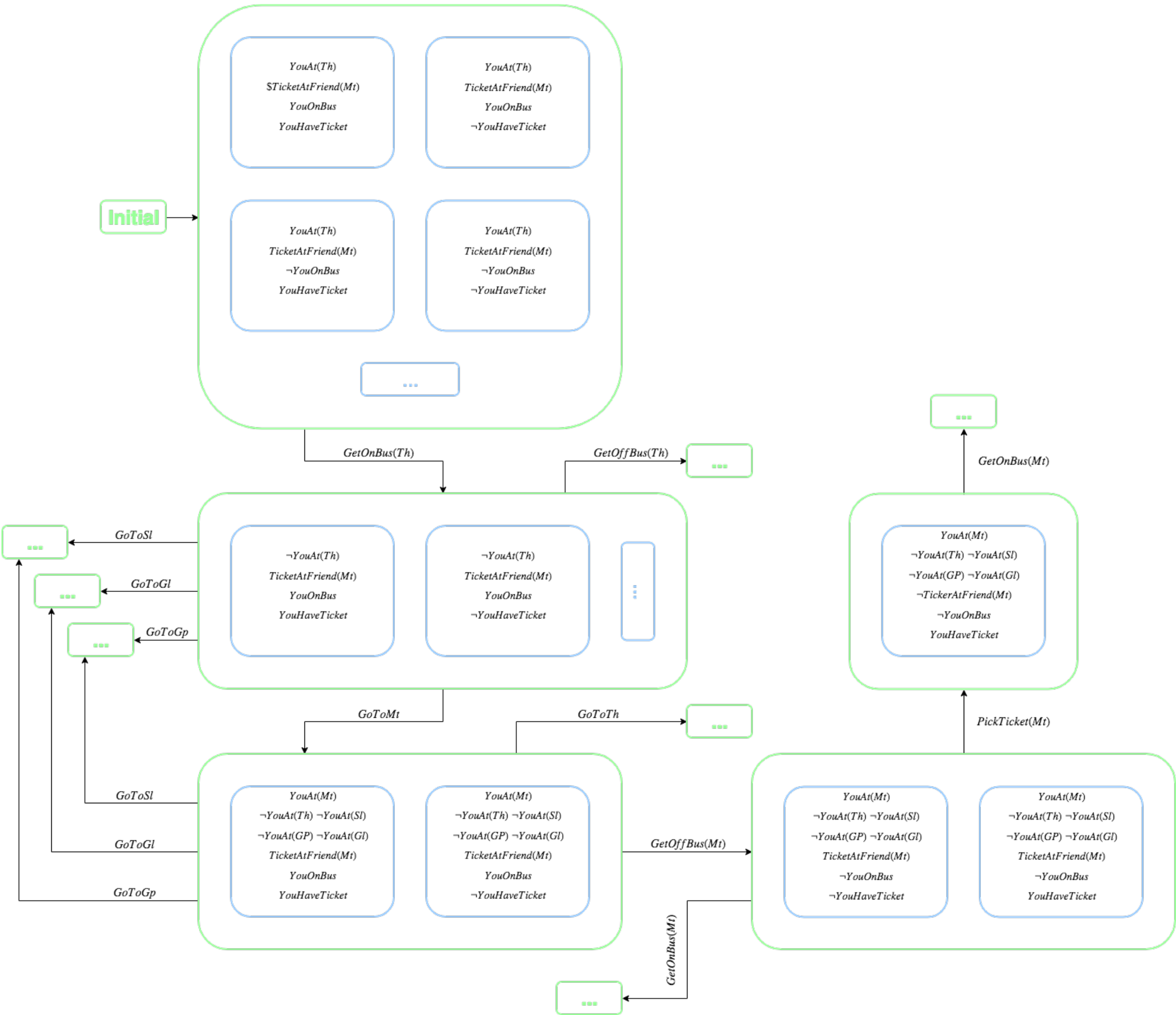

Figure 3: A part of the reachable belief state space.

- 64 actual physical states. We cannot observe whether we are on a bus, and whether we have a ticket, so $YouOnBus$ and $YouHaveTicket$ are unknown. Also, although we know we are at Th, we still don't know whether we are at Sl, Mt, Gp, and Gl or not. In all we have 6 unknown fluents, meaning the initial belief state contains $2^6 = 64$ actual physical states.

- Infinity. We can keep travelling between two stations, for example, by taking actions $GoToSl$ and $GoToTh$ after $YouOnBus$ becoming true.

- 7 actions: $GetOnBus(Th) \rightarrow GoToMt \rightarrow GetOffBus(Mt) \rightarrow PickTicket(Mt) \rightarrow GetOnBus(Mt) \rightarrow GoToGl \rightarrow GetOffBus(Gl)$.

3.5 C-level 10 points

A connected subgraph of the belief state space containing 10 different belief states assuming that we initially do not know where our friend lives is illustrated in fig 4.

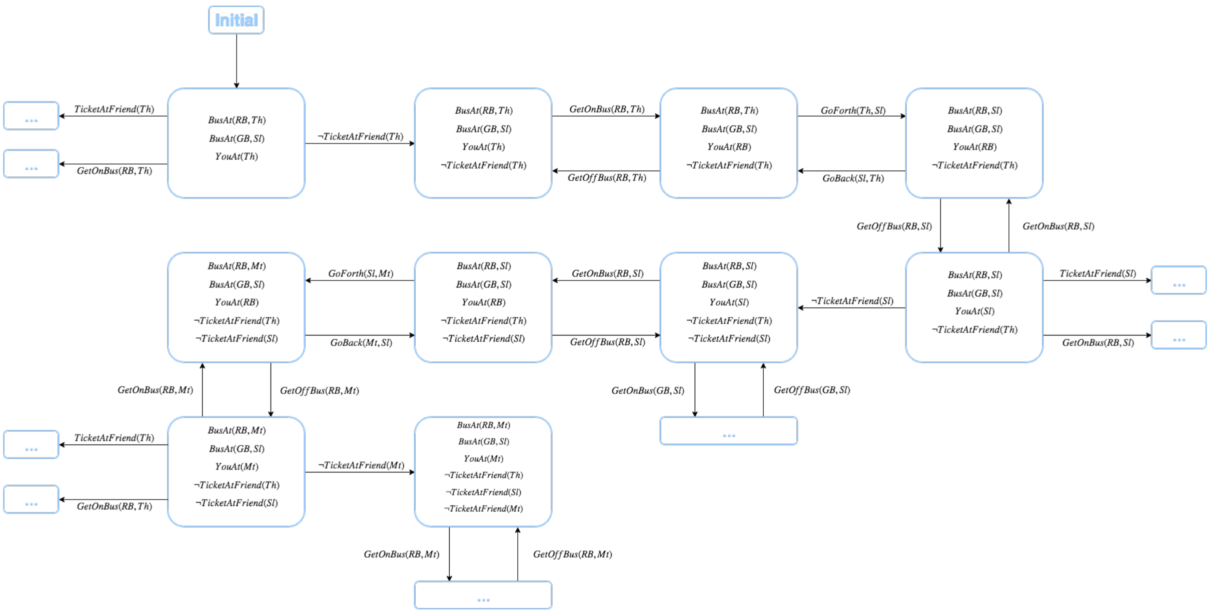

Figure 4: A connected subgraph of the belief state space containing 10 different belief states assuming that we initially do not know where our friend lives.

One feasible contingent plan is illustrated in listing 1.

Listing 1: One feasible contingent plan.

```
if TicketAtFriend(Th)
then[PickTicket(Th), GetOnBus(RB,Th), GoForth(Th,Sl), GetOffBus(RB,Sl), GetOnBus(GB
    ,Sl), GoForth(Sl,Gp), GoForth(Gp,Gl), GetOffBus(GB,Gl)]
else[GetOnBus(RB,Th), GoForth(Th,Sl), GetOffBus(RB,Sl), if TicketAtFriend(Sl)
  then[PickTicket(Sl), GetOnBus(GB,Sl), GoForth(Sl,Gp), GoForth(Gp,Gl), GetOffBus(
     GB,Gl)]
  else[GetOnBus(RB,Sl), GoForth(Sl,Mt), GetOffBus(RB,Mt), if TicketAtFriend(Mt)
    then[PickTicket(Mt), GetOnBus(RB,Mt), GoBack(Mt,Sl), GetOffBus(RB,Sl), GetOnBus
       (GB,Sl), GoForth](Sl,Gp), GoForth(Gp,Gl), GetOffBus(GB,Gl)]
    else[GetOnBus(RB,Mt), GoBack(Mt,Sl), GetOffBus(RB,Sl), GetOnBus(GB,Sl), GoForth
       ](Sl,Gp), GetOffBus(GB,Gp), if TicketAtFriend(Gp)
      then[PickTicket(Gp), GetOnBus(GB,Gp), GoForth(Gp,Gl), GetOffBus(GB,Gl)]
      else[GetOnBus(GB,Gp), GoForth(Gp,Gl), GetOffBus(GB,Gl), if TicketAtFriend(Gl)
        then[PickTicket(Gl)]
        else[NoOp]
      ]
    ]
  ]
]
```

3.6 B-level 15 points

- The size of the state space in the first fully observable case can either be smaller or larger than the size of the belief state space in the second sensorless case.

– Fully observable case **smaller than** sensorless case: taking the example in fig 5 as the example of the fully observable case.

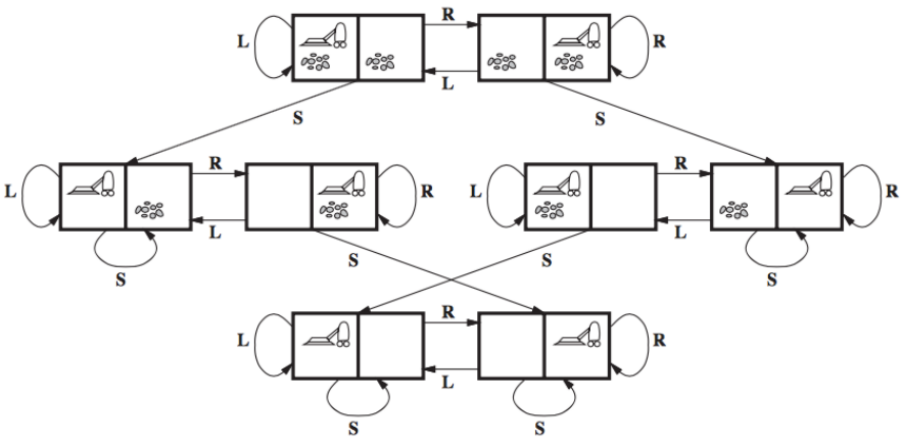

Figure 5: The fully observable case.

Assuming for the sensorless case, we don't know the position of the robot. Then the initial belief state would be the same with fig 6.

Figure 6: The initial belief state of sensorless case.

If we apply L or R to the initial belief state, we would get the one of the state on the top of the fully observable case, thus the size of the state space of the fully observable case would be smaller than the size of the belief state space of the sensorless case.

– Fully observable case **larger than** sensorless case: If there's no actions can be applied to the initial belief state, than the size of the belief state space in the second sensorless case would be 1. Then the size of the state space in the first case would be larger than the size of the belief state space in the second case. For example, the case in 3.1 is fully observable and the size of the state space is bigger than 1, while the case in 3.3 is sensorless and the size of the belief state space is 1.

- The size of the representation of the initial state in the first fully observable case is always larger than the size of the representation of the initial belief state in the second sensorless case.

  Assume the number of the fluent that are unfixed (meaning not always being true or false) is N. Then for the fully observable case, there would be N fluents listed in the state, thus, the size of the representation of the initial state is N.

  For the sensorless case, assume we have M fluents are unknown. Then we would also have $N - M$ fluents are known. If we are using the *open-world assumption*, the size of the representation of the initial belief state for the sensorless case is $N - M$. Since $M > 1$, the size of the representation of the initial state in the first fully observable case is always larger than the size of the representation of the initial belief state in the second sensorless case.

4 Sweet Cup

4.1 C-level 10 points

- Compare the initial state with the the goal state and ignore all preconditions, the $Sweet(Cup)$ can then be achieved by $Stir(Cup)$, so the value of h_1 for the initial state is 2.
- Remove all negative literals from effects, the $HasSugar(Teaspoon)$ would always be true after $FillTeaspoon()$ no matter $PourSugar(Cup)$ is conducted or not, while at the same time $Empty(Teaspoon)$ is also always true. Also, $Dry(Teaspoon)$ is always true. So all the plans is illustrated in fig 7.

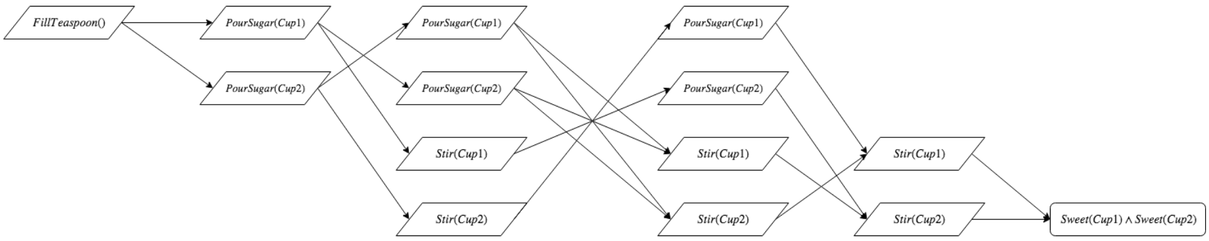

Figure 7: The initial belief state of sensorless case.

So the value of h_2 for the initial state is 5.

- h_1 dominate h_2 in general cases.

  Ignoring all the preconditions of all actions in the action scheme means we can apply any actions to any states and get the effects. But even if we would obtain negative literals from effects, they won't change the future actions.

  Ignoring all delete lists would still take preconditions into consideration but it would ignore the negative fluents in the effects.

  Since h_1 ignores all the preconditions, it would have all the function when using h_2. And furthermore, h_1 would also ignore the positive literals in the preconditions. So h_1 dominate h_2 .

4.2 B-level 20 points

- Does there exist a reachable recognized dead end for H1?

  No, because we don't need take preconditions into consideration, and any actions can be applied to any states to get the desired effect.

- Does there exist a reachable recognized dead end for H2?

  No in this case, because we would ignore all the negative literals in the effects, and all the preconditions in this "sweet cup" case are positive fluents.

- Does there exist a reachable unrecognized dead end for H1?

  No, the reason is the same with the first question.

- Does there exist a reachable unrecognized dead end for H2?

  Yes, if we conduct $Stir(Cup1)$ before conducting $PourSugar(Cup2)$.

4.3 B-level 5 points

It depends on how we set the value of the heuristics leading to unrecognized dead ends. If the value is large, then it would prevent finding a solution. If it's small enough, then it would not prevent finding a solution.