(a) (i) Intercausal Reasoning: we know a cause + effect but there are others that can be reasoned

(ii) Diagnostic Reasoning: reasoning from symptom to cause

Bayes Rule $\rightarrow P(A|B) = \frac{P(B|A)P(A)}{P(B)}$

(b) (i) $P(M) = 0.1$

$P(OB|M) = 0.82$ $\quad$ $P(NN|M) = 0.88$

$P(OB|\neg M) = 0.12$ $\quad$ $P(NN|\neg M) = 0.15$

$$P(M|OB) = \frac{P(OB|M)\,P(M)}{P(OB)} = \frac{P(OB|M)\,P(M)}{P(OB|M)\,P(M) + P(OB|\neg M)\,P(\neg M)}$$

$$= \frac{0.82 \times 0.1}{(0.82 \times 0.1) + (0.12 \times 0.9)}$$

$$= 0.432 \text{ (3 sf)}$$

$$P(M|NN) = \frac{P(NN|M)\,P(M)}{P(NN)} = \frac{P(NN|M)\,P(M)}{P(NN|M)\,P(M) + P(NN|\neg M)\,P(\neg M)}$$

$$= \frac{0.88 \times 0.1}{(0.88 \times 0.1) + (0.15 \times 0.9)}$$

$$= 0.395 \text{ (3 sf)}$$

Since $P(M|OB) > P(M|NN)$ the observatory prediction should be chosen.

(ii)

$$P(M \mid OB \land \neg NN) = \frac{\overbrace{P(OB \land \neg NN \mid M)\, P(M)}^{P(OB \mid M) \times P(\neg NN \mid M) \times P(M)}}{P(OB \land \neg NN)} \leftarrow P(OB) \times P(\neg NN)$$

$$= \frac{0.82 \times 0.12 \times 0.1}{0.19 \times (1 - 0.223)} = 0.0667 \text{ (3sf)}$$

$\uparrow$

< 0.5 do not expect meteor shower

(c) (i)

$$\begin{array}{c} S \\ \downarrow \\ I \\ \downarrow \\ A \end{array}$$

S: $P(\text{snow}) = 0.3$

I:

	snow	¬ snow
P(icy)	0.7	0.4

A:

	icy	¬ icy
P(accident)	0.6	0.5

(ii) $$P(S \mid A) = \frac{P(A \mid S)\,P(S)}{P(A)}$$

$$P(A) = P(A \mid S)\,P(S) + P(A \mid \neg S)\,P(\neg S)$$

since A and S conditionally independent

$$P(A \mid S) = P(A \mid I) \times P(I \mid S) + P(A \mid \neg I) \times P(\neg I \mid S)$$
$$= (0.6 \times 0.7) + (0.5 \times 0.3) = 0.57$$

$$P(A \mid \neg S) = P(A \mid I) \times P(I \mid \neg S) + P(A \mid \neg I) \times P(\neg I \mid \neg S)$$
$$= 0.6 \times 0.4 + 0.5 \times 0.6 = 0.54$$

$$P(A) = 0.57 \times 0.3 + 0.54 \times 0.7$$
$$= 0.549$$

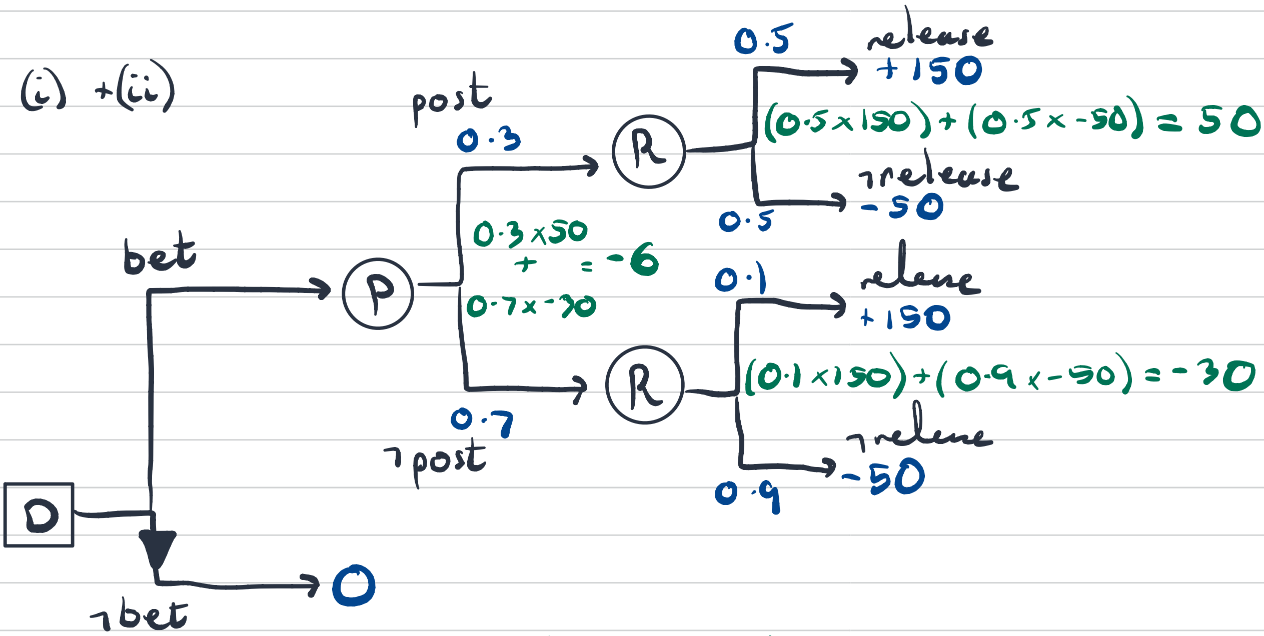
$$P(S \mid A) = \frac{0.57 \times 0.3}{0.549} = 0.311 \quad (3\text{ sf})$$

(d) Marginalization allows finding probabilities of a set of conditions given a joint probability distribution

e.g. $P(\text{Allergy} \wedge \text{Asthma})$ ← sum all cells where this condition is satisfied

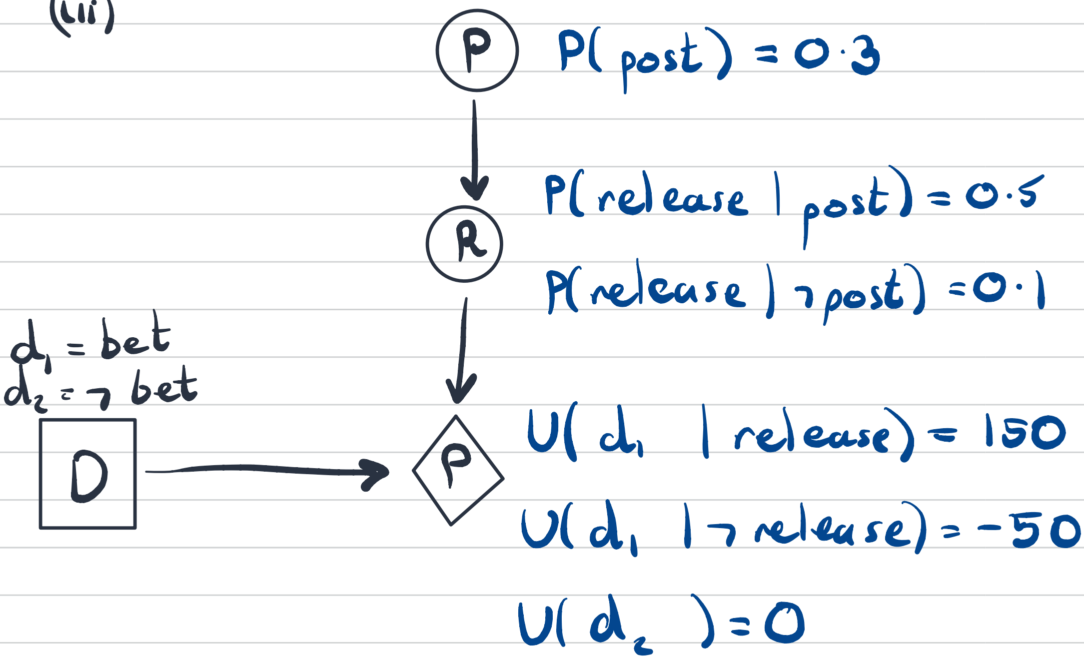
$$= 0.1 + 0.05 = 0.15$$

2. (a) (i) + (ii)

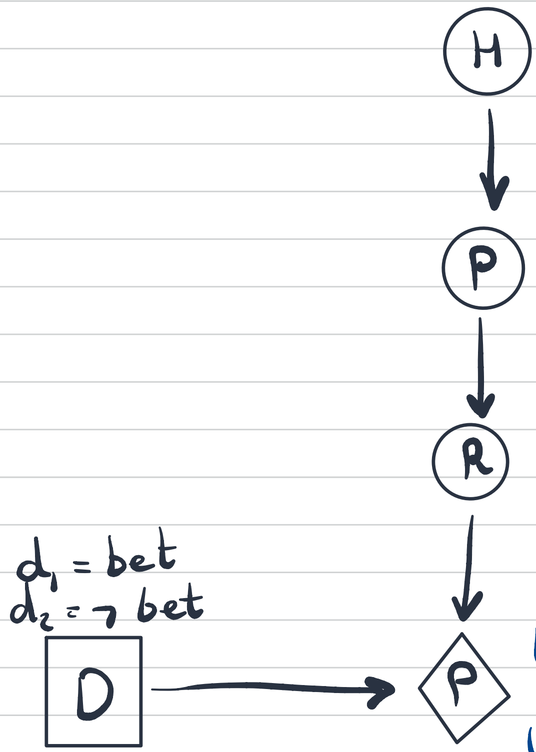


→ Don't take the bet since bet expects −6 whereas not betting expects 0.

(iii)



(iv)



$P(\text{home}) = 0.4$

$P(\text{post} \mid \text{home}) = 0.3$

$P(\text{post} \mid \neg\text{home}) = 0.1$

$P(\text{release} \mid \text{post}) = 0.5$

$P(\text{release} \mid \neg\text{post}) = 0.1$

$U(d_1 \mid \text{release}) = 150$

$U(d_1 \mid \neg\text{release}) = -50$

$U(d_2) = 0$

(b) (i) f_1(Blocked), f_2(Rain), f_3(Run, Rain),
f_4(Flooding, Blocked, Rain), f_5(Closed, Flooding)

(ii) P(Blocked | Closed ∧ Run)

f_6(Flooding) ⇒ P(Flooding) = 0.8
conditioning of f_5 P(¬Flooding) = 0.1

f_7(Rain) ⇒ P(Rain) = 0.2
conditioning of f_3 P(¬Rain) = 0.7

f_8(Rain) ⇒ P(Rain) = 0.2 × 0.4 = 0.08
$f_7 \times f_2$ P(¬Rain) = 0.7 × 0.6 = 0.42

f_9(Flooding, Rain, Blocked) ⇒
$f_4 \times f_6$

	Blocked Rain	¬Blocked Rain	Blocked ¬Rain	¬Blocked ¬Rain
P(flooding)	0.8 × 0.8 = 0.64	0.6 × 0.8 = 0.48	0.5 × 0.8 = 0.4	0.2 × 0.8 = 0.16
P(¬flooding)	0.2 × 0.1 = 0.02	0.4 × 0.1 = 0.04	0.5 × 0.1 = 0.05	0.8 × 0.1 = 0.08

f_{10}(Rain, Blocked) ⇒
sum out Flooding on f_9

	Rain	¬Rain
Blocked	0.64 + 0.02 = 0.66	0.4 + 0.05 = 0.45
¬Blocked	0.48 + 0.04 = 0.52	0.16 + 0.08 = 0.24

f_{11}(Rain, Blocked) ⇒
$f_{10} \times f_8$

	Rain	¬Rain
Blocked	0.66 × 0.08 = 0.0528	0.45 × 0.42 = 0.189
¬Blocked	0.52 × 0.08 = 0.0416	0.24 × 0.42 = 0.1008

$f_{12}(\text{Blocked}) \Longrightarrow$ Blocked $= 0.0528 + 0.189 = 0.2418$

sum out Rain on f_{11}

$\neg$Blocked $= 0.0416 + 0.1008 = 0.1424$

$f_{13}(\text{Blocked})$ Blocked $= 0.2418 \times 0.3 = 0.07254$

$f_{12} \times f_4$ $\neg$Blocked $= 0.1424 \times 0.7 = 0.09968$

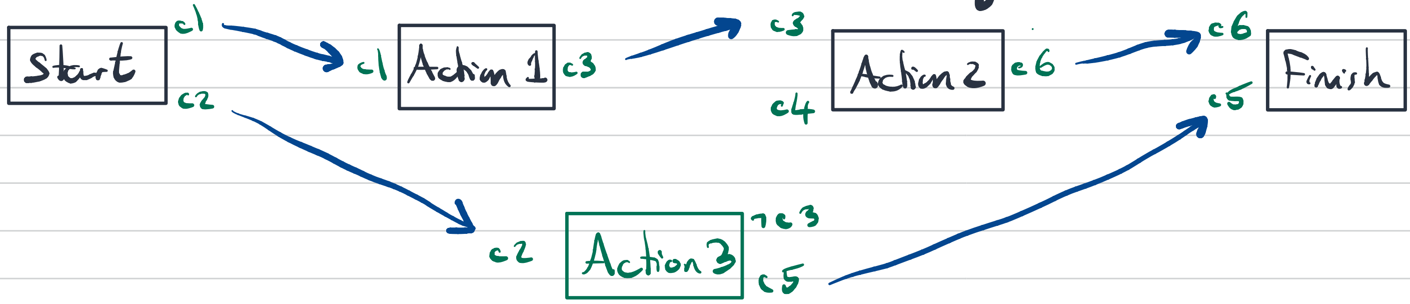
$$P(\text{Blocked} \mid \text{Closed} \wedge \text{Rain}) = \frac{f_{13}(\text{Blocked})}{\sum_{\text{Blocked}} f_{13}} = \frac{0.07254}{0.07254 + 0.09968}$$

$$= 0.4212 \ (4sf)$$

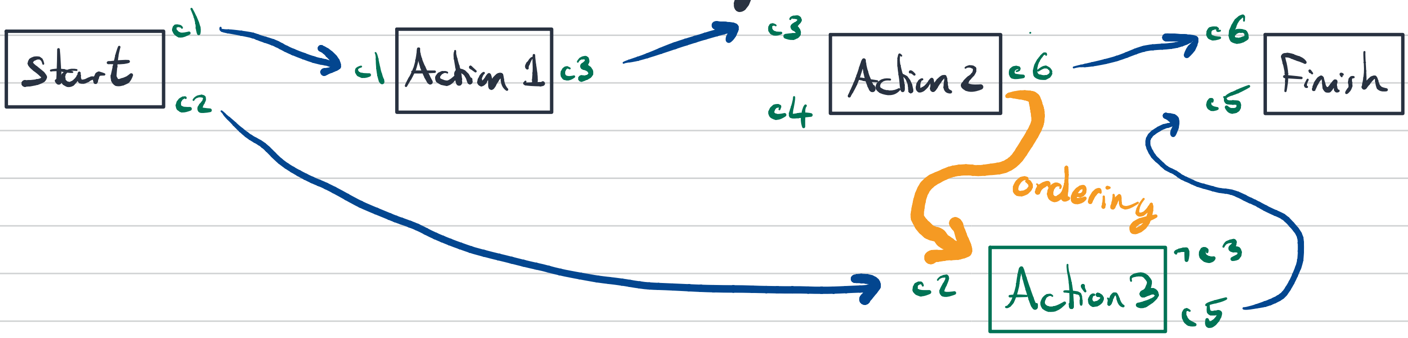
3

(a)

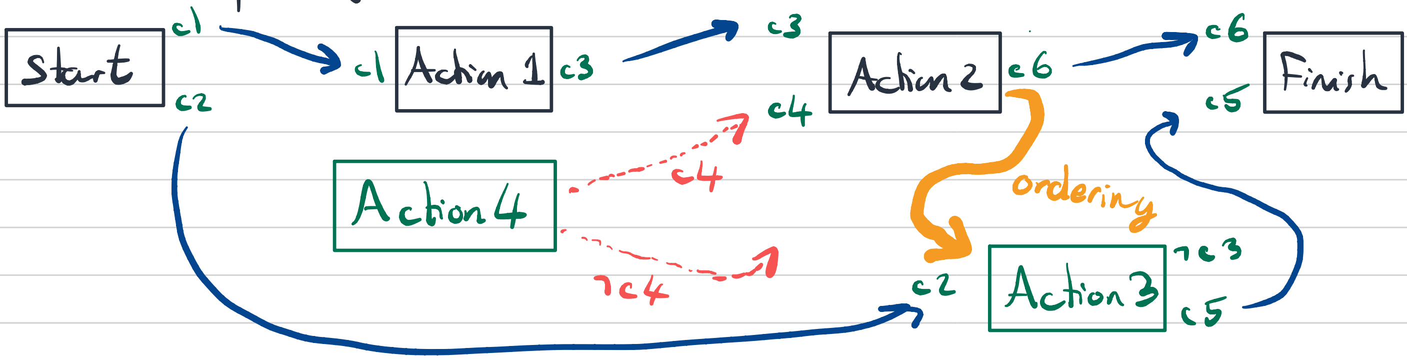
(i) • Planner would incorporate Action 3 to satisfy the precondition of Finish of c5
• The causal link from Action 3 to c5 will be added.
• Action 3 has precondition of c2 which is a postcondition of Start therefore the causal link from Start to c2 will also be added.
• Add Start < Action 3 < End ordering



(ii) • Action 3 clobbers the causal link from Action 1 to Action 2's c3 precondition due to having a $\neg c3$ postcondition
• Resolve by either promoting (placing after) the clobbering action. or demoting



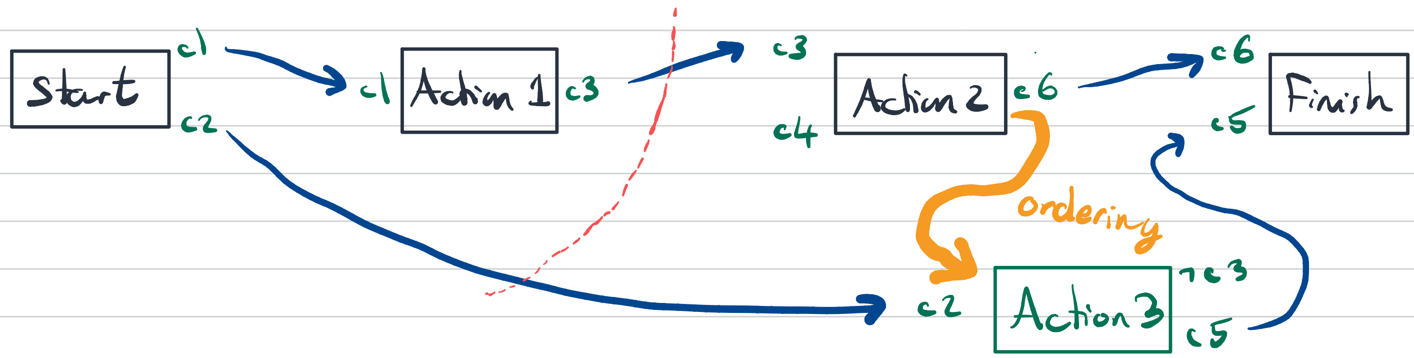
(b) • Introduce a new sensing action that has a conditional link to Action 2's c4 precondition.
• Add a plan for $\neg c4$.



(c) Action Monitoring : check that preconditions of only the next action are satisfied and that the next action can be completed

- check c3 + c4 and that Action 2 can be completed

Plan Monitoring : check the preconditions of all causal links that have been established at this time



- check c3 + c2 if promoted Action 3

(d) Replan - falling back to another action

(e)(i) $\{r_1, r_2, r_4\}$ ← any of these could be fired next

(ii) $\{r_2, r_5\}$ ← both use 2 out of 3 elements of KB

(iii) r_5 since uses most recently derived data (c).

(f) Abduction : make assumptions to explain observations

Default reasoning : make assumptions of normality to make predictions

- Use default reasoning first and then only do expensive reasoning when found to be false.

(g) using refractoriness + order of rules

Step	KB	Rule	Fired
1	A	$A \to E$	✓
2	A, E	$E \to F \wedge B$	✓
3	A, E, F, B	$B \to C \wedge D$	✓
4	A, E, F, B, C, D	$C \wedge E \to Z$	✓
5	A, E, F, B, C, D, Z	$F \to G$	✓
6	A, E, F, B, C, D, Z, G	no more rules to fire	

- Fired all rules and goal of Z achieved

4

(a) (i) Lowest-cost-first

Step	Frontier	Closed Set	Action
1	$\langle A\rangle_0$		expand $\langle A\rangle_0$
2	$\langle AB\rangle_1$	A	expand $\langle AB\rangle_1$
3	$\langle ABC\rangle_3$	A, B	expand $\langle ABC\rangle_3$
4	$\langle ABCD\rangle_5$	A, B, C	expand $\langle ABCD\rangle_5$
5	$\langle ABCDB\rangle_7$, $\langle ABCDG\rangle_7$, $\langle ABCDF\rangle_8$, $\langle ABCDE\rangle_9$	A, B, C, D	prune $\langle ABCDB\rangle_7$
6	$\langle ABCDG\rangle_7$, $\langle ABCDF\rangle_8$, $\langle ABCDE\rangle_9$	A, B, C, D	expand $\langle ABCDG\rangle_7$
7	$\langle ABCDF\rangle_8$, $\langle ABCDE\rangle_9$, $\langle ABCDGH\rangle_{16}$	A, B, C, D, G	expand $\langle ABCDF\rangle_8$
8	$\langle ABCDE\rangle_9$, $\langle ABCDFD\rangle_{11}$, $\langle ABCDFH\rangle_{11}$, $\langle ABCDGH\rangle_{16}$	A, B, C, D, G, F	expand $\langle ABCDE\rangle_9$
9	$\langle ABCDFD\rangle_{11}$, $\langle ABCDEF\rangle_{11}$, $\langle ABCDFH\rangle_{11}$, $\langle ABCDEH\rangle_{15}$, $\langle ABCDGH\rangle_{16}$	A, B, C, D, G, F, E	prune $\langle ABCDFD\rangle_{11}$
10	$\langle ABCDEF\rangle_{11}$, $\langle ABCDFH\rangle_{11}$, $\langle ABCDEH\rangle_{15}$, $\langle ABCDGH\rangle_{16}$	A, B, C, D, G, F, E	prune $\langle ABCDEF\rangle_{11}$
11	$\langle ABCDFH\rangle_{11}$, $\langle ABCDEH\rangle_{15}$, $\langle ABCDGH\rangle_{16}$	A, B, C, D, G, F, E	expand $\langle ABCDFH\rangle_{11}$
12	Goal expanded	A, B, C, D, G, F, E	

pruned 3, expanded 8, route found: $\langle ABCDFH\rangle$ cost: 11

(ii) Greedy best-first

Step	Frontier	Closed Set	Action
1	$\langle A\rangle_{10}$		expand $\langle A\rangle_{10}$
2	$\langle AB\rangle_9$	A	expand $\langle AB\rangle_9$
3	$\langle ABC\rangle_8$	A, B	expand $\langle ABC\rangle_8$
4	$\langle ABCD\rangle_6$	A, B, C	expand $\langle ABCD\rangle_6$
5	$\langle ABCDG\rangle_1$, $\langle ABCDF\rangle_2$, $\langle ABCDE\rangle_6$, $\langle ABCDB\rangle_9$	A, B, C, D	expand $\langle ABCDG\rangle_1$
6	$\langle ABCDGH\rangle_0$, $\langle ABCDF\rangle_2$, $\langle ABCDE\rangle_6$, $\langle ABCDB\rangle_9$	A, B, C, D, G	expand $\langle ABCDGH\rangle_0$
	goal expanded	A, B, C, D, G	

pruned 0, expanded 6, route found: $\langle ABCDGH\rangle$ cost: 16

(iii) A^*

Step	Frontier	Closed Set	Action
1	$\langle A\rangle^{0+10}_{10}$		expand $\langle A\rangle_{10}$
2	$\langle AB\rangle^{1+9}_{10}$	A	expand $\langle AB\rangle_{10}$
3	$\langle ABC\rangle^{3+8}_{11}$	A, B	expand $\langle ABC\rangle_{11}$
4	$\langle ABCD\rangle^{5+6}_{11}$	A, B, C	expand $\langle ABCD\rangle_{11}$
5	$\langle ABCDG\rangle^{7+1}_{8}$ $\langle ABCDF\rangle^{8+2}_{10}$ $\langle ABCDE\rangle^{9+6}_{15}$ $\langle ABCDB\rangle^{7+9}_{16}$	A, B, C, D	expand $\langle ABCDG\rangle_{8}$
6	$\langle ABCDF\rangle^{8+2}_{10}$ $\langle ABCDE\rangle^{9+6}_{15}$ $\langle ABCDB\rangle^{7+9}_{16}$ $\langle ABCDGH\rangle^{16+0}_{16}$	A, B, C, D, G	expand $\langle ABCDF\rangle_{10}$
7	$\langle ABCDFH\rangle^{11+0}_{11}$ $\langle ABCDE\rangle^{9+16}_{15}$ $\langle ABCDB\rangle^{7+9}_{10}$ $\langle ABCDGH\rangle^{16+0}_{16}$ $\langle ABCDFD\rangle^{11+6}_{17}$	A, B, C, D, G, F	expand $\langle ABCDFH\rangle_{11}$
8	goal expanded	A, B, C, D, G, F	

pruned 0 , expanded 7 , route found : $\langle ABCDFH\rangle$ cost: 11

(b) Use Bellman-Ford Algorithm

- Create table of shortest path from each node to H.
- Initialise all entries to ∞ and H to 0.
- While all nodes have not been reached:
  - Travel backwards along each edge uv
  - If Entry(u) > Entry(v) + cost(uv), set Entry(u) = Entry(v) + cost(uv)

(c) • H_2 would be best since it will be closest to the actual value

• H_1 + H_2 are admissible , but H_3 is not

(d) • <SABCDA> would be pruned at depth 5 since node A previously appears on its path.

• To check each path takes constant time by using a hash function

(a) Off-Policy : learns the value of an optimal policy

On-Policy : learns the actual value of a policy being followed

(b) • ε-greedy strategy

• Softmax

(c) $Q[s,a] = (1-\alpha)Q[s,a] + \alpha(r + \gamma \max_{a'} Q[s',a'])$

$Q[s_1, right] = ((1-0.1)\times 0) + 0.1(5 + (0.95\times 0))$

$= 0 + 0.5 = 0.5$

$Q[s_2, left] = (0.9\times 0) + 0.1(8 + (0.95\times 0.5))$

$= 0.8475$

$Q[s_1, pause] = (0.9\times 0) + 0.1(10 + (0.95\times 0.5))$

$= 1.0475$

$Q[s_1, right] = (0.9\times 0.5) + 0.1(6 + (0.95\times 0))$

$= 0.45 + 0.6 = 1.05$

(d) (i)

$$Q[\text{Green}, \text{Buy}] = (0.9 \times 10) + 0.1(13 + (0.95 \times 12))$$

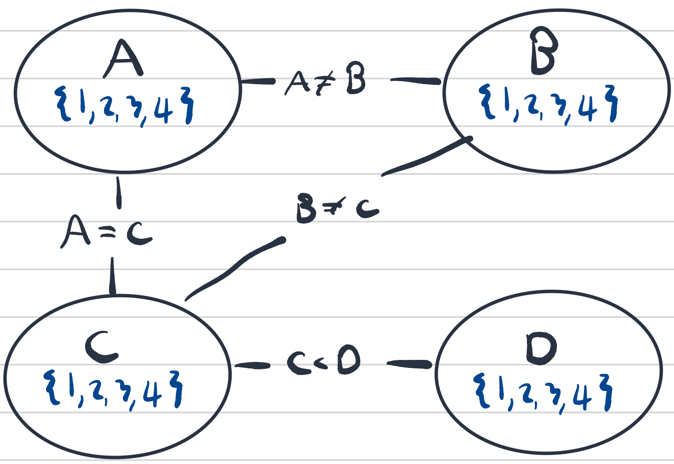
$$= 9 + 2.44 = 11.44$$

(ii) Softmax:

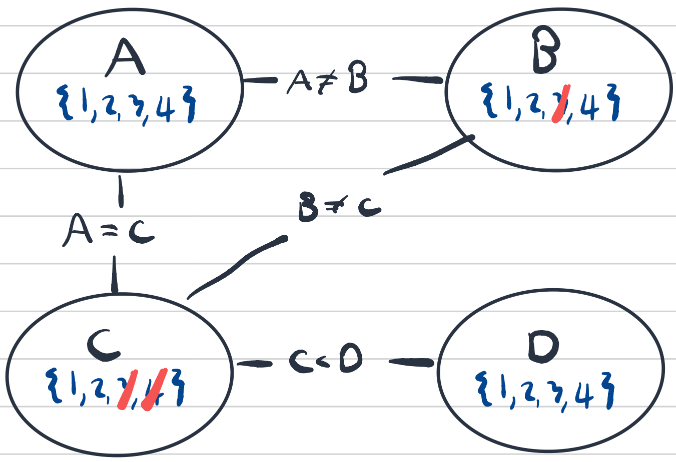
$$p(s,a) = \frac{e^{\frac{Q[s,a]}{\tau}}}{\sum_a e^{\frac{Q[s,a]}{\tau}}}$$

$$p(\text{Green}, \text{Sell}) = \frac{e^{\frac{12}{0.9}}}{e^{\frac{11.44}{0.9}} + e^{\frac{12}{0.9}}} = 0.651 \ (3sf)$$

(e) (i)



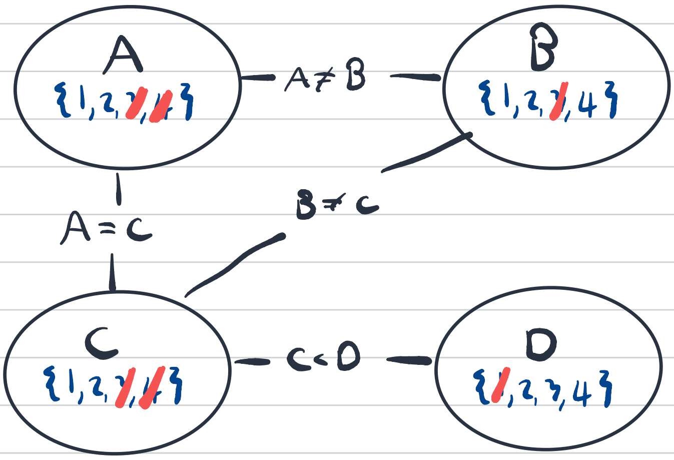
(ii)



(iii)

Relax	A	B	C	D
initial	1, 2, 3, 4	1, 2, 4	1, 2	1, 2, 3, 4
C < D	1, 2, 3, 4	1, 2, 4	1, 2	~~1~~, 2, 3, 4
A = C	1, 2, ~~3~~, ~~4~~	1, 2, 4	1, 2	2, 3, 4
A ≠ B	1, 2	1, 2, 4	1, 2	2, 3, 4
B ≠ C	1, 2	1, 2, 4	1, 2	2, 3, 4

should do each direction of constraint seperately



{1, 2, 3, 4}

(iv) Create graph with C = {1} and C = {2}