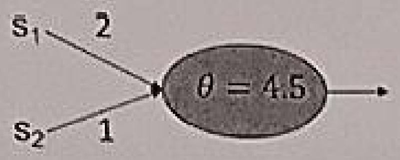
1. *(15 marks)* This question is about TLUs. Throughout, assume that the *activation function* of the TLUs, g, is defined as follows:

$$g(x) \stackrel{\text{def}}{=} \begin{cases} 1 & \text{if } x \geq \theta \\ 0 & \text{otherwise} \end{cases}$$

where θ is the threshold of the TLU.

i) *(4 marks)* The TLU below has two inputs, s_1 and s_2.



For each of the following pairs of inputs, what value does the TLU output?

a. $s_1 = 1, s_2 = 2$

b. $s_1 = 2, s_2 = 1$

c. $s_1 = 3, s_2 = 2$

d. $s_1 = 1, s_2 = 1$

ii) *(6 marks)* Design a TLU with two inputs, s_1 and s_2, that can take values of 0, 1, 2 or 3 only and that will produce the following outputs (o) for the given inputs:

s_1	s_2	o
1	2	1
2	1	0
3	2	1
1	1	0

It does not matter what values your TLU outputs for inputs not mentioned in the above table such as $s_1 = 3, s_2 = 1$. (Hint: It may help you to sketch a graph.)

iii) *(5 marks)* Explain in detail why it is impossible to design a TLU that will produce the following outputs (o) for the given inputs:

s_1	s_2	o
1	2	1
2	1	1
3	2	0
1	1	0

(Hint: It may help you to sketch a graph.)

2. (*25 marks*)

i) (*2 marks*) Briefly explain what it means for an heuristic to be *admissible*.

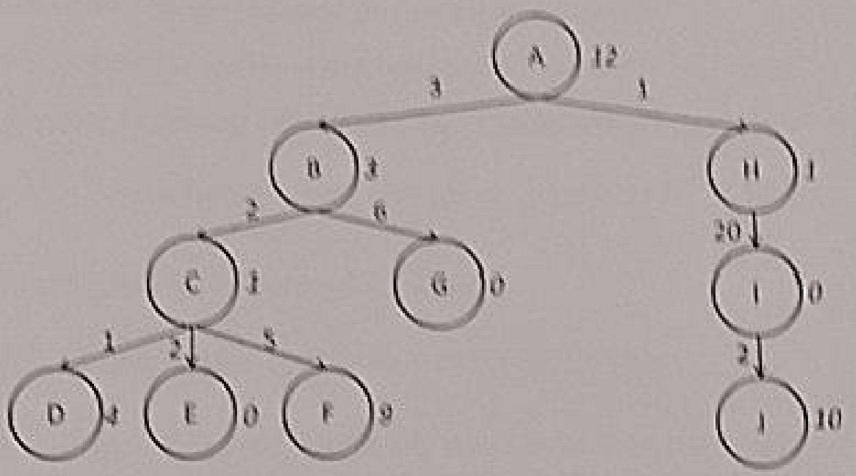
ii) (*8 marks*) An A.I. student designs three separate *admissible* heuristic functions, h_1, h_2 and h_3, for a state space search problem. The student thinks it would be a good idea to define further heuristic functions by combining h_1, h_2 and h_3.

Explain whether each of the following combinations is guaranteed to be admissible or not.

a. $h_4(n) = h_1(n) + h_2(n) + h_3(n)$

b. $h_5(n) = \frac{h_1(n) + h_2(n) + h_3(n)}{3}$

iii) (*15 marks*) Consider the following state space in which the states are shown as nodes labeled A through J. A is the initial state and E, G and I are goal states. The numbers alongside the edges represent the costs of moving between the states. To the right of every state is the estimated cost of the path from the state to the nearest goal.



Show how each of the following search strategies finds a solution in this state space by writing down, in order, the names of the nodes removed from the agenda. Assume the search halts when the goal state is removed from the agenda. (In some cases, multiple answers are possible. You need give only one such answer in each case.)

a. Breadth-first;

b. Depth-first;

c. Least-cost search;

d. Greedy search, i.e. heuristic search using $f(n) = h(n)$ as the evaluation function, where $h(n)$ is the estimated cost of the cheapest path from node n to a goal; and

e. Heuristic search using $f(n) = g(n) + h(n)$ as the evaluation function, where $g(n)$ is the cost of the path to node n, and $h(n)$ is the estimated cost of the path from node n to the nearest goal.

3. (*25 marks*) This question uses the following 'key' for the binary predicate symbols s and c, the ternary predicate symbol i, the unary function symbol nl, and the constant symbols a, b, d, eng and ger:

$s(x,y)$	:	person x speaks language y
$c(x,y)$	:	person x can communicate with person y
$i(x,y,z)$	:	person x can act as person y's and person z's interpreter
$nl(x)$	:	person x's native language
a	:	Ann
b	:	Ben
d	:	Deb
eng	:	English
ger	:	German

(w, x, y, z and subscripted versions of these will be used as variables.)

i) (*6 marks*) Translate the following sentences of English into FOPL:

a. *"Deb speaks Ann's native language or Ben's native language."*

b. *"Ann can communicate with everyone who speaks her native language."*

ii) (*7 marks*) Convert the following wff of FOPL into Clausal Form Logic. Show your working.

$$\forall w \forall x \forall y((s(w,y) \wedge s(x,y)) \Rightarrow \exists z(c(w,z) \wedge c(z,w)))$$

iii) (*12 marks*) You are given the following five *clauses*:

If x_1 and y_1 both speak language z_1, then they can communicate.

$$\neg s(x_1,z_1) \vee \neg s(y_1,z_1) \vee c(x_1,y_1)$$

If x_2 can communicate with y_2 and with z_2, then x_2 can be their interpreter.

$$\neg c(x_2,y_2) \vee \neg c(x_2,z_2) \vee i(x_2,y_2,z_2)$$

For any two languages, there is someone who speaks both.

$$s(f(x_3,y_3),x_3)$$

(f is a Skolem function.)

Ann speaks English and Ben speaks German.

$$s(a,eng)$$
$$s(b,ger)$$

From these clauses, use *resolution refutation* theorem-proving to show that there is someone who can act as Ann's and Ben's interpreter, i.e. in FOPL:

$$\exists x\ i(x,a,b)$$

Show your working, presenting your proof in the form of a *refutation tree*.

Note: It may help your answer if you standardize variables apart in resolvents, i.e. rename variables in resolvents.

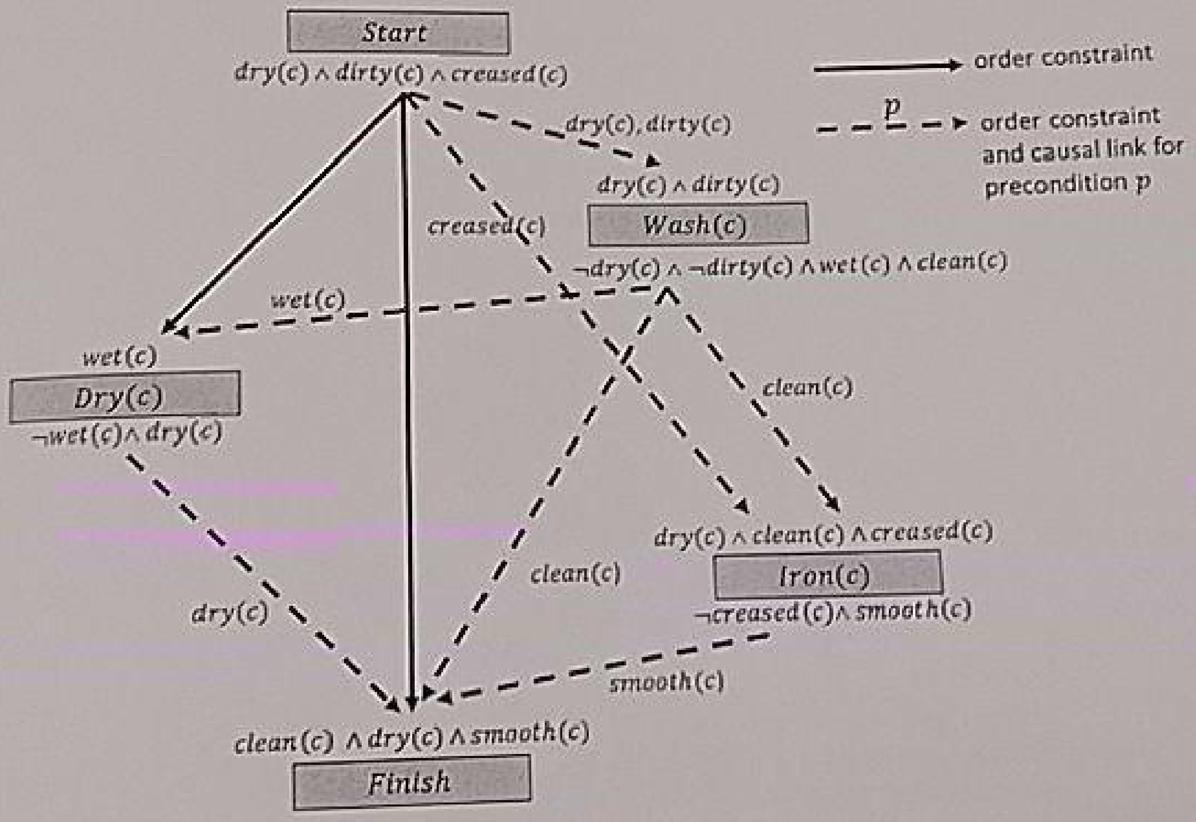
4. *(15 marks)* A robot operates in a launderette. Assume that it has the following repertoire of STRIPS-style operators for washing an object, for drying it, and for ironing it:

Op(ACTION: $Wash(x)$,
PRECOND: $dry(x) \wedge dirty(x)$,
EFFECT: $\neg dry(x) \wedge \neg dirty(x) \wedge wet(x) \wedge clean(x)$)

Op(ACTION: $Dry(x)$,
PRECOND: $wet(x)$,
EFFECT: $\neg wet(x) \wedge dry(x)$)

Op(ACTION: $Iron(x)$,
PRECOND: $dry(x) \wedge clean(c) \wedge creased(x)$,
EFFECT: $\neg creased(x) \wedge smooth(x)$)

Here is an incomplete plan of the kind that could be built by the POP planner covered in lectures for washing my cravat (c):



i) *(1 mark)* Give the *start state* of this plan.

ii) *(1 mark)* Give the *goal* of this plan.

iii) *(5 mark)* Give all linearizations of this incomplete plan.

iv) *(8 marks)* There is one unachieved precondition in this plan: *dry(c)* on the *Iron* step. There are two ways of achieving this precondition that re-use existing steps:

a. One way is to use the *dry*(*c*) effect of the *Initial* step. Explain in detail why this cannot lead to a solution plan.

b. The other way is to use the *dry*(*c*) effect of the *Dry* step. Explain in detail why this does lead to a solution plan.