ENGLISH

Problem 1 [Agents. Answer 1(True) or 0 (False) for each of the following sentences.]

A. Simple reflex agents often use situation-actions rules for their reasoning. (T)
B. Simple reflex agents have an internal model of the current state of the world. (F)
C. An agent's utility function is essentially internalization of the performance measure.(T)
D. In order to be rational an agent should have a utility function. (F) Not necessarily. For ex, Simple vacuum cleaner does not have one but behaves rationally.
E. In a learning agent the learning element is responsible for selecting the external action to be executed next. (F)
F. Taxi driving happens in a stochastic, sequential, partially observable, and continuous environment. (T)
G. Agents need an internal model to cope with partially observable environments. (T)
H. An agent system has an agent function that selects the next action and a state transition fuction which computes what the next state of the environment would be when an action is executed.(T)
I. The action selection in model based agents uses as input the currently sensed data as well as the internal representation of the environment. ((T)
J. In goal-based agents, rationality of the agents is measured based on the utility function. (F)

Problem 2 [General Questions about Search and Logic. Answer 1(True) or 0 (False) for each.]

a. Depth-first search is more space efficient than Breadth-first search. (True)
b. The basic Genetic Algorithm is Stochastic Beam Search supplemented with a crossover operator. (True)
c. Iterative Deepening search is more space efficient than Breadth-first search? (True)
d. One of the main reasons why Texas Hold'em poker is harder for AI than chess is that there are 52 cards in a deck, but only 32 pieces on a chessboard. (False)
e. Simulated Annealing is Best-First search supplemented with a temperature variable. (False)
f. All of the following are traditionally classified as Informed Search methods: A*, Iterative Deepening and Hill Climbing. (False)
g. To use a resolution theorem prover, all logical expressions must first be converted into horn-clause form. (False)
h. In first-order logic, a sentence is satisfiable if and only if there is at least one interpretation and one variable assignment in which it is true. (True)
i. PROLOG is a computer language that relies heavily on backward chaining. (True)
j. Skolemization is an important step of resolution theorem proving in both propositional logic and first-order logic. (False)

Problem 3

Assume the following predicates:

a. S(x) – x is a student
b. E(y) – y is an exam

c. Q(x) – x is a question.
d. EQ(x,y) – y is a question on exam x
e. K(x,y) – x knows the answer to question y.

and the following expressions:

1. $\forall$x: S(x) $\Rightarrow$ { $\exists$ y, z: E(y) $\wedge$ EQ(y,z) $\wedge$ $\neg$ K(x,z) }
2. $\forall$x,y: E(x) $\wedge$ EQ(x,y) $\Rightarrow$ { $\exists$ z: S(z) $\wedge$ $\neg$ K(z,y) }
3. $\forall$x,y,z: E(x) $\wedge$ Q(y) $\wedge$ S(z) $\Rightarrow$ { K(z,y) $\Rightarrow$ EQ(x,y) }

Part 1:

For each logical expression, select the one natural-language sentence below that best captures its meaning:

A. There are some students who miss every question on all exams.
B. All exams have at least one question that no student can answer correctly.
C. Every student gets everything correct on at least one exam.
D. No student is perfect.
E. No exam question is correctly answered by every student.
F. Students do not know the answers to questions that are not on exams.
G. Given any student, question and exam, the student can answer the question if it is on the exam.
H. Each exam has a question that every student can answer correctly.

Answers:

1: D
2: E
3: F

Part 2:

One of the three logical sentences above yields the following expression when converted to Conjunctive Normal Form (CNF), where F and G are skolem functions:

$$\{\neg S(x) \vee E(F(x))\} \wedge \{\neg S(x) \vee EQ(F(x),G(x)))\} \wedge \{\neg S(x) \vee \neg K(x,G(x))\}$$

Which one of the three logical sentences is it?

(Answer: #1)

Part 3:

What is the resolvent clause when the binary resolution rule is applied to the following two clauses (where F is a skolem function and Karen is a constant symbol)?

$\neg$S(x) $\vee$ E(F(x)) $\vee$ Q(y)
S(Karen)

`Answer: E(F(Karen)) v Q(y)`

Problem 4

Figure 1 displays a search tree generated by Minimax search. Inside of each leaf node is its evaluation. Child nodes are always generated and evaluted from left to right in the tree.

List all of the leaf nodes that will **NOT** be generated if Minimax is run again, but this time with alpha-beta pruning.

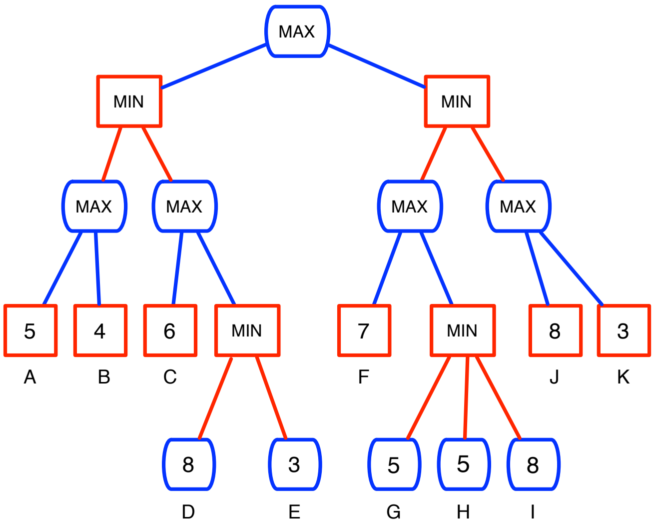


Figure 1: Minimax Search Tree

Answer: Nodes D, E, H, I, K

Problem 5

Figure 2 shows part of a tree built during A* search. The task is to rearrange the blocks to achieve the goal state while minimizing the total distance travelled by the blocks, where the width of each block has a distance = 1. The only legal operator is to switch the positions of two blocks. The heuristic is simply the total of the distances of all blocks from their goal locations.

Fill in all missing f, g and h values in the figure.

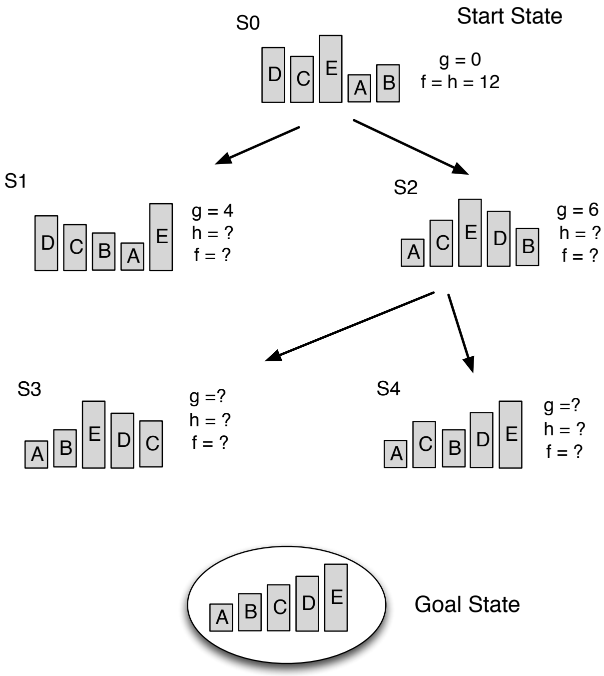


Figure 2: A* Search Tree

Answer: S1: h = 8, f = 12 S2: h = 6, f = 12
S3: g = 12, h = 4, f = 16 S4: g = 10, h = 2, f = 12

Problem 6

Figure 3 displays the use of model checking to test whether the following is a **valid** logical expression (using the formal definition of logical validity):

$$\{A \Rightarrow (B \Rightarrow C)\} \Rightarrow \{A \Rightarrow C\}$$

Fill in all missing cells of the table with a 1 (True) or 0 (False).
Next, based on the completed table, tell whether or not the expression is valid.

$$\{A \Rightarrow (B \Rightarrow C)\} \Rightarrow \{A \Rightarrow C\}$$

A	B	C	B ⇒ C	A ⇒ (B ⇒ C)	A ⇒ C
0	0	0	1	1	1
0	0	1	1	1	1
0	1	0	0	1	1
0	1	1	1	1	1
1	0	0	1	1 **	0 **
1	0	1	1	1	1
1	1	0	0	0	0
1	1	1	1	1	1

The two starred boxes prove that this is NOT valid.

Figure 3: Model Checking

Problem 7 [Constraint Satisfaction Problems (CSPs)]

Part 1:

Figure 4 shows a simple CSP involving 3 integer-valued variables and 3 constraints. The AC-3 (Arc consistency 3) algorithm is applied to the problem, and this involves several calls to the REVISE algorithm. The first 4 of these calls are shown. Fill in the updated domain for the variable listed after each call.

The right of the figure shows one complete solution to the CSP. Are there others? If so, list them.

Part 2:

Figure 5 shows a second CSP, with 3 integer-valued variables and 3 constraints. The solution method is local search, beginning with the state (3,3,3), and using the MIN-CONFLICTS algorithm to determine the best new value for each randomly-chosen variable. Assuming that the first variable chosen is Z, followed by Y, determine the missing values in the two states (2 and 3) shown in the figure. In this problem, a conflict is a constraint that is violated.

Variables & Domains

$X \in \{1, 2, 3, 4, 5\}$
$Y \in \{1, 2, 3, 4, 5\}$
$Z \in \{1, 2, 3, 4, 5\}$

Constraints

$2Y < X$
$X > 3Z$
$Y < 3Z$

1 REVISE(X,Y)

$X \in \{3, 4, 5\}$

2 REVISE(Z,X)

$Z \in \{1\}$

3 REVISE(Y,Z)

$Y \in \{1, 2\}$

4 REVISE(X,Z)

$X \in \{4, 5\}$

Solutions

X	Y	Z
4	1	1
5	1	1
5	2	1

Figure 4: AC-3 and REVISE

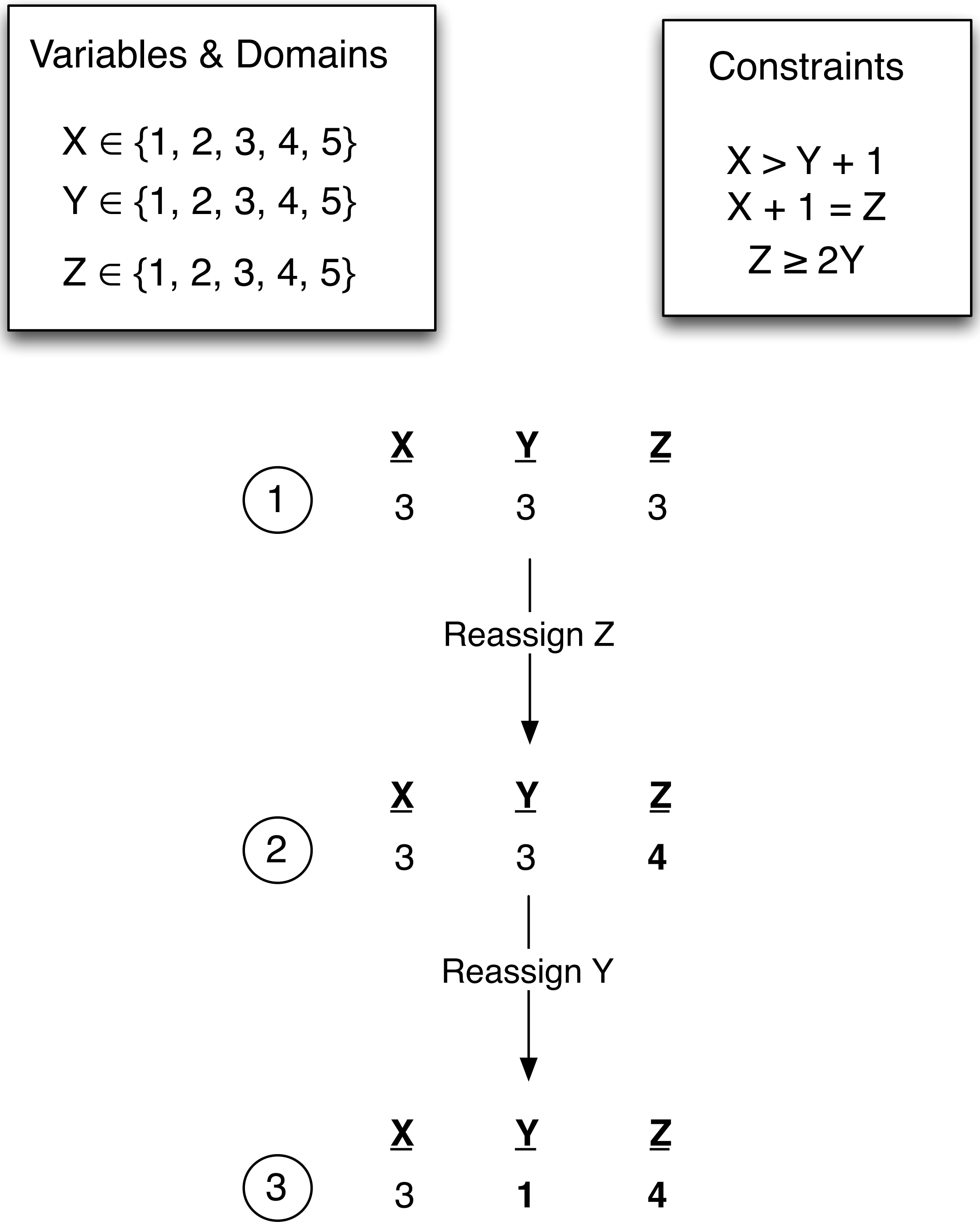


Figure 5: MIN-CONFLICTS

Problem 8 [Planning graphs]

Rob and Mary are at home. Rob has to get to work and has two options: either he walks or he uses the car. Mary needs to get to the airport and her only option is to use the car. The car needs fuel before it can be used. For the sake of brevity we will used the following simple string description for the states and actions.

robAtHome	Rob is at home
maryAtHome	Mary is at home
fuel	there is fuel in the car

car	car is at home

The actions to be modelled are:

```
Walk {
        precond: robAtHome
        add: robAtWork
        del: robAtHome
    }

GetFuel {
        precond:
        add: fuel
        del:
    }

DriveAirport{
        precond: maryAtHome, fuel, car
        add: maryAtAirport
    del:maryAtHome, car
  }

DriveWork{
        precond: robAtHome, fuel, car
        add: robAtWork
    del:robAtHome, car
  }
```

The goal : robAtWork, maryAtAirport
The initial condition: robAtHome, maryAthome, car

Figure 6 illustrates the incomplete planning graph. The dashed lines at A0 level show the mutex relations. The gray boxes mean ”no operation”.

Part 1:

Mark the following mutex relationships either ”correct” or ”wrong” according to whether they are mutex at stage A1 or not, respectively. It is recommended that you find the mutex relations at S1 first.

A. (Walk, robAtHome)
B. (Walk, robAtWork)
C. (DriveAirport, DriveWork)
D. (DriveAirport, car)
E. (robAtWork, DriveWork)
F. (robAtWork, ¬robAtWork)
G. (maryAtAirport,car)
H. (¬fuel, DriveWork)
I. (DriveWork, ¬robAtHome)
J. (DriveWork,fuel)

Part 2:
Is there a need to expand the graph after S2? Explain why (not) with 1 (or max 2) sentences.

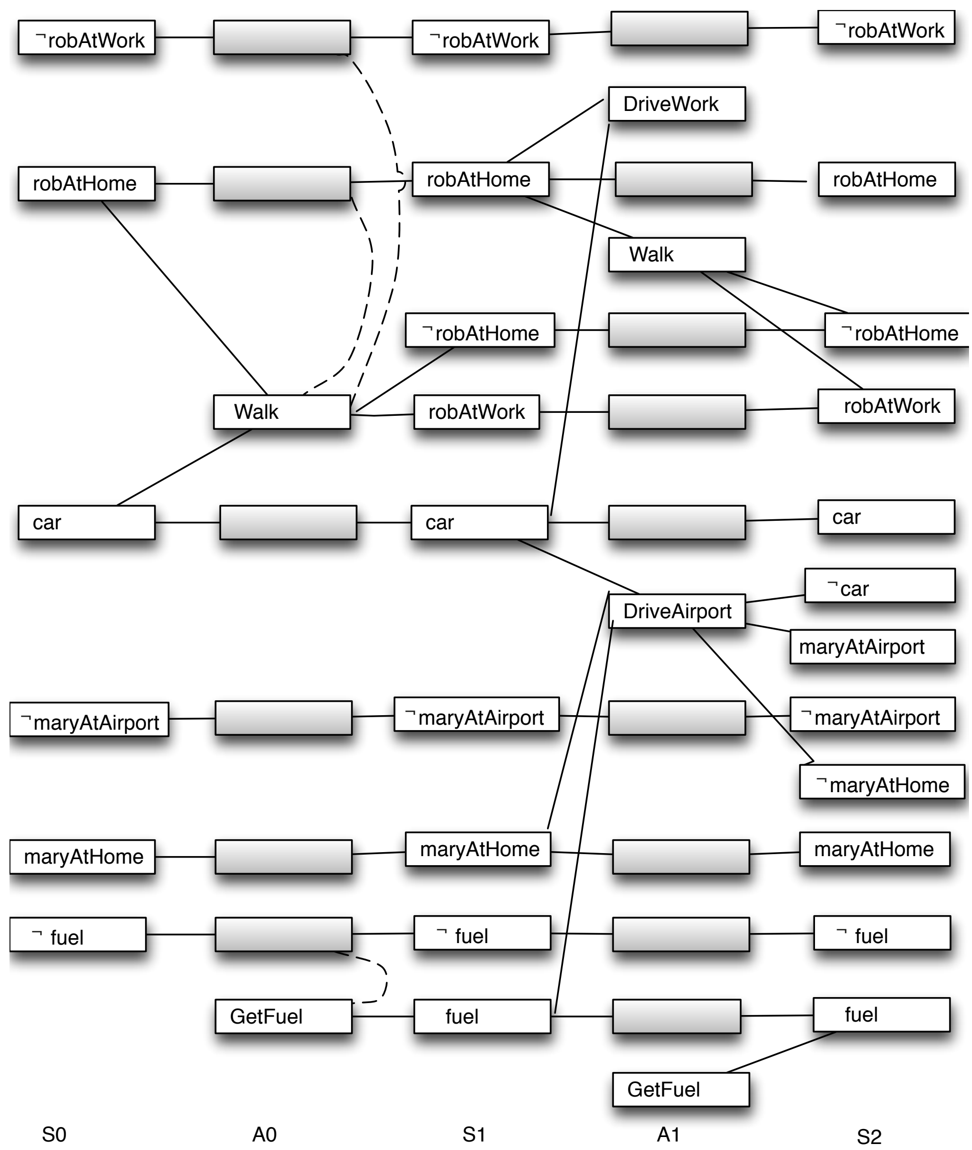


Figure 6 Planning graph for Problem 8

ANSWER:

Her er utskrift av alle lag med mutex relasjoner:

S0

-robAtWork
car
robAtHome

-maryAtAirport
maryAtHome
-fuel

A0

robAtHome
-maryAtAirport
car
Walk
maryAtHome
-fuel
GetFuel
-robAtWork

mutex:
(Walk,-robAtWork)
(Walk,robAtHome)
(-fuel,GetFuel)

S1

-robAtHome
-robAtWork
robAtWork
car
fuel
robAtHome
-maryAtAirport
maryAtHome
-fuel

mutex:
(-robAtHome,-robAtWork)
(-robAtHome,robAtHome)
(-robAtWork,robAtWork)
(robAtWork,robAtHome)
(fuel,-fuel)

A1:
robAtHome
DriveAirport
-maryAtAirport
car
-robAtHome
fuel
Walk
maryAtHome

DriveWork
robAtWork
-fuel
GetFuel
-robAtWork

mutex:
(Walk,-robAtWork)
(Walk,-robAtHome)
(Walk,DriveWork)
(Walk,robAtHome)
(Walk,robAtWork)
(DriveAirport,DriveWork)
(DriveAirport,-fuel)
(DriveAirport,-maryAtAirport)
(DriveAirport,maryAtHome)
(DriveAirport,car)
(robAtWork,DriveWork)
(robAtWork,-robAtWork)
(robAtWork,robAtHome)
(-fuel,DriveWork)
(-fuel,fuel)
(-fuel,GetFuel)
(DriveWork,-robAtWork)
(DriveWork,-robAtHome)
(DriveWork,robAtHome)
(DriveWork,car)
(-robAtWork,-robAtHome)
(robAtHome,-robAtHome)

S2

-car
-robAtHome
-robAtWork
robAtWork
maryAtAirport
car
fuel
-maryAtHome
robAtHome
-maryAtAirport
maryAtHome
-fuel

mutex:
(-car,car)
(-car,-fuel)

(-robAtHome,-robAtWork)
(-robAtHome,robAtHome)
(-robAtWork,robAtWork)
(robAtWork,robAtHome)
(maryAtAirport,car)
(maryAtAirport,-maryAtAirport)
(maryAtAirport,maryAtHome)
(maryAtAirport,-fuel)
(car,-maryAtHome)
(fuel,-fuel)
(-maryAtHome,-maryAtAirport)
(-maryAtHome,maryAtHome)
(-maryAtHome,-fuel)

Alle mål I S2 er oppnådd. Ingen expansion etter det.

Problem 9 [Knowledge representation languages.]

Part 1:
How would a Question Answering system answer the question ”What is the color of bird?” if it operates on the semantic network shown in Figure 7?

A. It is white.
B. It is yellow.
C. It is red.
D. It is red or white or blue.
E. Don’t know .

ANSWER: E ”I don’t now” – ”bird” har ikke farge attribute , heller ikke animal.

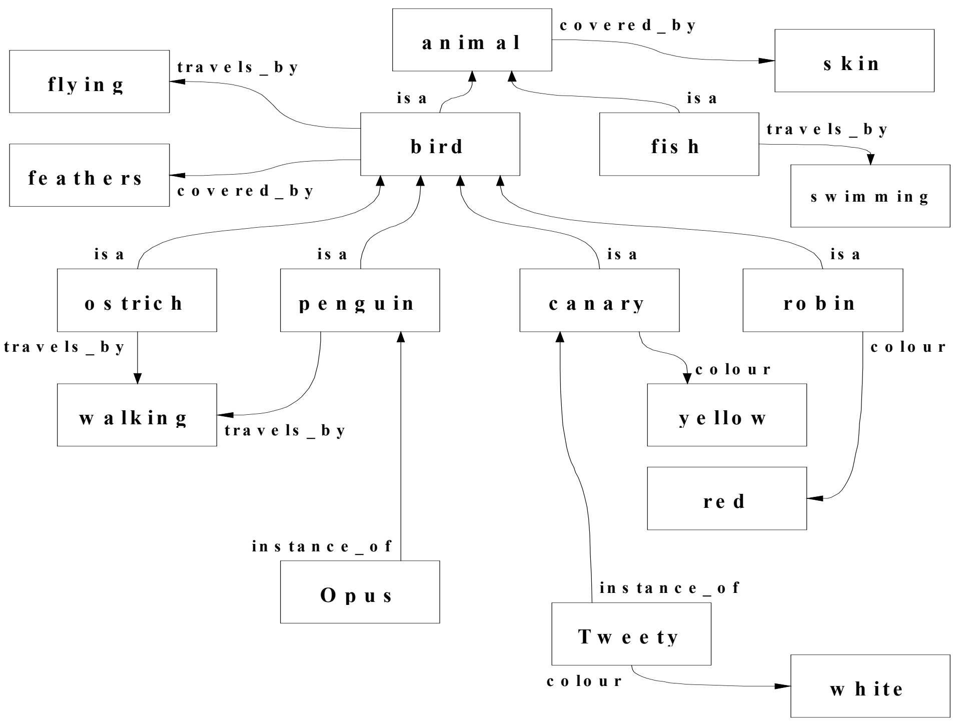


Figure 7. Semantic Network for "bird"

Part 2:
Which of the following is (are) true for the knowledge base shown in **Figure 8**?

A. Apple-1 weighs 10 gram.
B. Apple-1 weighs 50 gram.
C. Apple-1 weighs 100 gram.
D. Apple-1 weighs 200 gram.
E. Apple-1 is green or red.

ANSWER: E, Apple-1 is green or red

Part 3:
You will represent the sentence *"Jack kidnapped Billy on August 5"* be as an event in a frame-based language. Write down the frame.

ANSWER:

Kidnap1
Is-a: Kidnapping event
perpetrator: Jack
victim: Billy
date: August 5

ikke nødvendigvis disse attribute navnene trenges. Noe som har same funkjon/rolle blir/telles riktig.

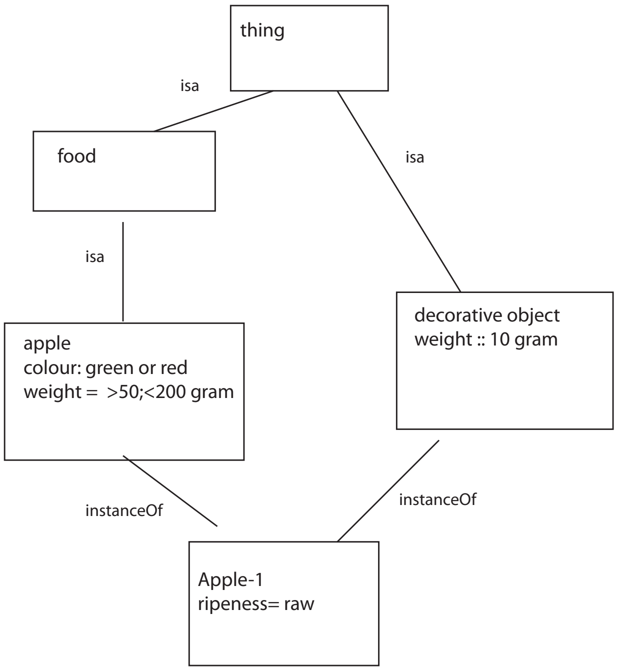


Figure 8 Apple model

Problem 10 [General, mixture of chapters 10-13 &22 and the "An Overview of Knowledge Acquisition" (Musen) paper].

Fill in the blanks in the following questions:

A. You are a knowledge engineer and are working on a problem where the system's reasoning mechanism relies on prototypical objects in the world. "…FRAME/FRAME-BASED lang.…." would be the most appropriate representation language to use for this problem.

B. Sentiment analysis is a form of text "…CATEGORIZATION…………………".

C. Knowledge elicitation (as described in Musen's paper) involves a knowledge engineer and a " DOMAIN………." expert.

D. Taste, smell and color of a cake are its "…INTRINSIC…….……" properties while weight and shape are its "…EXTRINSIC…………" properties.

E. "…PARTITIONS……………." are both disjoint and exhaustive decomposition of categories.

F. In natural language processing, information ”…EXTRACTION…………..” is the process of acquiring knowledge from text.

G. ”…TURING………” test is the most known scenario for testing the intelligence of an articial intelligence system.

H. ”…PRECISION……………” is a measure used to evaluate IR systems and measures the proportion of documents in the result set that are actually relevant.

I. In frame-based languages, default reasoning is facilitated by inheritance of ”…ATTRIBUTE/SLOT………..” values.

J. In rule based systems, a depth first approach can be implemented by using ”RECENCY………..” as the conflict resolution strategy when selecting between the candidate rules that can fire at a certain time point.

END of QUESTIONS

GOOD LUCK!

QUESTION 1 (30 poeng)

Answer he following questions with True or False

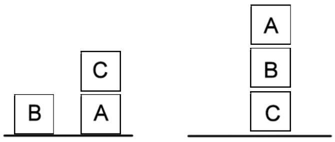
1. An agent that senses only partial information about the state cannot be perfectly rational. (True or False?)
    a. ANSWER: False. Perfect rationality refers to the ability to make good decisions given the sensor information received.
2. Every agent is rational in an unobservable environment.
    a. ANSWER: False. Some actions are stupid—and the agent may know this if it has a model of the environment—even if one cannot perceive the environment state.
3. "Strikking av en sokk involves a fully observable, deterministic, sequential, static, continuous, single agent miljø.
    a. Answer: T
4. "Bidding in auction" involves a fully observable, strategic, sequential, static, discrete, multi-agent.
    a. Answer: T
5. The Turing test evaluates a computer system's ability to act rationally. Answer: FALSE
6. A stochastic environment is one in which the next state is completely determined by the agent's action.
    a. Answer: FALSE
7. An advantage of Hill Climbing search is that it requires minimal memory.
    a. TRUE
8. A danger of depth-first search is that it may not terminate if the search space is infinite, even if a finite solution exists.
    a. TRUE
9. The knowledge, i.e, the content of the knowledge base determines the system 's performance while representation of knowledge determines its competence.
    a. FALSE, the opposite
10. Principal of rationality (due to Allen Newell) maintains that the agent chooses actions in order to achieve its goal using the knowledge it has the knowledge it might gather.
    a. FALSE, only the knowledge it has.
11. This is procedural knowledge about two cities in Norway: bigger (Oslo, Trondheim)
    a. FALSE, declarative
12. An advantage of declarative knowledge is the storage economy, that is, representation of declarative knowledge needs less memory than procedural knowledge.
    a. FALSE: storage economy means that the same declarative knowledeg can be used in different ways.
13. The prodction rules in a Rule-based system is represented in the " working memory".
    a. FALSE. They represent this model in the rule base, not in the working memory

14. Assume a rule-based system for classification of fruits. Assume also that the system is currently at time t2 and it uses a refractory conflict resolution strategy. The system will fire the rule R5 at t2.

Step	Applicable Rules	Chosen Rule	Derived Facts
T1	R2, R5		R2
T2	R2, R5		R5

   a. True – tries to avoid loops

15. Consider a block world problem where the goal is On(A,B), On(B,C), and the precondition is On(C,A), On(B,Table), On(A,Table), Clear(C), Clear(B), Block(A), Block(B), Block(C). See the figure below:

   i. 

Suppose a planner that, given subgoals $G_1,\ldots,G_n$, solves each subgoal consecutively (i.e., first one goal, and then the next one,…). If we use such a planner to solve the planning problem above and solve the goals in the given order (i.e., On(A,B), On(B,C)) the planning will obtain an optimal plan.

   b. ANSWER: FALSE: We will get into a deadlock if make a subgoal assumption. For if we try to achieve first On(A,B) efficiently then we will have do MoveToTable(C) and MoveToBlock(A,B) which does not work. Similarly, if we try to accomplish first the goal On(B,C) we will have to do one simple action: MoveToBlock(B,C) and ew are stuck again.

QUESTION 2 - oversettelse til FOPL (20)

a) Translate the following sentences in English to sentences in first order predicate logic

   1. All the existing kinds of birds can fly
      $\forall x Bird(x) \rightarrow Fly(x)$
   2. Some existing kinds of birds can fly
      $\exists x Bird(x) \wedge Fly(x)$
   3. At least two existing kinds of birds can fly
      $\exists x \exists y \neg(x = y) \wedge Bird(x) \wedge Bird(y) \wedge Fly(x) \wedge Fly(y)$
   4. All existing kinds of birds can fly, except two.
      $\exists x \exists y Bird(x) \wedge Bird(y) \wedge \neg(x = y) \wedge \neg Fly(x) \neg Fly(y) \wedge (\forall z Bird(z) \wedge \neg(y = z) \wedge \neg(x = z) \rightarrow Fly(z))$
   5. All birds that are not penguins fly
      $\forall x\ [bird(x) \wedge \neg p(x)) \rightarrow fly(x)]$

or

$\forall x\, [bird(x) \rightarrow [\neg p(x)) \rightarrow fly(x)]]$

6. There are no green Martians.

   $\neg(\exists x\ green(x)\ \wedge\ Martian(x))$

   or

   ∀x (¬green(x) ∨ ¬Martian(x))
7. Everything painted by Picasso is valuable.

   ∀x (painting(x) ∧ paintedBy(x, Picasso) → valuable(x))
8. Not all people have a cell phone.

   ∃p (person(p) ∧ ¬hasCellPhone(p))
9. Everyone who owns a violin knows someone that likes music written by Mozart.

   ∀x person(x) ∧ owns(x, violin) → (∃y person(y) ∧ knows(x, y) ∧ likesMozartM usic(y))
10. Every students at NTNU knows someone who likes dogs.

    ∀x studentAt(x, NTNU) → (∃y person(y) ∧ knows(x, y) ∧ likesDogs(y))

QUESTION 3

a) The figure below displays the use of model checking to test whether the following is a **valid** logical expression (using the formal definition of logical validity):

$$\{(A \Rightarrow B) \Rightarrow C\} \Rightarrow \{(C \wedge A) \Rightarrow B\}$$

A	B	C	$A \Rightarrow B$	$(A \Rightarrow B) \Rightarrow C$	$(C \wedge A)$	$(C \wedge A) \Rightarrow B$
0	0	0	1	0	0	1
0	0	1	1	1	0	1
0	1	0			0	
0	1	1			0	
1	0	0	0	1	0	
1	0	1	0	1	1	
1	1	0	1		0	1
1	1	1	1		1	1

Fill in all missing cells of the table with a 1 (True) or 0 (False).
Next, based on the completed table, tell whether or not the expression is valid.

Answer:

Here is the answer, with the newly filled-in values in parentheses. The two starred boxes indicate that the expression is NOT valid.

$$\{(A \Rightarrow B) \Rightarrow C\} \Rightarrow \{(C \wedge A) \Rightarrow B\}$$

A	B	C	$A \Rightarrow B$	$(A \Rightarrow B) \Rightarrow C$	$(C \wedge A)$	$(C \wedge A) \Rightarrow B$
0	0	0	1	0	0	1
0	0	1	1	1	0	1
0	1	0	(1)	(0)	0	(1)
0	1	1	(1)	(1)	0	(1)
1	0	0	0	1	0	(1)
1	0	1	0	1 **	1	(0) **
1	1	0	1	(0)	0	1
1	1	1	1	(1)	1	1

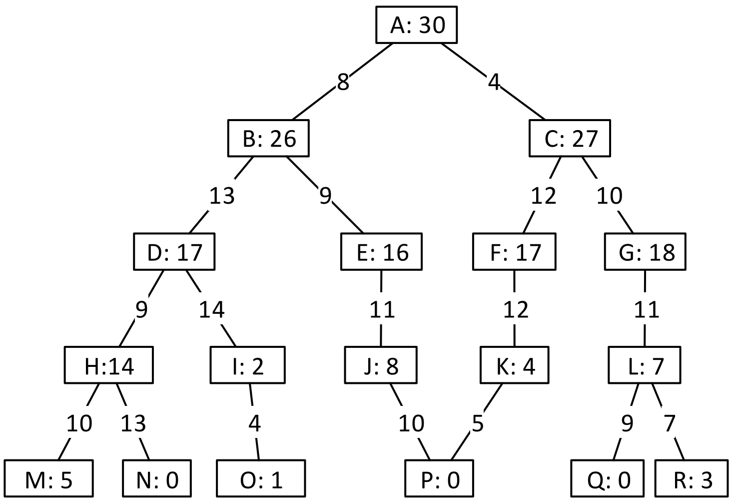
b) Answer the following question with True or False:

1. It is possible to remove the following two primitives from FOPL and still be able to represent all of the same expressions as in standard FOPL: OR and FORALL. Answer = T.
2. In a formal logic, the following expression is false: All 3-headed unicorns in Norway have purple tails. Answer = False (It's a true statement since the antecedent is never true – but correct me if I'm wrong ☺
3. Resolution is an effective (though not necessarily optimal) method for converting logical expressions into horn clauses. Answer = False

4. It is always easier to solve logic problems using backward chaining than forward chaining. Answer = False
5. One of the main benefits of FOPL compared to the vast majority of programming languages is the clean separation between the knowledge and the inference machinery. Answer = True (see page 286, top paragraph).

QUESTION 4

A search graph is shown below. Node A is the initial state and the nodes N, P, and Q are goal states. Each node is labeled with a number corresponding to the value of the heuristic evaluation function for that node, e.g. [A: 30] node with label A has heuristic function value 30.



Answer the following questions:

1. Assuming greedy best-first search strategy, list the nodes in the order that they get expanded. (2 points)
   Answer: Answer: A, B, E, J, P
2. Assuming greedy best-first search strategy, list the nodes along the final path between the initial state and the goal state. (2 points)
   Answer: A, B, E, J, P
3. Assuming A* search strategy, list the nodes in the order that they get expanded. (8 points)
   Answer: A, C, G, L, F, K, P
4. Assuming A* search strategy, list the nodes along the final path between the initial state and the goal state. (2 points)
   Answer: A, C, F, K, P
5. Find a node for which heuristic value is not admissible. Explain why it is not admissible.

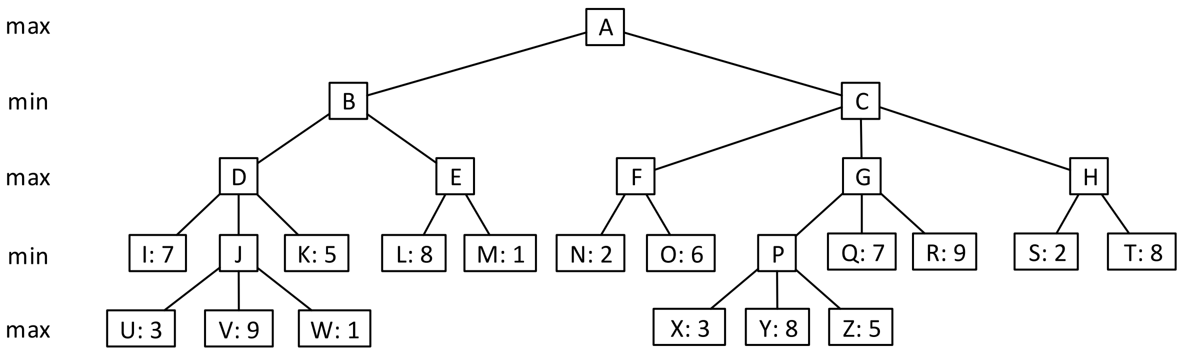
Answer: Node H overestimates the cost to reach the goal node N. (3 points)

6. Find a node for which heuristic value is admissible but not consistent. Explain why it is not consistent. (3 points)
   Answer: Node D is not consistent because h(D) > c(D, I) + h(I)

QUESTION 5

The minimax algorithm

1. What kind of games the minimax algorithm is used for? (2 points)
   Answer: zero-sum games of perfect information (fully observable)
2. Given that the maximum depth of a game tree is *m* with *n* legal moves at each point, what is the time complexity of the minimax algorithm? (2 points)
   Answer: $O(n^m)$
3. Why we may want to use alpha-beta pruning? (2 points)
   Answer: Eliminate part of the game tree from consideration, thus making the search faster
4. Assume the game tree below, in which the evaluation function values are given for the leaf nodes. Assuming an alpha-beta search strategy left to right, which nodes will not be expanded? (9 points)



Answer: G, H, M, P, Q, R, S, T, V, W, X, Y, Z

English. Bokmål på side 7, nynorsk på side 11. I tilfelle du er usikker på betydningen av noen av begrepene (noen er ikke så lette å oversette), se på den engelske versjonen. Answers in red text. If the student gets portions of the answer correct, reward accordingly.

Problem 1

10 points total, 1 point each subtask. Answer each question with *True* or *False*.

(a) Artificial intelligence was born when Alan Turing formulated the Turing Test. False, the field is considered to be born in 1956 with the first AI workshop at Dartmouth College.

(b) Early advances in artificial intelligence were met with skepticism and doubt. False, people were over-enthusiastic.

(c) The agent function maps percept sequences to action. True

(d) The real world is fully observable. False

(e) A taxi driving from A to B in traffic operates in a deterministic environment. False

(f) A simple reflex agent has a small but limited short-term memory. False, a reflex agent has no memory.

(g) Goal-based agents often rely on search and planning to find their goal. True

(h) A utility-based agent is better suited in the real world than a learning agent, since it is able to estimate its own utility. False, a learning agent is better suited to deal with the real world.

(i) Learning is necessary for complex agent behaviour to arise in a multi-agent setting. False, complex behaviour can arise from very simple agents.

(j) Learning helps in a stochastic and continuous environment. True

Problem 2

10 points total, 1 point each subtask. Answer each question with *True* or *False*.

(a) Intelligent agents are supposed to optimize their performance measure. False, they are supposed to maximize their performance measure - to optimize the performance measure does not make sense.

(b) The vacuum world is not a toy problem. False, it is a toy problem since it is an overly simplistic problem, also categorized as such in section 3.2.1.

(c) Redundant paths in a search tree are impossible to avoid. False

(d) GRAPH-SEARCH is the same as TREE-SEARCH, only with history. True

(e) Time complexity and space complexity are the two best ways to evaluate the performance of an algorithm. False, you must also consider whether it is complete and optimal in addition to the two mentioned above.

(f) Blind search is also known as heuristic search. False

(g) A graph with branching factor b and depth d can be solved in most cases by uninformed search. False, since the time/space complexity will be exponential, it cannot be solved in most cases by uninformed search. It can be solved in a few cases where b and d are small.

(h) Bidirectional search reduces the time complexity with the square root. True

(i) An heuristic estimates the cheapest cost from one node to the goal node, even if the path is impossible to execute. True

(j) A* is the best known form of best-first search. True

Problem 3

10 points in total, points indicated for each subtask. Express tasks a, b and e using first-order logic, otherwise follow the instructions.

(a) (1 point) All lectures are fun. $\forall x Lecture(x) \Rightarrow Fun(x)$

(b) (1 point) There exists a lecture that is not fun. $\exists x Lecture(x) \wedge \neg Fun(x)$

(c) (2 points) Siblinghood is a symmetric relationship (i.e. write how to express this relationship in first-order logic). $\forall x, y Sibling(x, y) \Leftrightarrow Sibling(y, x)$

(d) (2 points) Express that "everyone dislikes vegetables" in two ways, using the "FOR ALL" quantifier in one sentence and "THERE EXISTS" quantifier in the other sentence, and the same predicate in both sentences. $\forall x \neg Likes(x, Vegetables)$ is the same as $\neg \exists x Likes(x, Vegetables)$

(e) (4 points) Some siblings have different parents.
$\exists x, y Sibling(x, y) \wedge (\exists p Parent(p, x) \wedge \neg Parent(p, y))$

Problem 4

10 points in total, 2 points each subtask.

(a) What is another word for *unification*? Substitution. See 9.2.2 in AIMA, unification is described as $UNIFY(p, q) = \theta$ where $SUBST(\theta, p) = SUBST(\theta, q)$

(b) What is the purpose of *Universal Instantiation*? Infer any sentence obtained by substituting a ground term for the variable, it replaces a variable with a term to form a new sentence.

(c) *Existential Instantiation* is a special case of a more general process. What is the name of this general process? Skolemization.

(d) What is the best known programming language that builds on backward chaining? Prolog

(e) What is conjunctive normal form, and what is it used for? CNF is a conjunction of clauses where each clause is a disjunction of literals. It is used for first-order resolution.

Problem 5

15 points. Points indicated in each subtask.

(a) (2 points) What is the name of the tree structure in the figure below? Minimax tree.

(b) (2 points) What does it represent? An adversarial game.

(c) (5 points) Write down the node values that are missing in a breadth-first manner. 5 4 5 3 4 7 5 5 6 3 4 7

(d) (6 points) Apply alpha-beta pruning and write down the leaf nodes that won't get expanded. D J M N O P

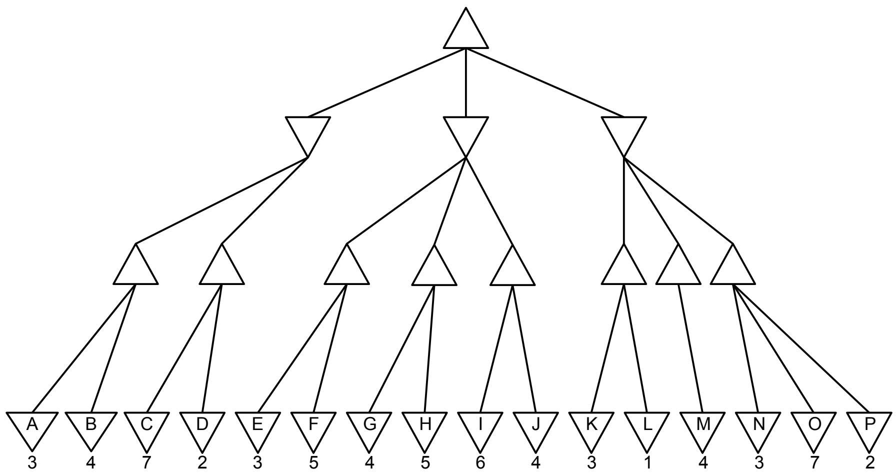
Problem 6

20 points. Points indicated in each subtask.

(a) (2 points) A* belongs to which class of search algorithms? Informed.

(b) (2 points) What is the worst-case time complexity of A*? Exponential, if the search space is unbounded. $O(b^d)$ It is sufficient to mention that it is exponential.

(c) (2 points) What does it mean to use an *admissible heuristic* in A* search? The heuristic must not overestimate the distance to the goal, i.e. it must be an optimistic estimate.



(d) (9 points) In the figure below, each node is labeled with the heuristic function for that node, e.g. node A has heuristic function value 40. Apply A* search to the tree and write down $f(n) = g(n) + h(n)$ for each node the algorithm visits, e.g. the starting node would be written $A(40)$. Assume we visit child nodes from left to right. A(40) B(42) C(35) F(34) G(33) L(34) M(28) V(39) T(36) U(34) Note: if the student has included K(35) after V(39) this is also OK. UNIFORM-COST-SEARCH in Figure 3.14 of AIMA says that the algorithms pops a node from the frontier with the lowest cost, so this will depend on the implementation of the ordering when two nodes are of equal value.

(e) (2 points) List the nodes along the final path between the start state and the end state, using A* search. A C G L U

(f) (3 points) What is the biggest drawback of the A* algorithm? All the expanded nodes are kept in memory, so it will run out of space before it runs out of time. Therefore it does not scale well.

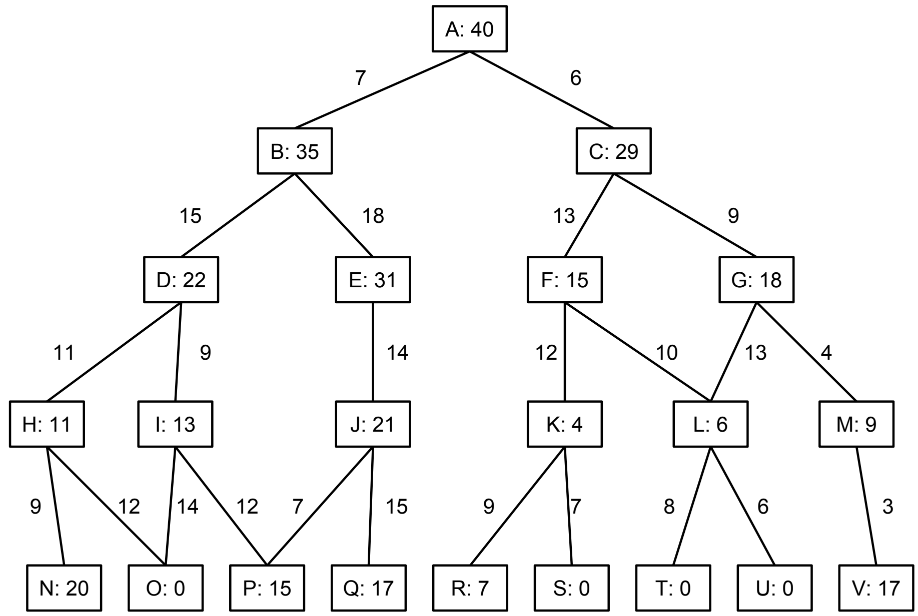
Problem 7

15 points. Points indicated in each subtask.

(a) (3 points) How are states and goals defined in STRIPS? States: first-order predicates over objects. Goals: conjunction of literals.

(b) (3 points) How are actions defined in STRIPS? Preconditions and effects.

(c) (9 points) You are unhappy and poor, but you are also hardworking and lucky. You want to be happy and it is possible to buy happiness. Write



down a representation of this domain in the STRIPS language, i.e. the intial state, goal state, and the actions required to achieve the goal state. Note: buying happiness will not make you poor, you stay rich.

Initial state:
$\neg Happy(You) \wedge \neg Rich(You) \wedge Hardworker(You) \wedge Lucky(You)$

Goal state:
$Happy(You) \wedge Rich(You)$

Actions:

$Action(GetRich(x),$
$PRECOND : Hardworker(x) \wedge Lucky(x) \wedge \neg Rich(You)$
$DELETE - LIST : \neg Rich(You)$
$ADD - LIST : Rich(x))$

$Action(BuyHappiness(x),$
$PRECOND : Rich(x) \wedge \neg Happy(x)$
$DELETE - LIST : \neg Happy(x)$
$ADD - LIST : Happy(x))$

Note: In STRIPS you cannot use negative literals (i.e. atomic sentences, such as True, False, P, Q). However you can use *predicates* (as done in this example), this is also shown as an example in lecture 9, page 9. What separates it from PDDL in this solutions is the explicit use of ADD and DELETE lists. However, the student should be rewarded for solutions that incorporate pre- and post-conditions, even though some syntax might be erroneous.

Problem 8

10 points. Points indicated in each subtask.

(a) (2 points) What are the best known examples of information retrieval systems? Web search engines.

(b) (3 points) What are the three essential elements in information retrieval? 1) A corpus of documents, 2) a query, 3) a result set of (ranked) relevant documents.

(c) (2 points) What separates information extraction from information retrieval? Information extraction is about acquiring knowledge from documents, whereas information retrieval is about finding the relevant documents given a query. The former builds upon the results of the latter.

(d) (3 points) What is the limiting factor in information extraction? The actual natural language processing, currently there does not exist an AI that understands text on a human level, in particular when it comes to ambiguity.

Oppgave 1

10 poeng totalt, 1 poeng hver deloppgave. Svar hver deloppgave med *True* eller *False*.

(a) Kunstig intelligens ble født da Alan Turing formulerte Turing-testen.

(b) De første fremskrittene i kunstig intelligens ble møtt med skepsis og tvil.

(c) Agent-funksjonen overfører oppfattelses-sekvenser til handlinger.

(d) Den virkelige verden er fullt observerbar.

(e) En drosje som kjører fra A til B i trafikken opererer i et deterministisk miljø.

(f) En enkel refleksiv agent har en lite men begrenset korttidshukommelse.

(g) Målrettede agenter er ofte avhengig av søk og planlegging for å nå sine mål.

(h) En nytte-basert agent er bedre tilpasset den virkelige verden enn en lærende agent, siden den er i stand til å estimere sin egen nytte.

(i) Læring er nødvendig for at kompleks agentoppførsel skal oppstå i en multi-agentsituasjon.

(j) Læring hjelper i et stokastisk og kontinuerlig miljø.

Oppgave 2

10 poeng totalt, 1 poeng hver deloppgave. Svar hver deloppgave med *True* eller *False*.

(a) Det er meningen at intelligente agenter skal optimalisere sitt ytelsesmål.

(b) Støvsugerverden er ikke et leke-problem.

(c) Overflødige stier i et søketre er umulige å unngå.

(d) GRAF-SØK er det samme som TRE-SØK, bare med historie.

(e) Tidskompleksitet og plasskompleksitet er de to beste måtene for å evaluere ytelsen til en algoritme.

(f) Blindt søk er også kjent som heuristisk søk.

(g) En graf med grenfaktor b og dybde d kan løses i de fleste tilfeller av uinformert søk.

(h) Dobbeltrettet søk reduserer tidskompleksiteten med kvadratroten.

(i) En heuristikk estimerer den billigste kostnaden fra en node til målnoden, selv om stien er umulig å utføre.

(j) A* er den mest kjente formen for beste-først søk.

Problem 3

10 poeng totalt, poengsum er indikert i hver deloppgave. Deloppgave *a*, *b* og *e* skal uttrykkes med første-ordens logikk, ellers følg instruksjonene.

(a) (1 poeng) Alle forelesninger er morsomme.

(b) (1 poeng) Det fins en forelesning som ikke er morsom.

(c) (2 poeng) Å være søsken er et symmetrisk forhold (dvs skriv hvordan man uttrykker dette forholdet i første-ordens logikk).

(d) (2 poeng) Uttrykk at "alle misliker grønnsaker" på to måter, ved å bruke "FOR ALLE" kvantifikatoren i en setning og "DET FINS" kvantifikatoren i den andre setningen, og det samme predikatet i begge setningene.

(e) (4 poeng) Noen søsken har forskjellige foreldre.

Oppgave 4

10 poeng totalt, 2 poeng for hver deloppgave.

(a) Hva er et annet ord for *unifisering*?

(b) Hva er formålet med *Universell Instansiering*?

(c) *Eksistensiell Instansiering* er et spesial-tilfelle av en mer generell prosess. Hva heter denne mer generelle prosessen?

(d) Hva er det mest kjente programmeringsspråket som bygger på bakover-kjeding?

(e) Hva er konjunktiv normalform, og hva brukes det til?

Problem 5

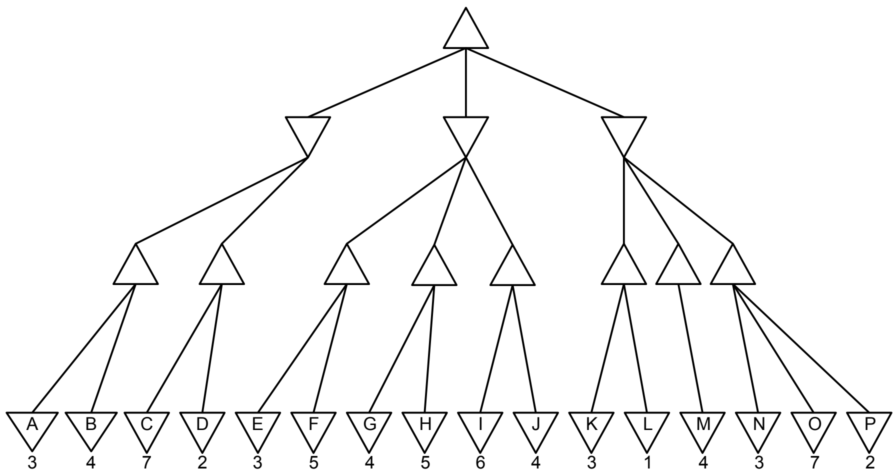
15 poeng totalt. Poeng indikert på hver deloppgave.

(a) (2 poeng) Hva heter trestrukturen i figuren nedenfor?

(b) (2 poeng) Hva representerer den?

(c) (5 poeng) Skriv ned nodeverdiene som mangler på bredde-først vis.

(d) (6 poeng) Anvend alpha-beta avskjæring og skriv ned løvnodene som ikke blir ekspandert.



Oppgave 6

20 poeng. Poeng indikert i hver deloppgave.

(a) (2 poeng) A* tilhører hvilken klasse søkealgoritmer?

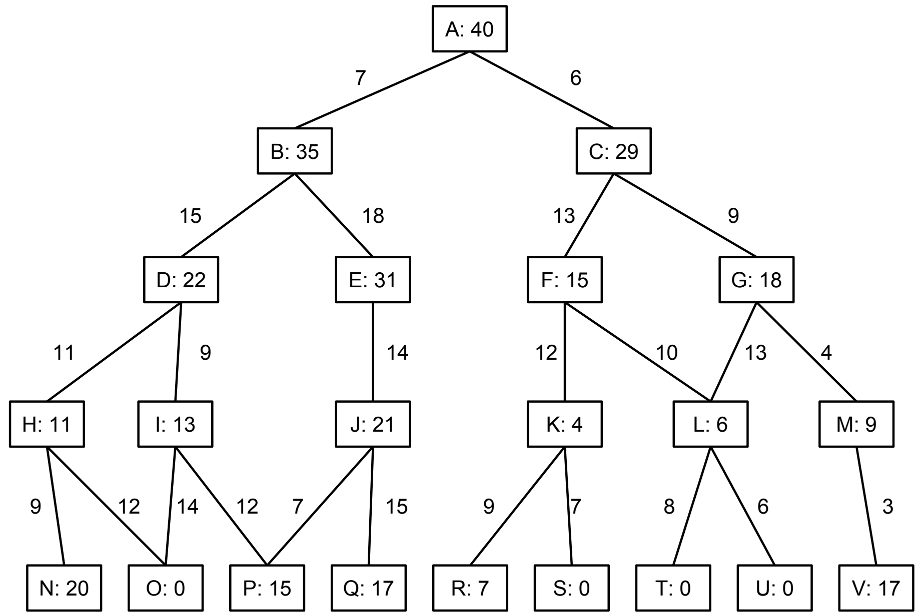
(b) (2 poeng) Hva er den verste tidskompleksiteten til A*?

(c) (2 poeng) Hva betyr det å bruke en *tillatt heuristikk* i A* søk?

(d) (9 poeng) I figuren nedenfor er hver node markert med den heuristiske funksjonsverdien, for eksempel har node A heuristisk funksjonsverdi 40. Anvend A*-søk på treet og skriv ned $f(n) = g(n) + h(n)$ for hver node algoritmen besøker, for eksempel vil startnoden bli skrevet $A(40)$. Anta at vi besøker barn-noder fra venstre til høyre.

(e) (2 poeng) Skriv nodene i rekkefølge langs den endelige stien mellom start-tilstanden og slutt-tilstanden.

(f) (3 poeng) Hva er den største ulempen med A*-algoritmen?



Oppgave 7

15 poeng totalt. Poeng indikert på hver deloppgave.

(a) (3 poeng) Hvordan er tilstander og mål definert i STRIPS?

(b) (3 poeng) Hvordan er handlinger definert i STRIPS?

(c) (9 poeng) Du er ulykkelig og fattig, men du er også hardtarbeidende og heldig. Du har lyst til å være lykkelig og det er mulig å kjøpe lykke. Skriv ned en representasjon av dette domenet ved bruk av STRIPS-språket, dvs starttilstand, måltilstand og handlingene som er nødvendige for å oppnå måltilstanden. NB: Å kjøpe lykke vil ikke gjøre deg fattig, du forblir rik.

Problem 8

10 poeng. Poeng indikert i hver deloppgave.

(a) (2 poeng) Hva er de mest kjente eksemplene på informasjonshentesystemer?

(b) (3 poeng) Hva er de tre essensielle elementene i informasjonshenting?

(c) (2 poeng) Hva skiller informasjonsekstraksjon fra informasjonshenting?

(d) (3 poeng) Hva er den begrensende faktoren i informasjonsekstraksjon?

Oppgåve 1

10 poeng totalt, 1 poeng kvar deloppgåve. Svar kvar deloppgåve med *True* eller *False*.

(a) Kunstig intelligens blei født da Alan Turing formulerte Turing-testen.

(b) Dei første fremskritta i kunstig intelligens blei møtt med skepsis og tvil.

(c) Agent-funksjonen overførar oppfattelses-sekvensar til handlingar.

(d) Den verkelege verda er fullt observerbar.

(e) Ein drosje som kjører fra A til B i trafikken opererar i eit deterministisk miljø.

(f) Ein enkel refleksiv agent har ein lite men begrensa korttidshukommelse.

(g) Målrettede agentar er ofte avhengig av søk og planlegging for å nå sine mål.

(h) Ein nytte-basert agent er betre tilpassa den verkelege verda enn ein lærende agent, sidan den er i stand til å estimera si eiga nytte.

(i) Læring er nødvendig for at kompleks agentoppførsel skal oppstå i ein multiagentsituasjon.

(j) Læring hjelp i eit stokastisk og kontinuerlig miljø.

Oppgåve 2

10 poeng totalt, 1 poeng kvar deloppgåve. Svar kvar deloppgåve med *True* eller *False*.

(a) Det er meininga at intelligente agentar skal optimalisera sitt ytelsesmål.

(b) Støvsugerverda er ikkje eit leke-problem.

(c) Overflødige stiar i eit søketre er umoglege å unngå.

(d) GRAF-SØK er det same som TRE-SØK, bare med historie.

(e) Tidskompleksitet og plasskompleksitet er dei to beste måtane for å evaluere ytelsen til ein algoritme.

(f) Blindt søk er også kjent som heuristisk søk.

(g) Ein graf med grenfaktor b og dybde d kan løses i dei fleste tilfella av uinformert søk.

(h) Dobbeltretta søk reduserar tidskompleksiteten med kvadratrota.

(i) Ein heuristikk estimerar den billigste kostnaden fra ein node til målnoden, selv om stien er umogleg å utføre.

(j) A* er den mest kjente formen for beste-først søk.

Problem 3

10 poeng totalt, poengsum er indikert i kvar deloppgåve. Deloppgåve *a*, *b* og *e* skal uttrykkes med første-ordens logikk, ellers følg instruksjonane.

(a) (1 poeng) Alle forelesningar er morosame.

(b) (1 poeng) Det fins ein forelesning som ikkje er morosam.

(c) (2 poeng) Å være sysken er eit symmetrisk tilhøve (dvs skriv korleis man uttrykker dette tilhøvet i første-ordens logikk).

(d) (2 poeng) Uttrykk at "alle mislikar grønsaker" på to måtar, ved å bruke "FOR ALLE" kvantifikatoren i ein setning og "DET FINS" kvantifikatoren i den andre setningen, og det samme predikatet i begge setningane.

(e) (4 poeng) Nokre sysken har forskjellege foreldre.

Oppgåve 4

10 poeng totalt, 2 poeng for kvar deloppgåve.

(a) Kva er eit annet ord for *unifisering*?

(b) Kva er føremålet med *Universell Instansiering*?

(c) *Eksistensiell Instansiering* er eit spesial-høve av ein meir generell prosess. Kva heiter denne meir generelle prosessen?

(d) Kva er det mest kjente programmeringsspråket som byggjar på bakoverkjeding?

(e) Kva er konjunktiv normalform, og kva brukes det til?

Problem 5

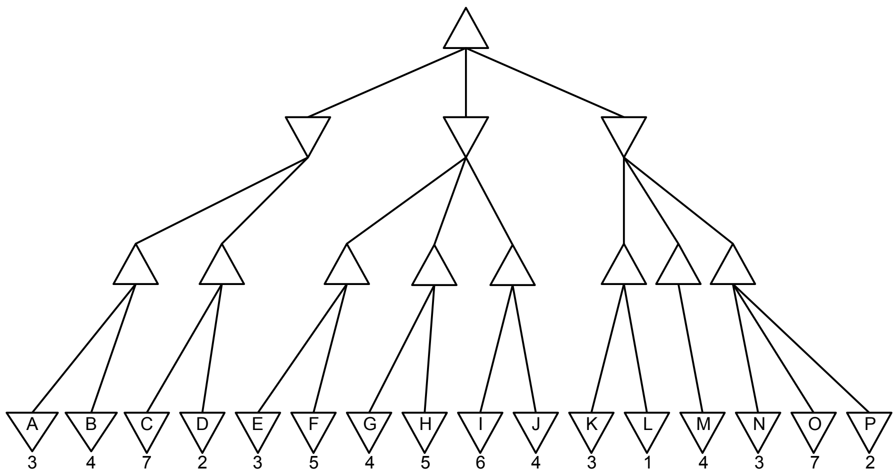
15 poeng totalt. Poeng indikert på kvar deloppgåve.

(a) (2 poeng) Kva heiter trestrukturen i figuren nedanfor?

(b) (2 poeng) Kva føresteller den?

(c) (5 poeng) Skriv ned nodeverdiane som manglar på bredde-først vis.

(d) (6 poeng) Anvend alpha-beta avskjæring og skriv ned løvnodane som ikkje blir ekspanderte.



Oppgåve 6

20 poeng. Poeng indikert i kvar deloppgåve.

(a) (2 poeng) A* tilhører kva for ein klasse søkelagoritmar?

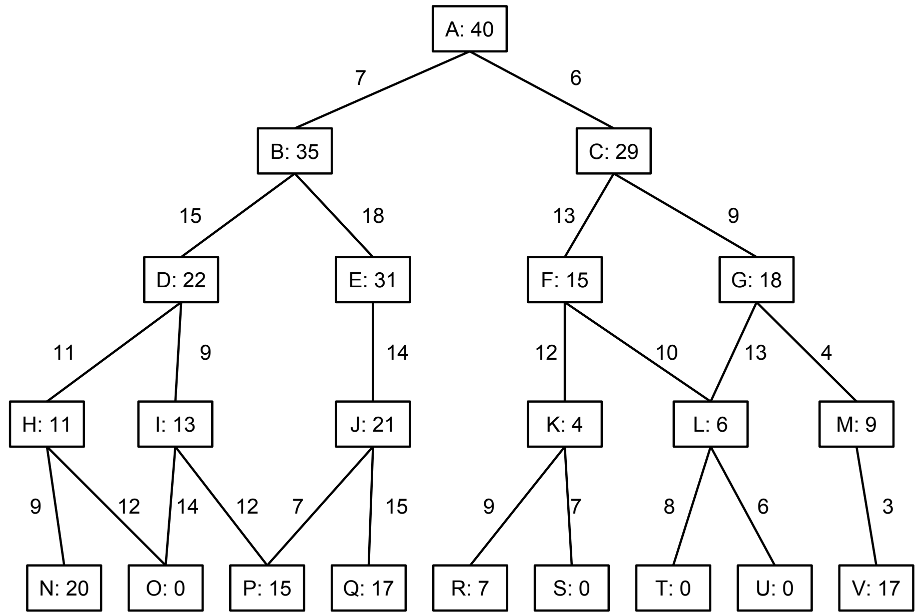
(b) (2 poeng) Kva er den verste tidskompleksiteta til A*?

(c) (2 poeng) Kva betyr det å bruke ein *tillatt heuristikk* i A* søk?

(d) (9 poeng) I figuren nedanfor er kvar node markert med den heuristiske funksjonsverdien, til dømes har node A heuristisk funksjonsverdi 40. Anvend A*-søk på treet og skriv ned $f(n) = g(n) + h(n)$ for kvar node algoritmen vitjar, til dømes vil startnoden bli skrevet $A(40)$. Anta at vi vitjar barn-noder frå venstre til høgre.

(e) (2 poeng) Skriv nodene i rekkefølge langs den endelege stien mellom start-tilstanden og slutt-tilstanden.

(f) (3 poeng) Kva er den største ulempa med A*-algoritmen?



Oppgåve 7

15 poeng totalt. Poeng indikert på kvar deloppgåve.

(a) (3 poeng) Korleis er tilstandar og mål definert i STRIPS?

(b) (3 poeng) Korleis er handlinger definerte i STRIPS?

(c) (9 poeng) Du er ulukkeleg og fattig, men du er også hardtarbeidande og heldig. Du har lyst til å vere lykkeleg og det er muleg å kjøpe lykke. Skriv ned ein representasjon av dette domenet ved bruk av STRIPS-språket, dvs starttilstand, måltilstand og handlingane som er nødvendige for å oppnå måltilstanden. NB: Å kjøpe lykke vil ikkje gjera deg fattig, du forblir rik.

Problem 8

10 poeng. Poeng indikert i kvar deloppgåve.

(a) (2 poeng) Kva er dei mest kjente eksemplane på informasjonshentesystemar?

(b) (3 poeng) Kva er dei tre essensielle elementa i informasjonshenting?

(c) (2 poeng) Kva skil informasjonsekstraksjon frå informasjonshenting?

(d) (3 poeng) Kva er den begrensande faktoren i informasjonsekstraksjon?

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Introduksjon til Kunstig Intelligens (TDT4136)

30th November 2015
Tid: 09:00 – 13:00

Language: English-Bokmål-Nynorsk
Aid - Tillatte hjelpemidler: D

No printed or hand written material is allowed. Simple calculator is allowed. Ingen trykte eller håndskrevne hjelpemidler tillatt.
Bestemt, enkel kalkulator tillatt.

English. Bokmål på side xx, nynorsk på side xx. I tilfelle du er usikker på betydningen av noen av begrepene (noen er ikke så lette å oversette), se på den engelske versjonen.

Dersom du mener at opplysninger mangler i en oppgaveformulering, gjør kort rede for de antagelser og forutsetninger som du finner nødvendige.

Problem 1 (20 pts, 2pts each question)

Answer the following questions with TRUE or FALSE.

a) Knitting is a fully observable, episodic, stochastic, static and exciting agent environment.
ANSWER: False. not episodic, not stochastic

b) Procedural attachment is used in semantic networks.
ANSWER: True .

c) Ontology is not a key component in simple-reflex agents.
ANSWER: True.

d) *Recall* is an evaluation metric used in information retrieval that measures the proportion of returned documents that are truly relevant
ANSWER: False. This is precision

e) Simulated annealing is a local search method.
ANSWER: True

f) Term Frequency (TF) defines the count of a term t in a collection of documents.
ANSWER: False. In a singe document.

g) A common heuristic function for 8-puzzle game is Manhattan distance which is the sum of the distances of the tiles to their goal positions.
ANSWER: TRUE

h) If both H1 and H2 are admissible heuristics for a problem and H2<H1, then H2 is a better heuristic.
ANSWER: False

i) An agent must think like a human in order to pass the Turing test.
ANSWER: False. It has to act like a human.

j) Iterative deepening search is optimal if step-costs is a constant, the search-space is finite and a goal exists. ANSWER: True .

Problem 2 (15 pts, 3 pts each question)
Choose the correct answers (one for each question) to the questions below.

a) Suppose the following action schema in a planning system for 8-puzzle.

$Action(Slide(t, s_1, s_2),$
  PRECOND : $On(t, s_1) \wedge Tile(t) \wedge Blank(s_2) \wedge Adjacent(s_1, s_2)$
  EFFECT : $On(t, s_2) \wedge Blank(s_1) \wedge \neg On(t, s_1) \wedge \neg Blank(s_2))$

Which of the following needs to be removed from the action schema in order to get "number-of-misplaced-tiles" heuristic?

A. $Blank(s_1)$

B. $Blank(s_2)$

C. $Adjacent(s_1, s_2)$

D. $Blank(s_2) \wedge Adjacent(s_1, s_2)$

E. None of the above

ANSWER: d - $Blank(s_2) \wedge Adjacent(s_1, s_2)$.

b) We look at a Constraint Satisfaction Problem (CSP) with the three variables X, Y and Z. Let the domain for each of these variables be the set of integers from 1 to 3:

$D_X = D_Y = D_Z = \{1, 2, 3\}$

Let the following binary constraint $C_{X,Y}$ apply between X and Y, and $C_{Y,Z}$ between Y and Z:

$C_{X,Y} = [(1, 1), (2, 1), (2, 2), (3, 1), (3, 2), (3, 3)]$

$C_{Y,Z} = [(2, 1), (3, 1), (3, 2)]$

After running AC-3, what is the domain of X?

A. $\{1, 2, 3\}$

B. $\{2, 3\}$

C. $\{1, 3\}$

D. $\{1, 2\}$

E. $\{1\}$

F. $\{2\}$

G. $\{3\}$

H. $\{\}$

ANSWER: B
As described in Chapter 6.1 in the textbook (7.1 in the green version), a constraint specifies the *valid* combinations of values between two given variables. Given that there is a constraint between two variables, any combination of values that is not explicitly listed in the constraint will thus not be valid. Therefore, according to $C_{X,Y}$ above, X has the following valid values:

- 1, if Y is 1
- 2, if Y is 1 or 2
- 3, if Y is 1, 2 or 3

Y's domain is currently $\{1, 2, 3\}$, so we cannot yet remove any values from X's domain. However, we then move on to $C_{Y,Z}$ and see if any values can be removed from Y's domain. According to $C_{Y,Z}$, Y has the following valid values:

- 2, if Z is 1
- 3, if Z is 1 or 2

Hence, 1 is not a valid value for Y's domain, so the domain is now reduced to $\{2, 3\}$. A crucial point is that we now need to check $C_{X,Y}$ again, to see if there are any consequences for X's domain from the changes in Y's domain. Indeed there is; with 1 removed from Y's domain, 1 is no longer a valid value for X either. X's domain is thus $\{2, 3\}$.

c) Z is then set to 2 in the CSP from the previous question, and AC-3 is run again. What is now the domain of X?

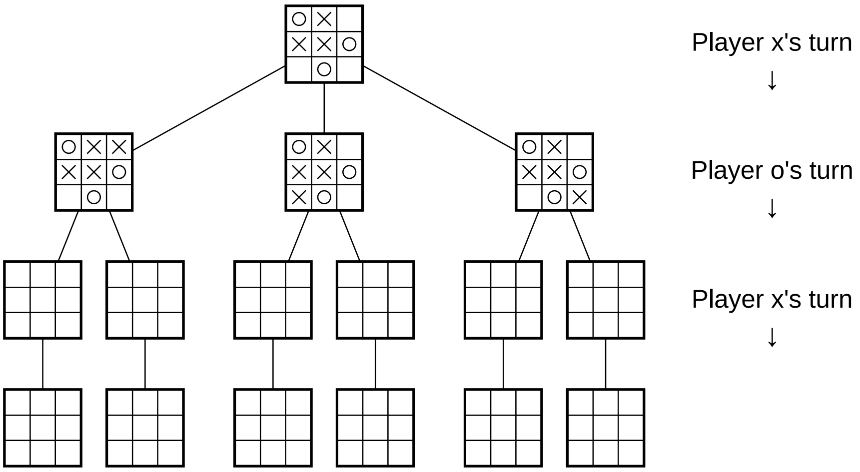
A. $\{1, 2, 3\}$
B. $\{2, 3\}$
C. $\{1, 3\}$
D. $\{1, 2\}$
E. $\{1\}$
F. $\{2\}$
G. $\{3\}$
H. $\{\}$

ANSWER: G
Recall that, according to $C_{Y,Z}$, Y has the following valid values:

- 2, if Z is 1
- 3, if Z is 1 or 2

Z is 2, so the only valid value for Y is 3. According to $C_{X,Y}$, then 3 is also the only valid value for X.

d) Consider the following (incomplete) game tree for tic-tac-toe. Tic-tac-toe is a two-player game where players "x" and "o" take alternating turns to place their respective symbols in an empty cell on the 3×3 game board, with the goal of getting three in a row (horizontally, vertically or diagonally):



Which one of the following statements is true?

A. Player x is guaranteed to win

B. Player o is guaranteed to win

C. Player x can win, but only if player o plays suboptimally

D. Player o can win, but only if player x plays suboptimally

E. Either player can win, if the other player plays suboptimally

F. Neither/none of the players can win

ANSWER: C

e) Which of the following may be most useful in generation of a semantic network automatically from documents?

A. Information retrieval

B. Sentiment analysis

C. Syntactic parsing

D. Information extraction

E. none of the above.

ANSWER: D. information extraction.

Problem 3 (15 points)

a) (2 points) For the following sentence in English, is the accompanying sentence in first-order logic a good translation? If yes, answer yes. If no, explain why not.

No two NTNU students have the same ID number.

$\neg\exists x, y, z(NTNUStudent(x) \wedge NTNUStudent(y) \wedge \neg(x = y)) \implies (IDNum(x, z) \wedge IDNum(y, z))$

ANSWER: This is NOT correct because it uses $\implies$ instead of $\wedge$ when quantified by $\exists$.

CORRECT: $\neg\exists x, y, z NTNUStudent(x) \wedge NTNUStudent(y) \wedge \neg(x = y) \wedge (IDNum(x, z) \wedge IDNum(y, z))$

b) (2 points) For the following sentence in English, is the accompanying sentence in first-order logic a good translation? If yes, answer yes. If no, explain why not.

All mammals except whales are similar to humans.
$\forall x, y Mammal(x) \wedge \neg Whale(x) \implies Mammal(y) \wedge Human(y) \wedge Similar(x, y)$

ANSWER: This is NOT correct because it says that if there is at least one mammal that is not a whale, then every mammal has to be a human.

CORRECT: $\forall x, y Mammal(x) \wedge \neg Whale(x) \wedge Mammal(y) \wedge Human(y) \implies Similar(x, y)$

c) (2 points) Consider the following knowledge base containing four sentences in propositional logic: $A \implies (B \vee C)$

$\neg A \implies (B \vee C)$

$\neg C$

$(B \vee D) \implies E$

Can these four sentences be converted to a set of Horn clauses? If yes, write them down; if not, explain why not.

ANSWER: No because the first sentence has two literals on the right hand side, meaning that the CNF has two positive literals in it.

d) (2 points) Consider the following knowledge base containing four sentences in propositional logic: $A \implies (B \vee C), \neg A \implies (B \vee C), \neg C, (B \vee D) \implies E$

Convert the four sentences above into conjunctive normal form(CNF) and show the result as a set of clauses.

ANSWER:

$\neg A \vee B \vee C, A \vee B \vee C, \neg C, \neg B \vee E, \neg D \vee E$

e) (3 points) Is the following sentence (1) the correct skolemization (i.e., elimination of existential quantificator) of the sentence $\forall x Person(x) \iff \exists y Heart(y) \wedge Has(x, y)$?

(1) $\forall x Person(x) \implies Heart(H1) \wedge Has(x, H1)$.

Why not? Write down the correct one.

ANSWER: No because this means that everone has the same heart called H1. Heart should be a function of a person.

CORRECT: (1)$\forall x Person(x) \implies Heart(H(x)) \wedge Has(x, H(x))$.

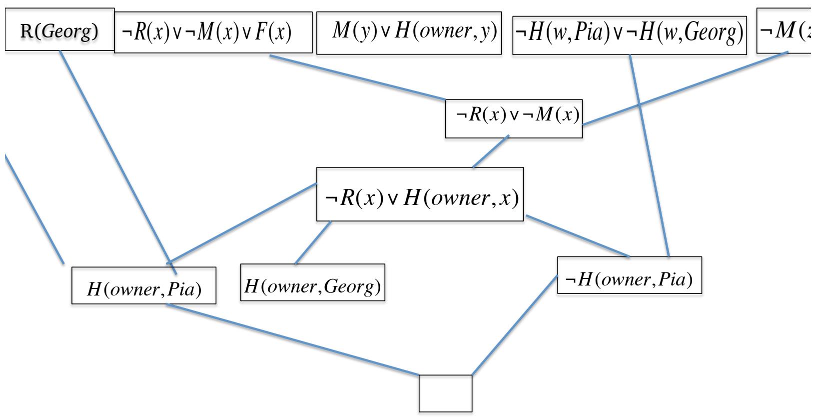
f) (4 points) Suppose the following facts are in the knowledge base:

- Pia works in a restaurant
  $R(Pia)$
- Georg works in a restaurant
  $R(Georg)$
- Anyone who works in a restaurant and makes a big mistake is fired
  $\forall x R(x) \wedge M(x) \implies F(x)$
- The restaurant owner is happy with anyone who doesn't make a big mistake
  $\forall y \neg M(y) \implies H(owner, y)$
- Anyone who is happy with Pia is unhappy with Georg
  $\forall w H(w, Pia) \implies \neg H(w, Georg)$

Using resolution refutation, prove that "there exists someone who makes a big mistake and is fired". Show your proof on a tree starting from the boxes in the figure below. Copy the boxes into your answer sheet and fill in the last box. Apply resolution and clearly indicate the clauses being resolved in each step. Show also the binding of variables in each step/link.

$\boxed{R(Pia)}$ $\boxed{R(Georg)}$ $\boxed{\neg R(x) \vee \neg M(x) \vee F(x)}$ $\boxed{M(y) \vee H(owner, y)}$ $\boxed{\neg H(w, Pia) \vee \neg H(w, Georg)}$ $\boxed{\ldots\ldots\ldots}$

ANSWER:



Problem 4 (10 points)

NOTE: There is a correction in the points of the sub-questions. (a) should be 4 points and (b) is 2 points.

We changed the rules of the wumpus world. First of all, we are dealing only with wumpuses, not with gold, breeze, stench, etc. There may be more than one wumpus in the grid and they may be in any square. In the beginning of the game all squares are blank and the agent does not know which square(s) contains a wumpus. When the agent clicks on a square with a wumpus, she loses the game. If the square that the agent clicked on does not contain a wumpus, a number will appear on that square indicating the number of wumpuses adjacent to the square. Adjacency here means the four squares to the immediate left, right, top and bottom, excluding the diagonals. The goal of the game is to click on all squares which do not have wumpuses. Suppose you are playing the game in the following figure showing the current state of the grid. In the figure, squares marked *a, b, c*, and *d* are not clicked on yet. You may refer to these squares by these variables. The upper-left square is labeled 1, meaning that it is adjacent to exactly one wumpus. The other squares show the number of wumpuses in their adjacent squares.

1	a
b	2
d	c

a) (4 points) Represent the current state of the grid using propositional logic. Use the predicate W(s) to express that square s contains a wumpus, and $\neg W(s)$ s not having a wumpus.

b) (2 points) Suppose you click on the lower-left square (which is a d in the beginning, see the figure) and number two (2) is revealed. This means that there is no wumpus in that square but two of squares adjacent to it have wumpuses. Represent this situation of the grid using propositional logic.

c) (4 points) Prove $\neg W(a)$, that is, the square labeled a does not contain a wumpus. For this use the combination of initial knowledge base and the new knowledge obtained by clicking on d. Show your proof by resolution refutation on a drawing.

ANSWER:

a) **First part** (upper left is 1):

$(W(a) \wedge \neg W(b)) \vee (W(b) \wedge \neg W(a))$

Or one of the equivalent expressions:

- $W(a) \Leftrightarrow \neg W(b)$
- $(W(a) \Rightarrow \neg W(b)) \wedge (\neg W(b) \Rightarrow W(a))$
- $(W(a) \vee W(b)) \wedge (\neg W(a) \vee \neg W(b))$

- $(W(a) \lor W(b)) \land \neg(W(a) \land W(b))$
- ...

Second part (middle right is 2):

$(W(a) \land W(b) \land \neg W(c)) \lor$
$(W(a) \land W(c) \land \neg W(b)) \lor$
$(W(b) \land W(c) \land \neg W(a))$

Or: $((W(a) \land W(b)) \lor (W(a) \land W(c)) \lor (W(b) \land W(c))) \land \neg(W(a) \land W(b) \land W(c))$

Or even simply $W(c)$, *assuming the first part is correct.*

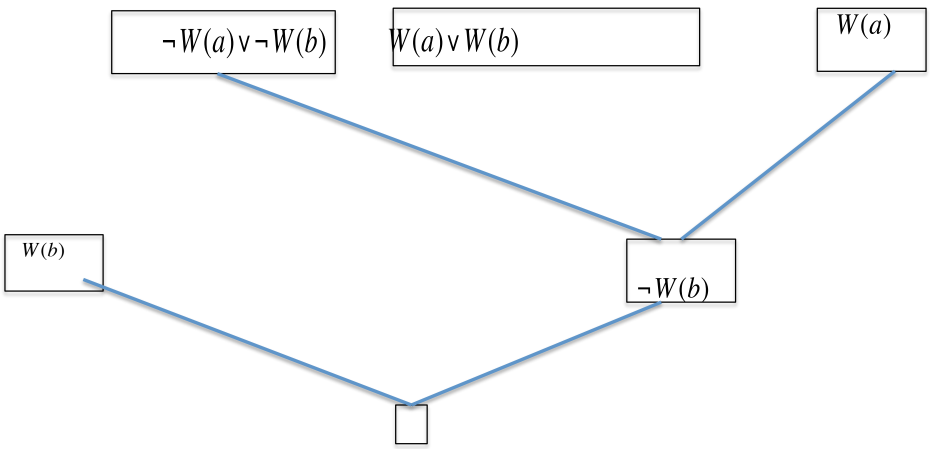
b) Both b and c should have a wumpus. Therefore we can write

$W(b) \land W(c)$

c) First convert the KB into CNF form. E.g.,

$(W(a) \lor W(b)) \land (\neg W(a) \lor \neg W(b))$
In CNF form: $(W(a) \lor W(b)) \land (\neg W(a) \lor \neg W(b))$ etc.

To prove, add the contradiction (i.e. W(a)) of the query to the KB. Then resolve W(a) with $(\neg W(a) \lor \neg W(b))$ to conclude $\neg W(b)$.
Apply AND-elimination on W(b) $\land W(c)$ to get W(b). Resolve this with $\neg W(b)$ obtained above to get the contradiction.



Problem 5 (10 points)

This is a planning problem to be solved using GraphPlan algorithm. The initial state is represented as $\{R, H, Q\}$. The goal state is $\{D, P, C\}$. There are four actions (Cx, Wx, Tx, and Vx) of which preconditions and effects (in terms of add and delete) are shown in the following figure.

Action	Precond	Add	Delete
Cx	{H}	{D}	{}
Wx	{Q}	{P}	{}
Tx	{}	{C}	{H , R}
Vx	{}	{C}	{Q , R}

a) (1 point) Under which conditions does a plan graph level off (i.e., stops expanding)?

b) (3 points) Starting from state level zero (i.e., S_0) **draw** the graph of the plan (i.e, the state and the action levels with mutex relations) applying the GraphPlan algorithm. Expand the graph as long as it is necessary for obtaining a plan. Use "NOP" for the persistence (no operation/maintenance) actions.

c) (3 points) Is it possible to find a plan for this problem at state level S_1? In case it is possible, write down the plan. In case it is not possible, justify your answer by writing down the mutex relation(s) that hinders the extraction of a plan from the graph. Write down each mutex relation (both those between the states and between the actions) and explain why it is mutex.

d) (3 points) Are the following plans in (1) and (2) below valid plans, according to your answers above? Explain why or why not.

1. $Cx \rightarrow Wx \rightarrow Tx$
2. $Wx \rightarrow Cx \rightarrow Tx$

ANSWER:

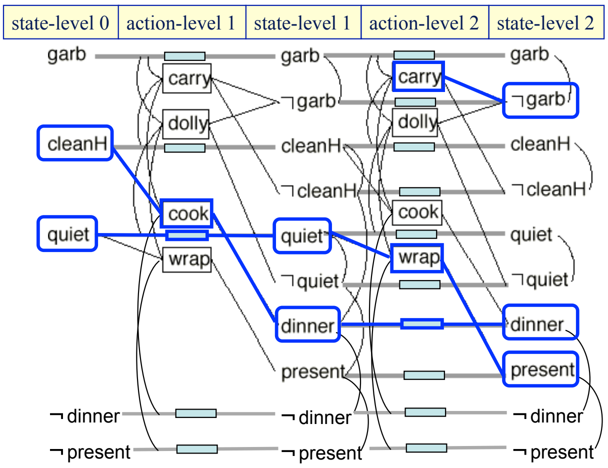
In order to leave off, the last state must include all goals in the goal state without mutex between them, and when back-searching on the graph there must be actions without mutex at each action level so that this chaining goes back to the initial state. Or the two consequtive states are equal- no change any longer.

At S1: It is not possible to find a plan at this level. Because: mutex between Tx and Cx, and Vx and Wx.

Expand with A1 and S2. At A0 there is mutex between Cx and Tx as well as Wx and Vc. At S2 the golal $\{D, P, C\}$ seems possible. Which actions enable this? $\{Cx, Wx, NO(C)\}$ is possible, without mutex.Now, need to check if the new goal $\{H, Q, C\}$ is possible at A0. No action set for this at A0. Backtract to S2, try another action set. What about $\{Cx, NO(P), Vx)\}$. This is OK. Then Try to find a nonmutex set of actions in A0 to get the newest goal $\{H, P\}$. Yes: $\{NO(H), Wx\}$. New goal now $\{H, Q\}$ which is possible at S0.Done. There are indeed more than one possible plans.

In our question, both plans (1) and (2) are valid plans, because $\{C_x, W_x\} \rightarrow T_x$ is a valid plan.

The following figure shows the graphplan where Cook coresponds to Cx in the question in this exam, while Wrap: Wx, Carry: Tx and Dolly: Vx. Also. CleanH: H, Quiet: Q, Dinner: D, Present: P and Garbage: R in the exam question.



Problem 6 (10 pts, 2 pts each question)
Choose the correct answers (one for each question) to the questions below.

a) What is the primary drawback of hill-climbing search?

A. The search can get stuck in a local maximum

B. The algorithm requires a lot of memory

C. The search can get stuck in a global maximum

D. The result depends strongly on the temperature schedule

ANSWER: A

b) When we illustrate the Minimax algorithm, we use the symbols $\triangle$ and $\bigtriangledown$ for nodes in the search tree. A variation of the Minimax algorithm additionally uses the symbol $\bigcirc$ for some of the nodes. What does this symbol represent?

A. A second opponent in a multiplayer game

B. A game rule has been broken

C. An element of chance in the game

D. An estimated score, due to cutoff

E. A tie between the players

ANSWER: C

c) Which of the following researchers did not participate in the Dartmouth conference where the name "artificial intelligence" was coined?

A. John McCarthy

B. Marvin Minsky

C. Herbert Simon

D. Allen Newell

E. Alan Turing

ANSWER: E. Alan Turing

d) Which of the following is the main inference mechanism in semantic networks?

A. Resolution refutation

B. Generalized modus ponens

C. Inheritance

D. Skolemization

E. De Morgan's law

ANSWER: C. inheritance .

e) Which of the following would you choose as the unifier for $UNIFY(Loves(Per, x), Loves(y, z))$? Explain why. No points will be given without correct explanation.

A. (y/Per, x/z)

B. (y/Per, x/Per, z/Per)

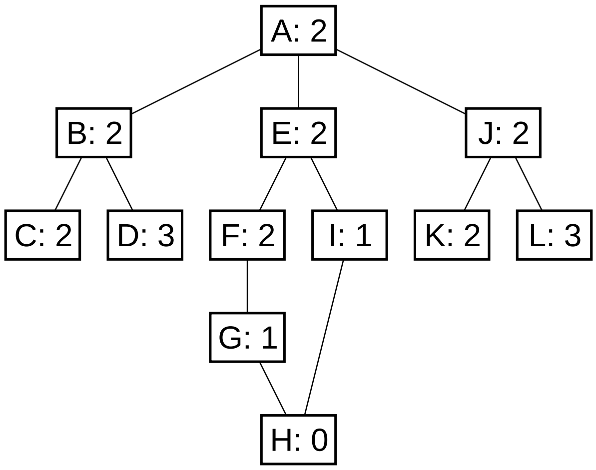
C. (y/Per, x/z, z/Siri)

D. none of the above are suitable unifiers.

ANSWER: A. (y/Per, x/z). Most general is chosen.

Problem 7 (10 points)

Consider the following search problem:



The initial node is A and the goal node is H. All step costs are 1, and a heuristic value is given for each node in the figure (for example, the heuristic value for node D is given as 3). Assume that there is a goal-test function which will be called by the search algorithm every time it needs to determine whether a node is a goal node.

a) (2 points) Using breadth-first search (BFS): What is the sequence of nodes for which the goal-test function will be called? Write the letters for each node, and in the correct order.

ANSWER: ABEJCDFIKLGH

b) (1 point) Using breadth-first search (BFS): What will be returned as the shortest path to the goal?

ANSWER: AEIH

c) (6 points) Using A*: What is the sequence of nodes for which the goal-test function will be called? Whenever several nodes have the same estimated cost, always choose the node that comes first alphabetically.

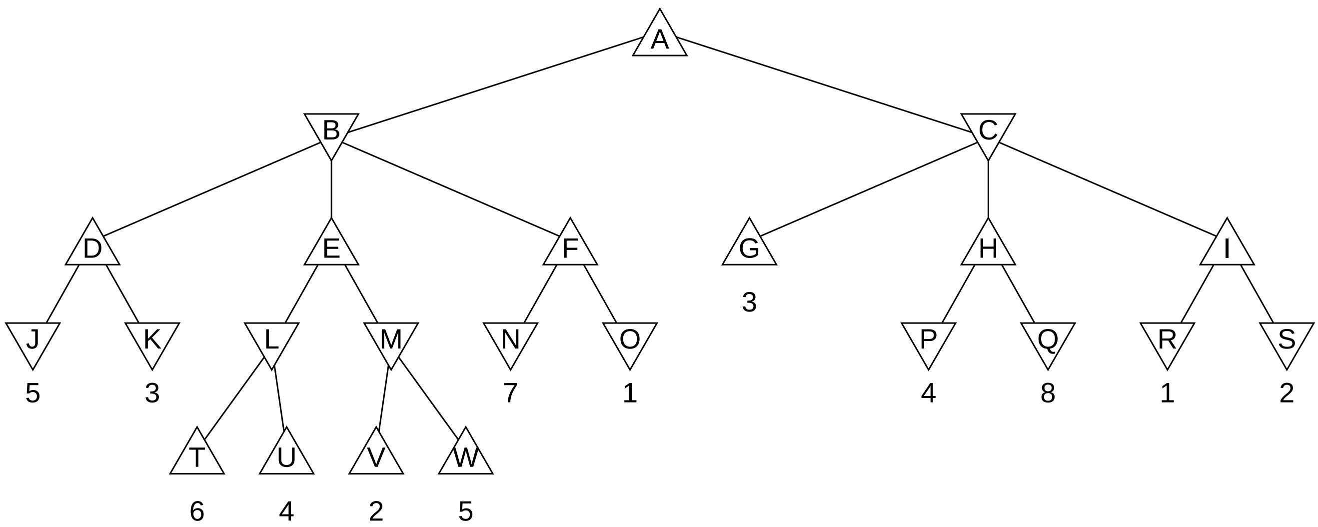
ANSWER: ABEIH

d) (1 point) Using A*: What will be returned as the shortest path to the goal?

ANSWER: AEIH

Problem 8 (10 points)

Consider the following Minimax tree:



The leaf nodes have their final utility values given as numbers below them.

a) (2 points) What is the final value in node A, after running Minimax?

ANSWER: 4

b) (3 points) What is the final value of the rest of the internal nodes, after running Minimax? Write the values for the nodes in alphabetical order, and do not include the root node or the leaf nodes. In other words, write the numbers in the order B, C, D, E, F, H, I, L, M.

ANSWER: 425478242

c) (5 points) Which nodes will be pruned when using alpha-beta pruning on this tree (assuming nodes are evaluated from left to right)? Give the answer as a list of the nodes' letters in alphabetical order, and include *all* of the nodes in the branches that are pruned.

ANSWER: HIOPQRSW

GOOD LUCK!

NTNU

Department of Computer and Information Science

Examination paper for (course code) (course title)

TDT4136 - Introduction to Artificial Intelligence

Academic contact during examination: Odd Erik Gundersen

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Examination date: 19/12/2016

Examination time (from-to): 09:00 – 13:00

Permitted examination support material: D
No printed or handwritten material is permitted.
Calculator is permitted.

Other information:
Results: 19 January 2017
If you believe that some information is missing in the formulation of a problem, briefly describe the necessary assumptions you made.

Language: English

Number of pages (front page excluded): 6

Number of pages enclosed: 7

Checked by:

Date Signature

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(NOTE: All the answers need to be written down into answer sheets, not into the question list.)

TASK 1: Task Environment (10p)

Specify the task environment of the following four agents.

Possible answers:
Observable: Fully (F) or partially (P).
Agents: Single (S) or Multi (M)
Deterministic: Deterministic (D) or stochastic (S).
Episodic: Episodic (E) or sequential (S)
Static: Static (S), semi (I) or dynamic (D)
Discrete: Discrete (D) or continuous (C)

Agent 1: Deep Blue
Deep Blue is a chess playing agent that played and won against Garry Kasparov in 1997. Consider one game against Garry using a clock.

Agent 2: Roomba
Roomba is a vacuum-cleaning robot that drives around and vacuums the floors in all the rooms of a home.

Agent 3: A Tesla factory paint-robot.
A paint robot on the Tesla factory paints one and one car. The cars are transported by a transport robot to and from the paint robot. The paint robot uses a spray-painting robot arm to paint the cars.

Agent 4: Stats Monkey the robot journalist
Stats Monkey collects box scores and play-by-play data to spit out credible accounts of college baseball games while the games are being played.

Answer to be written down into answer sheet following the given table:

Task Environment	Observable P/F	Agents S/M	Deterministic D/S	Episodic E/S	Static S/D/I	Discrete D/C
Deep Blue	F	M	D	S	I	D
Roomba	P	S	S	S	D	C
Paint robot	P	M	S	S	S	C
Stats Monkey	P	S	D	S	I	C

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TASK 2: Propositional and first-order logic (20p)

a) (4p) What are the advantages and disadvantages of the propositional logic ? What is the difference between implication and entailment in propositional logic ? (*The answer should be shorter than one page)*.

Pros:

- Propositional logic is declarative: Pieces of syntax correspond to facts
- Propositional logic allows partial/disjunctive/negated information
- Propositional logic is compositional

Cons:

- Propositional logic has very limited expressive power.

Implication: $(S \rightarrow Q)$ is true iff $(\neg S \vee Q)$ is true.

Entailment: $(KB \vDash Q)$ is true iff every interpretation that makes all $(S \in KB)$, makes Q true.

b) (4p) Convert the following formula to CNF (conjunctive normal form)

$$(A \wedge B) \Rightarrow (\neg A \Leftrightarrow B)$$

$\neg A \vee \neg B$

c) (2p) Multiple choice

The formula $\forall x \exists y\ P(x,y) \rightarrow \exists q\ P(q,q)$ would be treated as a validity

1. Under all possible circumstances
2. By an inference engine that implements occurs check as Skolem functions
3. By an inference engine that implements occurs check as Skolem constants
4. Under no possible circumstances

3 (R&N, p.362)

d) (3p) True or False (*correct answer= 1p; wrong answer= -½p; total score will be 0-3p*)

1. Universal Instantiation is built on Skolemization.

   F (R&N, p.323)

2. The Backward Chaining Algorithm can be described as follows:
   i. Pose the original query as a goal.
   ii. Find every clause in the knowledge base whose right-hand side unifies with the goal under some substitution.
   iii. Prove in turn every conjunct on the left-hand sides of each of these clauses, keeping track of the accumulated substitutions.

   T (R&N, p.337)

3. There exists a sentence S in First Order Logic such that S cannot be converted into an inferentially equivalent sentence in Conjunctive Normal Form.

   F (R&N, p.345)

e) The statement "Every Russian school boy knows a game"[1] has two interpretations

A. There exists a game such that every Russian school boy knows this game.

B. For each Russian school boy, there exists a game so that the boy knows this game.

---

[1] *The saying "Every Russian schoolboy knows ..." (that you must recapture with the pawn!) is attributed to the Soviet chess Grandmaster David Bronstein who used it to imply how little Western chess players (in the 1950s) understood of the game compared to any Russian. However, Bronstein never met Magnus Carlsen* ☺

Students will find the examination results in Studentweb. Please contact the department if you have questions about your results. The Examinations Office will not be able to answer this.

Questions:

1. (2p) Formulate each of these two interpretations in first order logic.

   Let R(x): x is a Russian schoolboy, G(y): y is a game, K(x,y): x knows y.

   A: $\exists y \, [\, G(y) \wedge (\forall x \, R(x) \Rightarrow K(x,y)) \,]$

   B: $\forall x \, [\, R(x) \Rightarrow \exists y \, (G(y) \wedge K(x,y)) \,]$

2. (2p) Convert the formulas into clausal form.

   Clausify A (eliminate $\exists$ and replace $A \Rightarrow B$ with $\neg A \vee B$):

   G1: G(s1)

   G2: ¬R(x) (K(x,s1)

   Negate B and clausify (move $\neg$ inwards, using that $\neg\forall x \, P \equiv \exists x \, \neg P$ and $\neg\exists x \, P \equiv \forall x \, \neg P$ and De Morgan's Laws: $\neg(A\wedge B) \equiv \neg A\vee\neg B$ and $\neg(A\vee B) \equiv \neg A\wedge\neg B$):

   $\neg\forall x \, [\, R(x) \Rightarrow \exists y \, (G(y) \wedge K(x,y)) \,]$

   $\exists x \, \neg[\, R(x) \Rightarrow \exists y \, (G(y) \wedge K(x,y)) \,]$

   $\exists x \, [\, R(x) \vee \neg\exists y \, (G(y) \wedge K(x,y)) \,]$

   $\exists x \, [\, R(x) \vee \forall y \, \neg(G(y) \wedge K(x,y)) \,]$

   $\exists x \, [\, R(x) \vee \forall y \, (\neg G(y) \vee \neg K(x,y)) \,]$

   $R(s2) \vee \forall y \, (\neg G(y) \vee \neg K(s2,y))$

   G3: R(s2)

   G4: $\neg G(y) \vee \neg K(s2,y)$

3. (3p) Use either a resolution proof or the Tableaux method to show that the logical formulation of interpretation A implies the logical formulation of interpretation B.

   Resolution proof (use the clausal forms from task 2e2 or derive them here):

G5: ¬K(s2,s1)	(G1,G4)
G6: K(s2,s1)	(G3,G2)
G7: []	(G5,G6)

   Tableaux proof (use the formulations in 2e1 directly and falsify the implication):

1. F $(\, \exists y \, [\, G(y) \wedge (\forall x \, R(x) \Rightarrow K(x,y)) \,] \Rightarrow \forall x \, [\, R(x) \Rightarrow \exists y \, (G(y) \wedge K(x,y)) \,] \,)$		
2. T $\exists y \, [\, G(y) \wedge (\forall x \, R(x) \Rightarrow K(x,y)) \,]$		1,$F_{\Rightarrow}$
3. F $\forall x \, [\, R(x) \Rightarrow \exists y \, (G(y) \wedge K(x,y)) \,]$		1,$F_{\Rightarrow}$
4. T $G(s1) \wedge (\forall x \, R(x) \Rightarrow K(x,s1)) \,]$		2,$T_{\exists}$
5. F $R(s2) \Rightarrow \exists y \, (G(y) \wedge K(s2,y))$		3,$F_{\forall}$
6. **T G(s1)**		4,$T_{\wedge}$
7. T $\forall x \, R(x) \Rightarrow K(x,s1)$		4,$T_{\wedge}$
8. **T R(s2)**		5,$F_{\Rightarrow}$
9. F $\exists y \, (G(y) \wedge K(s2,y))$		5,$F_{\Rightarrow}$
10. T $R(s2) \Rightarrow K(s2,s1)$		7,$T_{\forall}$
11. F $G(s1) \wedge K(s2,s1)$		9,$F_{\exists}$
12. **F R(s2)** |	**T K(s2,s1)**	10,$T_{\Rightarrow}$
13. **F G(s1)** |	**F K(s2,s1)**	11,$F_{\wedge}$

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TASK 3: Search (20p)

You are going to evaluate search algorithms that can find the shortest indoor walking paths. Figure 2 illustrates seven rooms and the actual walking distances between them. Table 1 specifies the straight-line distances between room 127D and all the other rooms. The evaluation function f(n) evaluates node n. When we evaluate the algorithms, we start our path search in room 181 and we want to find the shortest path to room 127D, which is our end node.

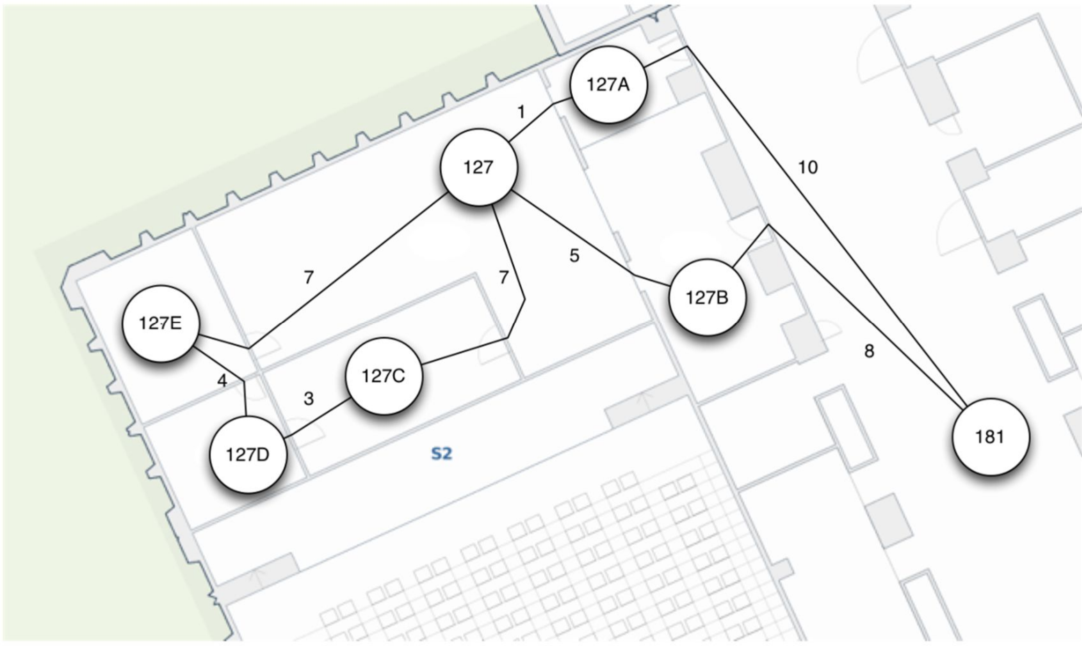


Figure 1: The graph represents the possible walking paths between the seven rooms 127D, 127E, 127C, 127, 127A, 127B and 181. The numbers close to the paths indicate the actual walking distances between the connected rooms.

Table 1: Straight line distance between the rooms and 127D

Room	SLD from 127D
127	7
127A	10
127B	9
127C	3
127E	2
181	14

a) Greedy best-first search (3p): What is the evaluation function f(n) for greedy best-first search? Write the function and describe the term(s) on the right hand side.

Answer: f(n) = h(n), h(n) is a heuristic function that estimates how fra n is from the goal state, for example SLD for the indoor paths in this task.

Students will find the examination results in Studentweb. Please contact the department if you have questions about your results. The Examinations Office will not be able to answer this.

b) A* (3p): What is the evaluation function for A*? Write the function and describe the term(s) on the right hand side.

Answer: f(n) = g(n) + h(n), h(n) is the heuristic, such as SLD, and g(n) is the actual cost of getting to n, for instance the actual distance travelled in this task.

c) Greedy best first search (3p): For each step in the search, write the evaluation function for the node that is selected for expansion.

Step	Node	f(n) = g(n)	Open/Closed
1	181	14	O: 127B (9), 127A (10) C: 181
2	127B	9	O: 127 (7), 127A (10) C: 181, 127B (9)
3	127	7	O: 127E (2), 127C (3), 127A (10) C: 181, 127B (9), 127 (7)
4	127E	2	O: 127D (0), 127C (3), 127A (10) C: 181, 127B (9), 127 (7), 127E (2)
5	127D	0	O: 127C (3), 127A (10) C: 181, 127B (9), 127 (7), 127E (2), 127D (0)

Answer: f(127B)=9, f(127)= 7, f(127E)=2, f(127D)=0. Total actual distance travelled: 24.

Students will find the examination results in Studentweb. Please contact the department if you have questions about your results. The Examinations Office will not be able to answer this.

d) A* (3p): For each step in the search, write the evaluation function including all the terms and their values for the node that is selected for expansion.

Answer:

Step	Node	g(n)	h(n)	f(n)	Frontier/Expanded
1	181	0	14	14	F: 127B (17), 127A (20) E: 181
2	127B	8	9	17	F: 127A (20), 127 (20) E: 181, 127B What if 127 is explored first (look at 3, alt, which will take one extra step to go to 3)
3	127A	10	10	20	F: 127 (18) ~~127 (20)~~, E: 181, 127B, 127A
3, alt	127	13	7	20	F: 127A (20), 127E (22), 127C (23) E:181, 127B, 127 (20) Ends up at 3.
4	127	11	7	18	F: 127E (20), 127C (21) E: 181, 127B, 127A, 127
5	127E	18	2	20	F: 127C (21), 127D (22), E: 181, 127B, 127A, 127, 127E
6	127C	18	3	21	F: 127D (20), ~~127D (22),~~ E: 181, 127B, 127A, 127, 127E, 127C (21),
7	127D	20	0	20	F: E: 181, 127B, 127A, 127, 127E, 127C (21), 127D (20)

Students will find the examination results in Studentweb. Please contact the department if you have questions about your results. The Examinations Office will not be able to answer this.

e) Admissible heuristics (4p): Explain what an admissible heuristics is in one sentence only. Give two examples of admissible heuristics for the 8-puzzle where the objective is to slide tiles horizontally or vertically into the open space until the goal state is reached.

Answer: An admissible heuristic is one that never overestimates the cost to reach the goal. Two admissible heuristics for the 8-puzzle:

1. Number of misplaced tiles and
2. The sum of the distances that of the tiles from their goal position.

f) Optimality of A* for graph search (1p): Must the heuristics be both admissible and consistent in order for A* to be optimal when applied to graph search? Alternatives: Yes or No.

Answer: yes

g) Search algorithms (3p): Which of the search algorithms 1) A*, 2) genetic algorithms, 3) minimax, 4) constraint propagation should be chosen for the following search problems:

1. Search for a schedule of flights that has some restrictions.
2. Search for best action in backgammon.
3. Find the best design of a car.
4. Find the shortest route for a self-diving car.

Answer:

Task	Answer
A	4 (constraint propagation)
B	3 (minimax)
C	2 (genetic algoritms)
D	1 (A*)

Students will find the examination results in Studentweb. Please contact the department if you have questions about your results. The Examinations Office will not be able to answer this.

TASK 4: Constraint satisfaction (20p)

Figure 2 shows the water regions in Norway, which there are eleven of, and these are Finnmark (F), Troms (T), Norland (N), Sør-Trøndelag (ST), Møre og Romsdal (MR), Østfold (Ø), Sogn of Fjordane (SF), Hordaland (H), Buskerud (B), Rogaland (R) and Vest-Agder (VA).

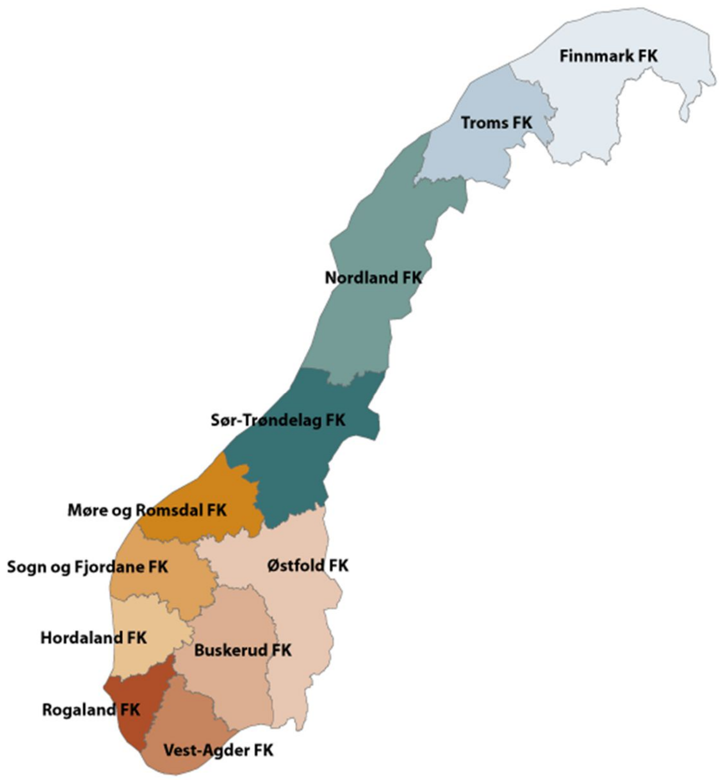


Figure 2: Water regions of Norway.

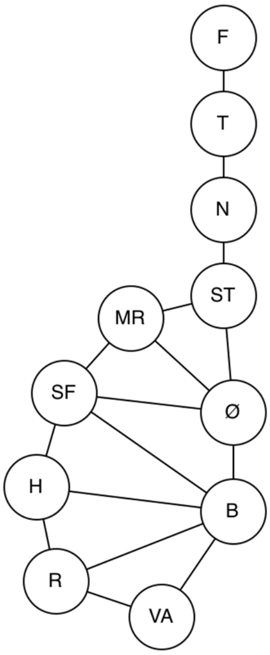
You are going to color the map. Unlike the artist that has colored the map of figure 2, you can use three colors only (red, green and blue), but no neighboring regions can have the same color. To solve this problem, you have to use your knowledge of constraint satisfaction. You will use the full constraint graph for b, and the reduced constraint graph for d and e. The reduced constraint graph only includes the regions south of Møre og Romsdal (that is we are not including Møre and Romsdal in the reduced constraint graph).

a) Constraint satisfaction problems (3p): Specify 1) the variables, 2) the domain and 3) give at least three examples of constraints.

Answer:
Variables: F, T, N, ST, MR, Ø, SF, H, B, R and VA.
Domain: red, green, blue.
Constraints: No neigboring region should have the same color. F!=T, T!=N, N!=ST.

Students will find the examination results in Studentweb. Please contact the department if you have questions about your results. The Examinations Office will not be able to answer this.

b) Graph (3p): Draw the full constraint graph illustrating the water regions of Norway. Use the abbreviations in your graph: F, T, N and so on.



c) Description (3p): Which of the following terms describe the domain and the constraints of the specified problem?

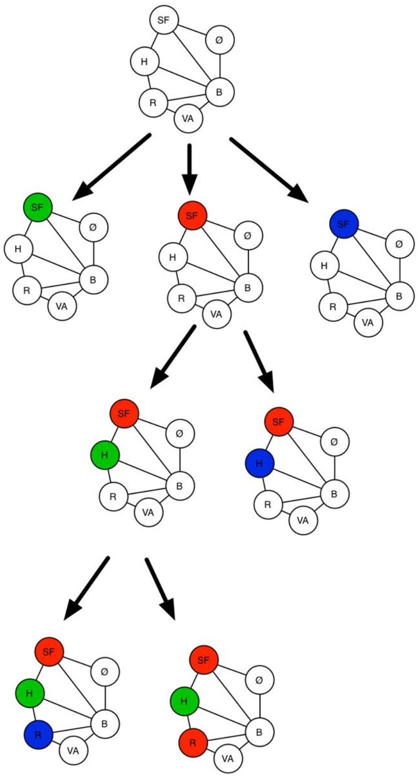
1. Discrete domain,
2. Continuous domain,
3. Finite domain,
4. Infinite domain,
5. Linear constraints
6. Nonlinear constraints,
7. Unary constraints,
8. Binary constraints,
9. N-ary constraints.

Answer:
a. Discrete domain
c. Finite Domain
h. Binary constraints

Students will find the examination results in Studentweb. Please contact the department if you have questions about your results. The Examinations Office will not be able to answer this.

d) Backtracking search (4p): Illustrate the first three levels of the search tree of backtracking search using the constraint graph. Each node in the tree should list all the assignments made by that point in the search. Use the reduced constraint graph.

Answer: From book: The term backtracking search is used for a depth-first search that chooses values for one variable at a time and backtracks when a variable has no legal values left to assign.



e) Forward checking (4p): Illustrate forward checking with a table. Each variable should have a column in the table, showing the remaining domain for that variable at each point in the search (represented by rows). Show three steps. Use the reduced constraint graph.

Answer:

From Book: One of the simplest forms of inference is called forward checking. Whenever a vari- able *X* is assigned, the forward-checking process establishes arc consistency for it: for each unassigned variable V that is connected to X by a constraint, delete from V's domain any value that is inconsistent with the value chosen for *X*.

Students will find the examination results in Studentweb. Please contact the department if you have questions about your results. The Examinations Office will not be able to answer this.

Domain	*SF*	*Ø*	*H*	*B*	*R*	*VA*
Initial	*R G B*	*R G B*	*R G B*	*R G B*	*R G B*	*R G B*
After SF=red	*R*	*G B*	*G B*	*G B*	*R G B*	*R G B*
After H=green	*R*	*G B*	*G*	*B*	*R B*	*R G B*
After R=blue	*R*	*G B*	*G*	-	*B*	*R G*

f) Heuristics (3p): Of the three heuristics minimum-remaining-values (MRV), degree (D) and least-constraining-value(LCV):
   a. Which heuristic should be used to choose which region to color next?
   b. Which heuristic should be used to decide the order to examine values?

Answer:
From Book:

a) The **minimum-remaining-values** (MRV) heuristic chooses the variable with the fewest "legal" values.
The MRV heuristic doesn't help at all in choosing the first region to color. In this case, the **degree heuristic** comes in handy. It attempts to reduce the branching factor on future choices by selecting the vari- able that is involved in the largest number of constraints on other unassigned variables.

b) Once a variable has been selected, the algorithm must decide on the order in which to examine its values. For this, the **least constraining-value** heuristic can be effective in some cases. It prefers the value that rules out the fewest choices for the neighboring variables in the constraint graph.

Answer to be written down into answer sheet following the given table:

Task	**Answer**
a.	MRV, D
b.	LCV

Students will find the examination results in Studentweb. Please contact the department if you have questions about your results. The Examinations Office will not be able to answer this.

TASK 5: Planning (10p)

a) Characterizing planning (5p): How can a planning (problem) be characterized? Name two situations when planning is necessary. (*The answer should be shorter than one page)*.

Answer:
Planning is a way of problem solving that focuses on the effects of actions. Therefore the Situation Calculus is an important concept when describing a planning problem as it takes the time aspects of facts into account. The Situation Calculus says that facts hold only in situations, not eternally. This means that something can be true in one situation, but may not be true in another situation.

Situations, when planning is necessary:

- when addressing a new situation
- when tasks are complex
- when the environment imposes high risk/cost
- when collaborating with others

b) Plan representation (5p): Explain how a plan can be represented? Give an example of withdrawing cash from an ATM in either STRIPS or PDDL. (*The answer should be shorter than one page*.)

A plan can be represented as:

- States: First-order predicates over objects describing a point in the search space of an application
- Actions:
  - Name: identifier of the action
  - Precondition: conjunction of literals describing whether the action can be taken
  - Effects: conjunction(s) describing the change
- Goals: A conjunction of literals

There are different languages that can be used, we discussed STRIPS and PDDL: buying a Christmas tree:

STRIPS:
Action (withdraw(cash),
PRECOND: At(ATM) $\wedge$ Sells(ATM, cash, person) $\wedge$ hasMoneyOnAccount (person)
DELETE-LIST: hasMoneyOnAccount (person)
ADD-LIST: have (cash))

PDDL:
Action (withdraw(cash),
PRECOND: At(ATM) $\wedge$ Sells(ATM, cash, person) $\wedge$ hasMoneyOnAccount (person)
EFFECT: $\neg$hasMoneyOnAccount (person) $\wedge$ have (cash))

NB! - hasMoneyOnAccount(person) is the negation

Students will find the examination results in Studentweb. Please contact the department if you have questions about your results. The Examinations Office will not be able to answer this.

TASK 6: Natural Language Processing (20p)

a) (6p) True or False (*correct answer= 1p; wrong answer= -½p; total score will be 0-6p)*

- Sentiment analysis is a text classification application.
  T (R&N, p.865)

- The purpose of smoothing is to avoid dramatic effects of low-frequency counts.
  T (R&N, p.863)

- The bag of words model can be seen as a simple language model.
  T (R&N, p.866)

- ‘Freeze’, ‘halt’, ‘cease’ and ‘finish’ are examples of stop words.
  F (NLP lecture, slide 67)

- The task of Information Retrieval is to return the answer to a user query.
  F (R&N, p.867)

- Information Extraction systems are often based on templates
  T (R&N, p.874)

b) (2p) What are the main features of human languages that make parsing of these different from the parsing of programming languages?

Ambiguity and redundancy (NLP lecture, slide 5)
Other differences relate to that humans languages are constantly **evolving** and (to some extent) that they exhibit higher level of **context dependency**

c) (2p) Sentiment analysis of Twitter messages (tweets) faces several challenges. Give examples of at least four problems that need to be addressed.

There are a whole range of challenges, for example:
Word meaning can be domain dependent; modifers (e.g., negation) can change or reverse the meaning; figurative language can change the meaning (sarcasm, irony, humour); the very restricted length of the messages; brevity, idiomatic language, non-conventional grammar, spelling errors, hashtags, etc. make processing more difficult - as well as the same issues as in Task6b; references to other tweeters and tweets; links and pictures; mixing of languages;
and so on (NLP lecture, slide 48)

Students will find the examination results in Studentweb. Please contact the department if you have questions about your results. The Examinations Office will not be able to answer this.

d) (4p) The documents in a collection that were returned respectively not returned by an Information Retrieval system in response to a given query were analysed for relevance and shown to be distributed as follows:

	Returned	Not returned
Relevant	60	40
Not relevant	20	180

1. What was the system's precision?

    0.75 [(relevant returned) / (all returned) = 60 / (60+20) = 3/4]
    (R&N, p.869)

2. What was the system's recall?

    0.60 [(relevant returned) / (all relevant) = 60 / (60+40) = 3/5]
    (R&N, p.869)

3. What is F_1 score?

    A way to combine precision and recall; their harmonic mean: 2PR/(P+R)
    (R&N, p.869)

4. Calculate the F_1 score of the system.

    0.67 [2PR/(P+R) = 2*(3/4)*(3/5) / (3/4+3/5) = (18/20) / (27/20) = 2/3]
    (R&N, p.869)

e) (6p) Suppose you have access to the following knowledge sources:

- Dictionaries of basic word forms (lemmas) for English and Norwegian,
- Morphological inflection rules for the same two languages,
- A large set of English e-mails already classified as spam,
- A large set of Norwegian e-mails already classified as spam,
- A large set of English e-mails already classified as not being spam,
- A large set of Norwegian e-mails already classified as not being spam,
- A huge set of unclassified e-mails written in a wide range of human languages, and
- A stream of incoming messages, each of the length of no more than one sentence.

Describe how you would go about building a system which would analyze each incoming message and produce one of the following outputs:

1. The message is not written in a human language.
2. The message is written in a human language which is neither English nor Norwegian.
3. The message is written in English and is spam.
4. The message is written in Norwegian and is spam.
5. The message is written in English and is not spam.
6. The message is written in Norwegian and is not spam.

Students will find the examination results in Studentweb. Please contact the department if you have questions about your results. The Examinations Office will not be able to answer this.

You do not need to produce a complete solution, but rather sketch the steps that would have to be taken.

Several solutions are possible. We could, for example, view it as a **language modelling and classification** problem, and do the following:

1. Preprocess the words in the classified and unclassified e-mails, for example by
   a. removing punctuation
   b. converting all upper case characters to lower case
2. Further analyse / normalise the words in the pre-classified e-mails:
   a. Apply the inflection rules to each word
   b. Map each word to its basic form (lemma) in the dictionaries
3. Create five language models (e.g., bag of words or bigrams) from all the words:
   a. English spam
   b. English non-spam
   c. Norwegian spam
   d. Norwegian non-spam
   e. Human language
4. Analyse an incoming message to see which language model it fits closest to
   a. by either using statistical information from the language models, or
   b. by applying a machine learning-based classifier trained on the data.

Alternatively, we could address it as an **information retrieval** task (potentially after doing the same preprocessing and word-level analysis as in steps 1 and 2 in the solution above) and then:

1. Treat each incoming message as a query to the documents (the analysed e-mails)
2. Retrieve the top N (e.g., 100) documents closest matching that query.
3. Assign the class to the query which the majority of the documents belong to.
4. (If the query matches several classes, more documents can be retrieved.)

Students will find the examination results in Studentweb. Please contact the department if you have questions about your results. The Examinations Office will not be able to answer this.

NOTE: All the answers need to be written down into answer sheets, not into the question sheet.

Problem 1 (10 points, 2.5 pts each question))

You are a map-coloring robot assigned to the task of coloring the following map (see Figure 1). Each region must be colored one of Red (R), Green(G) or Blue(B). Adjacent regions must be a different color. The map (left) and the constraint graph (right) are shown below.

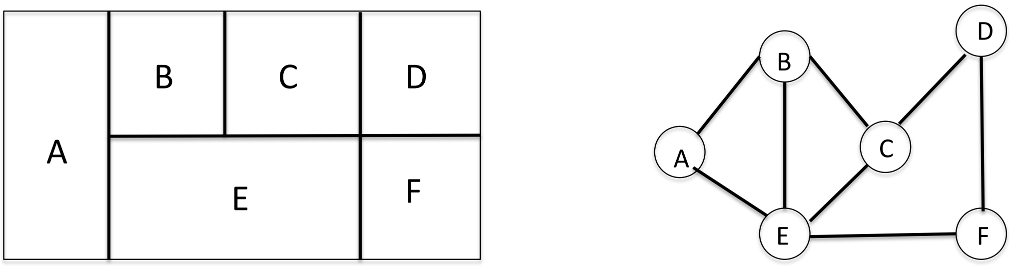


Figure 1: Map coloring problem

a) Consider the partial assignment in Figure 2 below where variable A and E have been assigned values as shown in the figure. Cross out all values that should be eliminated by Arc Consistency (using AC-3 in the textbook.)

Regions in the map

A	B	E	C	D	F
Blue	R G B	Red	R G B	R G B	R G B

Figure 2: Partial assignment for Region A= Blue and E= Red

ANSWER: See Figure 3

Regions in the map

A	B	E	C	D	F
Blue	R G B X X	Red	R G B X X	R G B X	R G B X

Figure 3: Answer to (a)

b) Minimum Remaining Values Heuristics. Consider the partial assignment in Figure 4 where B is assigned value Green and constraint propagation has been done. Write down all unassigned variables (just the letters that correspond to these variables) that might be selected by Minimum Remaining Values Heuristic (MRV)

Regions in the map

A	B	E	C	D	F
R B	Green	R B	R B	R G B	R G B

Figure 4: Partial assignment for Region B= Green

Answer: A, E, C

c) Degree Heuristic. Consider the partial assignment in Figure 4 where B is assigned Green and constraint propagation has been done. Write down all unassigned variables that might be selected by the Degree Heuristics

Answer: E

d) Consider the following complete but inconsistent assignment in Figure 6. E has been selected to be assigned a value during local search for a complete and consistent assignment. What new value would be chosen for E by the MINIMUM-CONFLICT heuristic?

Regions in the map

A	B	E	C	D	F
R B	Green	R B	R B	R G B	R G B

Figure 5: Partial assignment for Region B= Green

Regions in the map

A	B	E	C	D	F
B	G	?	G	G	G

Figure 6: Complete assignment where the value of Region E needs to be changed, and to be found.

Answer: R

Problem 2 (10 points)

Assume the following knowledge base KB:

$\forall$ x allergies(x) $\implies$ sneeze(x)

$\forall$ x $\forall$ y cat(y) $\wedge$ allergicToCats(x) $\implies$ allergies(x)

cat(Felix)

allergicToCats(Mary)

The Goal/Query: Does Mary sneeze?, I.e., sneeze(Mary)?

Perform Resolution Refutation (RR) and find out if the query has a positive (True) or negative (False) answer for this KB? Answer the question with True (Yes) or False (No), and show how you derived this answer through RR. Show also unifications if any. T/F answers without the poof/refutation of the query will not be given any point. Partial points will be given to the proof.

ANSWER: See (Figure 7)Result of Resolution is {}, i.e, Mary sneezes. i.e., sneeze(Mary) is true. 1 point for unification. No point reduction for lack of standardization (i.e., variable w in the figure)

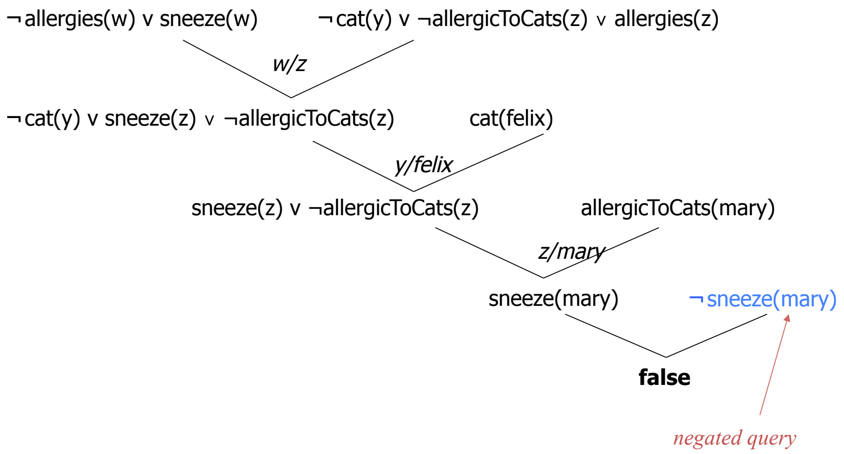


Figure 7: ANSWER to Resolution Refutation Problem.

Problem 3 (10 points, division: 3-3-4 pts)

In the following adversarial game (see Figure 8) it is MAX's turn to play. The numbers at each leaf node is the estimated score of that position. Check nodes from left to right order.

a) Perform mini-max search and label each branch node with its value. Draw the figure on your answer sheet and fill the squares above the leaf nodes. You don't need to draw the nodes at the leaf level.

ANSWER: See Figure 9

b) What is Max's best move, i.e., which node it is and which utility does it give?

ANSWER: Node B, value 5

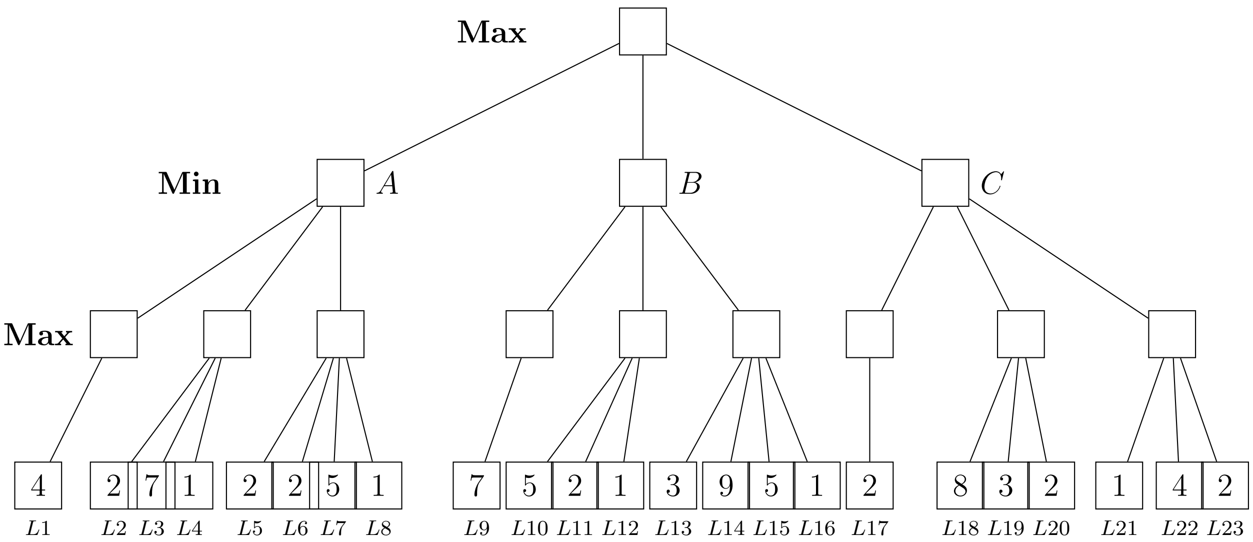


Figure 8: Adversarial game problem.

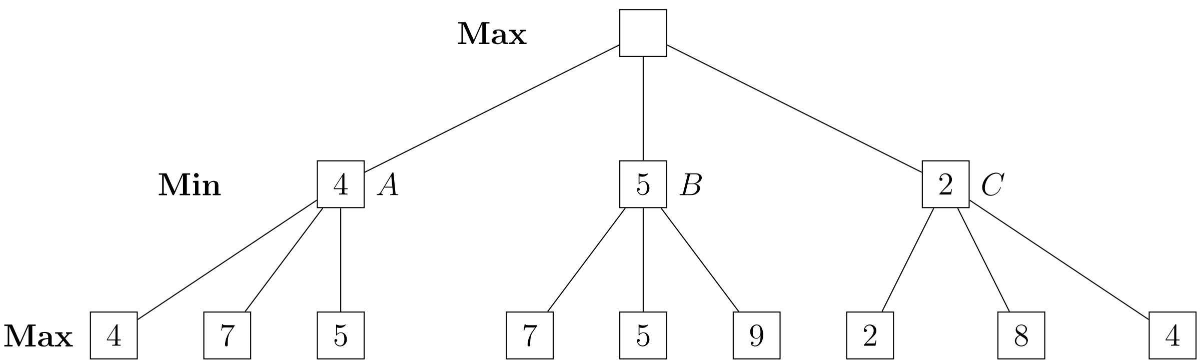


Figure 9: M
inimax. ANSWER: Adversarial game problem.

c) Write down all leaf nodes that the alpha-beta algorithm would prune. Your answer will be a list of L_i labels .

ANSWER: L4, L8, L15, L16,L18, L19,L20, L21, L22, L23)

Problem 4 (15 points total, 4 points for each of the first questions. The sum will not be negative for this problem.)

This is a mixture of multiple choice (b) , Classical "writing the answer" (a and c), and

True/False type of tasks.

a) Assume the following problem represented as a graph (see Figure 10) where the numbers on the edges represent the cost of traveling between the nodes connected by the edge. You will apply A* graph search algorithm and the nodes in the graph have the following h-values:

h(S)= 7
h(A)= 6
h(B)= 2
h(C)= 1
h(G)= 0

Write down the to-be expanded node and the content of the priority queue at each step. Ties break alphabetically. Write down the generated solution path - you will not get any points if you dont show how the solution is generated (i.e., the queue and the currently expanding node). Is this an optimal solution? Why or why not, explain very briefly.

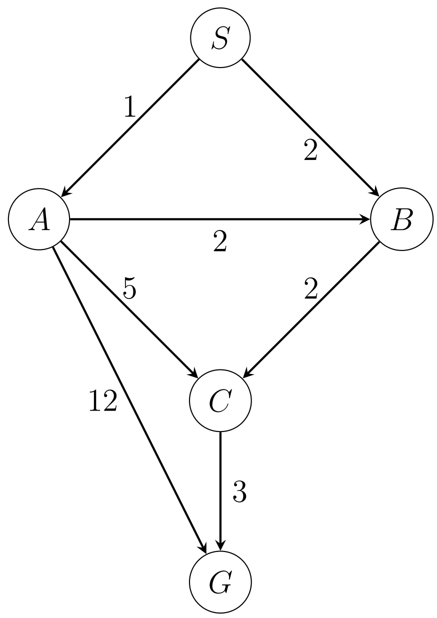


Figure 10: A* Problem

REMOVE ANSWER: The solution is S B C G. Optimal. Because cost for this solution is 7 and there is no other path with less cost. SEE FIGURE 11 for expansion and Queu.

- <u>Expanding</u> <u>Queue</u>
  S(7)
- S (7) -→ A(1+6,S), **B(4,S)**
- B(4,S) A(7,S), **C(5,SB)**
- C(5,SB) **A(7, S)** , G(7+0,SBC)
- A(7,S) **G(7,SBC)**, G(13, SA),B&C are already in Closed
- G(7,SBC) goal

Soluton path: S B C G

Figure 11: ANSWER A:STAR question(a).

b) Which of the following set of heuristic values provide a consistent heuristic for this problem (Figure 10)? Choose one of the options below.

1. $\{h(S) = 7, h(A) = 6, h(B) = 2, h(C) = 1, h(G) = 0\}$
2. $\{h(S) = 7, h(A) = 6, h(B) = 2, h(C) = 2, h(G) = 0\}$
3. $\{h(S) = 7, h(A) = 6, h(B) = 4, h(C) = 2, h(G) = 0\}$
4. $\{h(S) = 7, h(A) = 4, h(B) = 4, h(C) = 4, h(G) = 0\}$
5. None of the above. IMPORTANT: Note that for consistency, every pair of adjacent nodes (node that have direct connection) schould be checked. Not only between S–>A or A–B but all pairs, and all nodes must be used in these pairs (including G, which is also "a node". Those answers which make part of the Figure consistent but not the entire one will not be accepted as correct.

(ANSWER: 5, None of the above. For example $\{h(S) = 7, h(A) = 6, h(B) = 2, h(C) = 1, h(G) = 0\}$ is not consistent because for example h(A)-h(B)=4 is not $\leq$ C(A,B)=2). Remember that for consistency, h(n)-h(n«) $\leq$ C(n, n«), should be true throughout the graph

c) Write down a consistent heuristic set and apply A* graph search with it on the same graph (Figure 10). What is the solution path with this heuristic set? You don't get any points by writing only the optimal solution if it is not accompanied with a consistent set of heuristics. One consistent set is: $\{h(S) = 7, h(A) = 6, h(B) = 5, h(C) = 3, h(G) = 0\}$.

Check for h(n)-h(n′) $\leq$ C(n, n′) condition for consistency. Solution is SBCG.

d) Uniform cost Seach is a special case of A-star. True or False?

ANSWER: True, the case where (h = 0)

e) Simulated annealing is a stochastic optimization method. True or False?

ANSWER: True

Problem 5 (15 points. Division: 3-2-2-3-2-3, and -1 for each wrong answer. Sum of the points will not be negative for the whole problem.)

This is a combination of multiple-choice and True/False types of task. Choose the correct answer for each question.

a) "Men and women are welcome to apply." is equivalent to

$\forall(x)$ [(M(x) $\wedge$ W(x)) $\implies$ Apply(x)]

ANSWER: False. The FOL sentence says that everything that is both a man and a woman is welcome to apply, obviously not what is meant. The disjunction would give a correct one

b) Which of the following represents the sentence "Some person plays every game"?

1. $\exists x \forall y [Person(x) \wedge Game(y) \rightarrow Plays(x, y)]$
2. $\exists x \forall y [Person(x) \wedge Game(y) \wedge Plays(x, y)]$
3. $\forall x \forall y [Person(x) \wedge [Game(y) \rightarrow Plays(x, y)]]$
4. $\exists x \forall y [Person(x) \wedge [Game(y) \rightarrow Plays(x, y)]]$
5. None of the above.

   ANSWER: 4. $\exists x \forall y [Person(x) \wedge [Game(y) \rightarrow Plays(x, y)]]$.

c) Which of the following is the Skolemized version of this sentence:
$\forall x [(\neg P(x) \wedge Q(x)) \vee \exists y (R(x, y) \wedge T(y)))]$

1. $\forall x [\neg P(x) \wedge Q(x) \vee (R(f(x), y) \wedge T(y)))]$
2. $\forall x [P(x) \wedge \neg Q(x) \vee (R(x, f(x)) \wedge T(f(x)))]$
3. $\forall x [\neg P(x) \wedge Q(x) \vee (R(x, f(x)) \wedge T(f(x)))]$
4. $\forall x [\neg P(x) \wedge Q(x) \vee (R(x, x) \wedge T(x)))]$
5. None of the above.

ANSWER: 3.

$\forall x [\neg P(x) \wedge Q(x) \vee (R(x, f(x)) \wedge T(f(x)))]$.

d) For the sentence below, write V=valid if the sentence is valid, U=unsatisfiable if the sentence is unsatisfiable and S=satisfiable if the sentence is satisfiable but not valid.

1. $\forall x[[Student(x) \wedge \neg Student(x)] \rightarrow BornOn(x, Moon)]$

ANSWER: Valid. Because the antecedent is false.

e) Apply one step resolution to the following clauses: $p \vee q$ and $\neg p \vee \neg q$. Which of the below is the correct result of the resolution step.

1. $\{p, \neg p\}$ and $\{q, \neg q\}$
2. $\{\}$

(ANSWER: $\{p, \neg p\}$ and $\{q, \neg q\}$ is correct. Because when two clauses have multiple pairs of complementary literals, only one pair of literals may be resolved at a time.)

f) You will convert the folllowing sentence into Conjunctive Normal form.
$(A \wedge B) \vee (C \wedge D) \vee (E \implies F)$

Which one is the resultant CNF?

1. $(A \vee C) \wedge (B \vee C) \wedge (A \vee D) \wedge (B \vee D \vee \neg E \vee F)$
2. $(A \vee C) \vee (B \vee C) \vee (A \vee D) \wedge (B \vee D \vee \neg E \vee F)$
3. $(A \vee C) \wedge (B \vee C) \wedge (A \vee D) \wedge (B \vee D \vee E \vee F)$
4. $(A \vee C \vee \neg E \vee F) \wedge (A \vee D \vee \neg E \vee F) \wedge (B \vee D \vee E \vee F) \wedge (B \vee C \vee E \vee F)$
5. none of the above

ANSWER: None of the above. Cot«rrect answer: $(A \vee C \vee \neg E \vee F) \wedge (A \vee D \vee \neg E \vee F) \wedge (B \vee D \vee \neg E \vee F) \wedge (B \vee C \vee \neg E \vee F)$

Problem 6 (20 points. Each question is 2 points. -1 for each wrong answer but the total points will not be negative.)

True/False type of questions. Answer with either True(T) or False(F)

a) Randomized behaviour may be rational in competitive multi-agent environments.

ANSWER: TRUE, in competitive multi-agent environments it can avoid the pitfalls of predictability

b) There exists a task environment in which every agent is rational.

ANSWER: True. Consider a task environment in which all actions (including no action) give the same, equal reward

c) Philosopher John Searle suggests that any physical symbol system has necessary and sufficient means for general intelligent action. True or False?

ANSWER: False. This is suggested by Alan Newel and Herbert Simon. Searle suggested the opposite

d) If h is a consistent heuristic, then h is also an admissible heuristic. True or False? ANSWER: True.

e) Purely reactive agents use semantic networks for planning. True or False?

ANSWER: False .

f) Backgammon is a fully observable, sequential, deterministic, static, dicrete and multi-agent environment. True or False?

ANSWER: False not deterministic .

g) Circumscription allows the entailed sentences to be removed after new sentences added to the knowledge base. ANSWER: True

h) "Multiple inheritance" is one of the reasons that leads to undecidability problem in first order logic. True or False?

ANSWER: False. It is not in logic but semantic networks

i) "Closed world assumption" is the assumption that atomic sentences not known to be true are in fact false.

ANSWER: True

j) Two agents participate in a game which is defined as follows:

Agents. {Agent-i, Agent-j}
Actions: {0,100,200,300} - these actions can be thought as giving bid in an auction for

		Agent j			
		0	100	200	300
	0	**300,0**	**200,0**	**0,100**	**0,0**
	100	200,0	200,0	200,100	0,300
Agent i	200	0,0	0,200	0,0	0,0
	300	-100,0	-100,0	-100,0	-100,0

Figure 12: Game theory question

example.
The Payoff matrix is shown in Figure 12 .

Which of the options below is the strongly dominant equilibrium in this game? Each option shows the pair of actions, (action of agent-i, action of agent-j):

1. (0, 100)
2. (200, 200)
3. (300,0)
4. (300,100)
5. None of the above

ANSWER: None of the above. There is no strongly dominan equilibrium in this payoff matrix .

Problem 7 (20pts- division of points: 3-3-3-3-2-2-2-2. Minus point: -1 for each wrong answer)

Multiple Choice or True/False type of tasks. .

a) In situation calculus, something true in one situation may not be true in another situation. True or False?

ANSWER: True

b) The following plan describes the process of withdrawing money from an ATM. Which of the representations is written in STRIPS?

1. Action (withdraw(cash),
   PRECOND: At(ATM) $\wedge$ Sells(ATM, cash, person) $\wedge$ hasMoneyOnAccount (person)
   DELETE-LIST: hasMoneyOnAccount (person)
   ADD-LIST: have (cash))

2. Action (withdraw(cash),
   PRECOND: At(ATM) $\wedge$ Sells(ATM, cash, person) $\wedge$ hasMoneyOnAccount (person)
   EFFECT: $\neg$ hasMoneyOnAccount (person) $\wedge$ have (cash))

ANSWER: 1

c) Which statements about partial order planning are true?

1. Search in plan space and use least commitment when possible.
2. Make only choices that are relevant to solving the current part of the problem.
3. Both of the above.
4. None of the above.

ANSWER: 3

d) Progression planners reason from the goal state, trying to find the actions that will lead to the start state. True or False?

ANSWER: False. That is regression planner.

e) In Medieval Europe, Latin worked as the Lingua Franca. Today English has taken over that role, obviously giving an advantage to persons who have it as mother tongue. There have been attempts to create artificial human languages (e.g., Esperanto and Interlingua) that would not give anybody such an advantage, but those languages have not been very successful. Suppose you were given the task of creating such as language. Which of the following would say say would be most important to try to restrict:

1. The lexicon.
2. The grammar.
3. Ambiguity.
4. Redundancy

ANSWER: 2 or 3

f) Two search engines were evaluated on a web search query. Engine A returned 27 web pages, 18 of which were deemed relevant to the query. Engine B returned 9 pages, all of which were relevant to the query. Which of the following statements is definitely correct?

1. System A had a higher recall than system B.
2. System B had a higher precision than system A.
3. System B had a higher F1-score than system A.
4. System A had a better performance than system B.

ANSWER: 2

g) When performing sentiment analysis, it is normally important to find out:

1. Who the opinion holder is.
2. What object the opinion is expressed on.
3. If the opinion is positive, negative or neutral.
4. All of the above.

ANSWER: 3

h) Which of the following statements is not correct?

1. The distributional hypothesis assumes that words with similar usage have similar meanings.
2. The bag of words model ignores the grammatical structure of the language.
3. An n-gram model is an example of a language model.
4. Grounding means that a speaker defines the basis for a dialogue.

ANSWER: 4

LYKKE TIL!

EXAM TDT4136 HØST-2018 ORDINARY.
QUESTIONS and ANSWERS (at the very end)

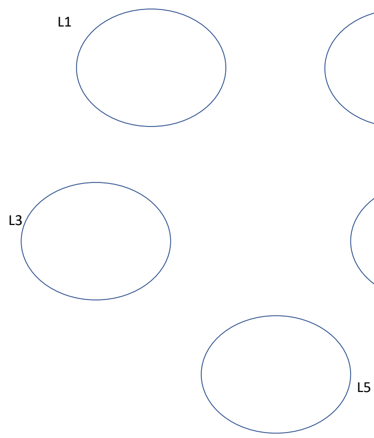
Problem 1: CSP (10 POINTS)

In a 2-days seminar, there are 5 lectures to be allocated to 3 professors. Each professor can teach at most 1 lecture on a day. Each professor has knowledge to teach only a subset of the lectures. The following table shows which professor has the knowledge to teach which lectures where "L" means "lecture":

Prof. Arne	L1, L2, L3
Prof. Berit	L1, L2, L5
Prof. Carl	L2, L4, L5

There are some constraints about the sequence that the lectures can be given: Day(L1) < Day(L2), i.e., Lecture 1 must be taught the day before the day of Lecture 2, and Day(L3) < Day(L5). Each lecture will be assigned to a professor and to a day.

1) Complete the following drawing to a constraint graph that represents this problem. Nodes represent the lectures that are the Variables in this Constraint Satisfaction Problem. You will draw the links between the nodes in the graph.



2. Write down the domains of the variables. Each value in the domain of a variable shows the combination of a professor that can teach the course and the time it can be taught. Instead of the whole name of a professor use only the first letter of his/her name, i.e., A, B, C shows the three professors. A domain value, hence looks like this: A2 (i.e., Arne on Day=2), B1 (i.e., Berit on Day=1. You can write the domain values by filling in the curly brackets for each variable (L1,…., L5).

   L1: { ……… }

L2: { }

L3: { }

L4: { }

L5: { }

2) Write down all the constraints, as implicit constraints, for this problem. Hint: You can use n-ary Alldiff to represent one type of the constraints you need.

3) Is this initial constraint graph arc-consistent? If not, apply AC-3 arc consistency algorithm and find the reduced domains. Write these domains for each variable in the form:

L1: { ……… }

L2: { }

L3: { }

L4: { }

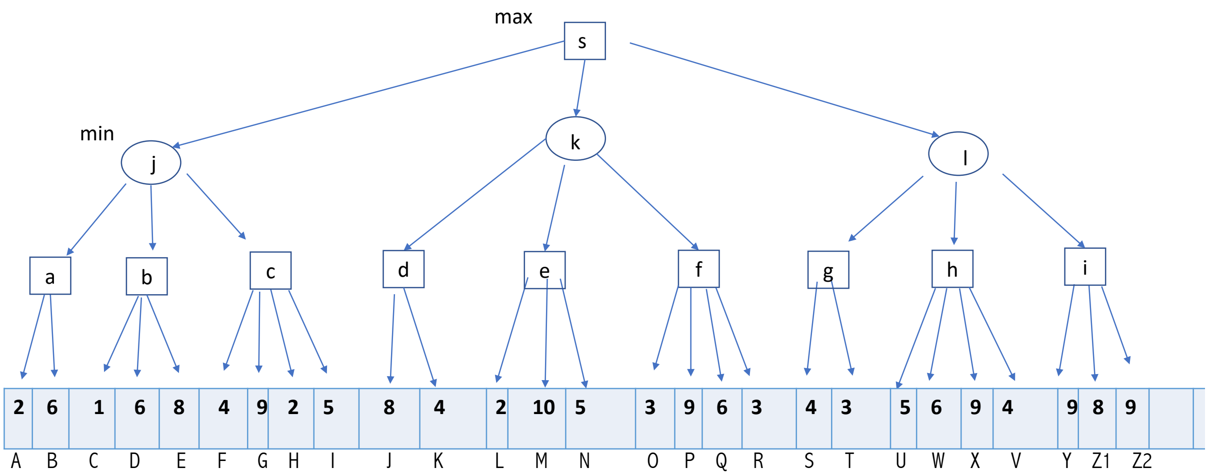
L5: { }

5) Apply Backtracking on this arc-consistent graph without forward checking. Use Minimum Remaining Value for variable ordering (tie breaking in numerical order), and Least Constraining Value for value ordering (tie breaking alphanumerically). What order are the variables are assigned and what are their values? Your answer will look like this:

The 1. assigned variable is ………………, and its value is …………………
The 2. assigned variable is ………………, and its value is …………………
The 3. assigned variable is ………………, and its value is …………………
The 4. assigned variable is ………………, and its value is …………………
The 5. assigned variable is ………………, and its value is ……………......

Problem 2: Adversarial Search   (10 POINTS)

1) Write the minimax values in the nodes (s, j,k,l….h,i) at different layers of the search tree above the leaf nodes.



2) Apply alpha-beta pruning algorithm to prune the parts of the tree that don't need to be examined.
   For each pruned part (i.e., one or more leaf nodes) of the tree write down which nodes are pruned and why, referring to V and Alpha/Beta values, in the following format:

   PRUNE <The letter(s) that represent the pruned leaf nodes> BECAUSE : <Reason>

   The "reason" is either

   V= <value> **<** Alpha = <value> or

   V= <value> **>** Beta = <value>

   Example (not necessarily correct, just to show the requested format):

   Prune A,B,C because: v=4 < Alpha=7

   So, if there are more than one leaf nodes next to each other write them at once and together as in the example above.

PROBLEM 3 True/False Questions (2 points for each correct answer, -1 point for each wrong answer, 0 for each unanswered question. Total score between 0-20 points)

1. Reactive agents typically use partial planning.

2. This is procedural knowledge about two cities in Norway: bigger (Oslo, Trondheim)

3. Expectimax is better suited for a deterministic environment than minimax.

4. In simulating annealing search the states represent a complete solution.

5. Principal of rationality (due to Allen Newell) maintains that the agent chooses actions in order to achieve its goal using the knowledge it has the knowledge it might gather.
6. Shortcoming of hill climbing algorithms are local maximas and plateaus.

7. Consider a block world problem where On(A,B), On(B,C) is the goal, and the KB Consists of these sentences: On(C,A), On(B,Table), On(A,Table), Clear(C), Clear(B), Block(A), Block(B), Block(C). Suppose a planner that, given subgoals G1,...,Gn, solves each subgoal consecutively (i.e., first one goal, and then the next one,…). If we use such a planner to solve the planning problem above and solve the goals in the given order (i.e., On(A,B), On(B,C)) the planning will obtain an optimal plan.

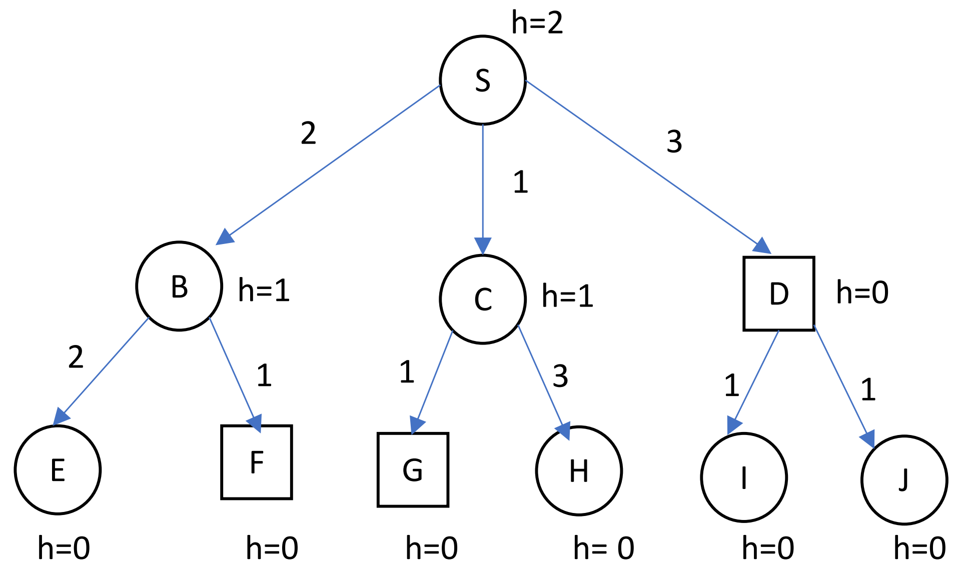
8. "Frames" as knowledge representation language combines declarative and procedural knowledge through their resolution mechanism.

9. Semantic networks allow multiple inheritance on the basis of specificity in the hierarchy.

10. Precision measures an NLP system's ability not to exclude a relevant document from the list of retrieved documents

PROBLEM 4 (Search Algorithms) (10 POINT)

In the following tree, the goals are shown by squares - there are three goals. Heuristic values and the step costs are as shown in the figure.



For each of the following algorithms, write the list of expanded nodes, and the path found. Ties are broken alphabetically.

1. Depth-first search

   Expanded nodes:

   The final path:

2. Breadth first search

   Expanded nodes:

   The final path:

3. Uniform Cost search

Expanded nodes:

The final path:

4. Greedy Best First search

   Expanded nodes:

   The final path:

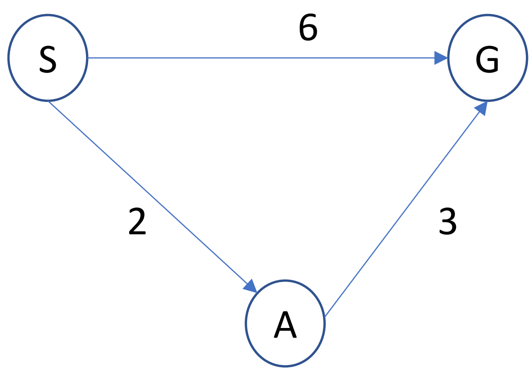
5. A* search

   Expanded nodes:

   The final path:

PROBLEM 5 (A* heuristics) (10 POINTS)

Consider A* search for the following search graph where S is the starting and G is the goal node. There are 4 different heuristic functions (H1-H4) of which values for the S, G, A nodes are shown in the table on the right of the graph.



Heuristic	h(S)	h(A)	h(G)
H1	4	1	0
H2	5	4	0
H3	4	3	0
H4	5	2	0

1) For each heuristic function fill in the following table with Y/N for admissibility and consistency for the search graph above. Explain your answer for each Yes or No.

Heuristic	Admissible (Yes/No)	Consistency (Yes/No)
H1		
H2		
H3		
H4		

2) Dominance of Heuristics. Remember that domination has a special meaning in the context of heuristic functions. What does it mean that a heuristic function dominates another one? Write the definition of dominance of heuristics.

Now your task is to investigate the dominance relationship between H1 – H4.

3) Do heuristic functions H3 and H4 have a dominance relationship?
4) Is there a dominance relationship between Heuristic function H4 and H1?

PROBLEM 6 (Propositional Logic) 10 POINTS

Four bunny rabbits played together in the forest. Each bunny is either brown or white. However, none of them could see each other very clearly, and their views were obscured by bushes.
Bunny 1 says, “One of bunnies 2 & 3 is brown and one is white, but I can’t tell which.”
Bunny 2 says, “One of bunnies 3 & 4 is brown and one is white, but I can’t tell which.”
Bunny 3 says, “Bunny 4 is brown.”
Bunny 4 says, "It is not the case that both Bunny 1 and Bunny 4 are brown."

Bunny 1 asks, “Is it true that I am a white bunny rabbit?”

Converting these statements into propositional logic and using resolution refutation, can we answer the question of Bunny 1? Use Bi for "Bunny *i* is brown", e.g., B2: Bunny 2 is brown.

Show all the steps you have taken to prove/answer this question.

PROBLEM 7 (GAME THEORY) (10 POINTS)

This problem is about watering rice farms in Sumatra. Two farms are located in the riverside, upstream and downstream farms. Water is not sufficient---meaning if both farmers water their rice crops at the same time the upward one gets enough water but the downstream one is not watered sufficiently. However, if they don't water their crops at the same time, both farms will suffer from a pest problem.

The game is about the timing of watering. Assume two possible times for watering, A and B.

Let x represent the utility loss for the farmer who gets reduced water and let y represent the loss in utility due to pests. Assume that when there is no crop loss due to lack of water or a pest problem, then the payoff is equal to 1.

1. Draw the payoff matrix using A and B as actions. Use x and y to define the payoffs for the upward and downward farms.
2. Under which conditions does a strongly dominant strategy equilibrium arise?

PROBLEM 8 SHORT QUESTIONS

1. In some environments randomized behaviour can be rational. Describe what type of environments and give an example.
2. Entailment for first-order logic is semidecidable. What does this mean? Explain very briefly.
3. Convert this sentence into Conjunctional normal form and show all the steps in this process:
   ∀Y (∀X (taller(Y,X) V wise(X)) => wise(Y))

5 Fill in the blank so that the sentence becomes correct.

A entails B if and only if (. . . . .) is unsatisfiable.

PROBLEM 9 (LOGIC) (10 points, 2 point each)

Translation from English to Logic.

1) There is a mouse that every cat chases.
2) For every flavor, there is some person who likes that flavor.
3) “There was no student who scored 100 on every quiz.”
4) There is a barber who shaves all men in town who do not shave themselves.
5) There exists a lawyer all of whose clients are doctors

ANSWERS

PROBLEM 1 (CSP): (points: 2-2-1-2-3)

1) Fully connected graph. Alldiff (L1, L2, L3, L4,L5). A lecture is represented in terms of 2 attributes, the prof and the day/time, combination of these two. In map colouring problem there was 1 attrib, i.e, the color. Here each leture is different from all others because no lecture has same prof-day combination. 2 points are given only if each lecture node has an edge with each of the rest of the lectures, otherwise zero points.

2)

L1: {A1, A2, B1, B2 }

L2: { A1, A2, B1,B2, C1,C2 }

L3: { A1, A2 }

L4: { C1, C2 }

L5: { B1, B2, C1, C2 }

3) Constraints:

   Alldiff(L1, L2, L3, L4, L5)
   Day(L1) < Day (L2)
   Day(L3)< Day(L5)

4) Not arc-consistent.

L1: { B1 }

L2: { A2,B2, C2 }

L3: { A1 }

L4: { C1, C2 }

L5: { B2, C2 }

5) Bactracking:

The 1. assigned variable is L1, and its value is B1

The 2. assigned variable is L3, and its value is A1

The 3. assigned variable is L4, and its value is C1

The 4. assigned variable is L5, and its value is B2

The 5. assigned variable is L2, and its value is A2

PROBLEM 2 (Adversarial Search): (points 3-7)

1) 8 ; 6,8,4 ; 6,8,9 ; 8,10,9 ; 4,9,9

2) Here full point both for strictly larger/smaller and larger&equal/smaller&equal versions where the former was the version the exam question. If the answer is correct for either of these cases, ful point for this question is given

Prune H and I because: V=9 > Beta=6

Prune E Because V=6 >= beta=6. (counted as correct both if E is pruned and not pruned)

Prune N because: V= 10 > Beta=8

Prune Q and R because: V=9 > Beta=8

Prune h (i.e., U, W, X, V) and i (i.e., Y, Z1,Z2) because: V=4 < Alpha=8

PROBLEM 3 (True/False): (total 20 pts, 2 points each correct answer, -1 each wrong answer. 0 for no answer)

F **F** **F** **T** **F** **T** **F** **F**(Frame does not have resolution mechanism) **T** **F**

PROBLEM 4 (Search Algorithms) (points 2-2-2-2-2)

1 Depth-first search

Expanded nodes: SBEF

The final path: SBF

2 Breadth first search

Expanded nodes: S
Children(S): B,C,D where goal test immediately, D is goal

The final path: SD

3 Uniform Cost search

Expanded nodes: SCBG

The final path: SCG

4 Greedy Best search

Expanded nodes: SD

The final path: SD

5 A* search

Expanded nodes: SCG

The final path: SCG

Problem 5 (Heuristics) (points: 6-2-1-1)

1)

Heuristic	Admissible (Yes/No)	Consistency (Yes/No)
H1	Yes	No
H2	No	No
H3	Yes	Yes
H4	Yes	No

H2 is not inadmissible heuristic, because it overestimates the cost from A. The actual cost of A to G is 3 while its heuristic value is 4.
Heuristic H1 is not consistent: h(S) - h(A) = 4 - 1 = 3 NOT <= path(S →A) = 2.
Heuristic H3 is consistent: h(S) - h(A) = 4 - 3 = 1 <= 2
Heuristic H4 is not consistent: h(S) - h(A) = 5 - 2 = 3 NOT <=2

2) A heuristic dominates another if all of its values are greater than or equal to the corresponding values of the other heuristic
3) Heuristic functions H3 and H4 have no dominance relationship.
4) Heuristic function H4 dominates H1.

PROBLEM 6 Propositional Logic (Bunny)

You translate these facts into Propositional Logic as:
"One of bunnies 2 & 3 is brown and one is white, but I can't tell which." : (B2 and ¬ B3) or (¬ B2 and B3) **! Note that the propositional sentence should represent that one of 2 and 3 is white and one is brown, i.e., only one is brown - and they don't have the same colour. You lose point if you represent this sentence for example as (B2 or B3).**

[B3 and (¬ B4) or [(¬ B3) and B4)]
B4
¬(B1 and B4)

Bunny 1 asks, "Is it true that I am a white bunny rabbit?"
You translate this query into Propositional Logic as "(¬ B1)" and form the negated goal as "B1." Your
knowledge base (KB) in CNF plus negated goal (in clausal form) is:
(B2 or B3)
[(¬ B2) or (¬ B3)]
(B3 or B4)
[(¬ B3) or (¬ B4)]
B4
[(¬ B1) or (¬ B4)]
B1 (negation of ¬B1 (= white Bunny)

You have B4 and B1 and [(¬ B1) or (¬ B4)]. So you reach a contradiction immediately.

From B4 and [(¬ B1) or (¬ B4)] derive (¬ B1)
Contradiction with B1.

PROBLEM 7 (GAME THEORY, 10 points) (points: 5-5)

1) The payoff matrix:

	A	B
A	1, 1 − x	1 − y, 1 − y
B	1 − y, 1 − y	1, 1 − x

2. There is no strongly dominant strategy equilibrium in this problem. Assume x,y are positive numbers. Then (B,A) cannot be a dominant strategy equilibrium (DSE) as both agents could get a positive payoff by choosing another action. the same holds for (A,B). For (A,A) to be a DSE, it would have to be the case that $x < y$ (so that A-for the column player- is a strict best response to to A-for the row player). However, for A-column player to be a dominant strategy, it must also do better if row player plays B, which can only be the case when $y < x$. Thus (A,A) cannot be a DSE. The same reasoning holds for (B,B) meaning there is no DSE for any value of x or y.

The question goes like this:

This problem is about….

The game is about the timing of watering. Assume two possible times for watering, A and B.

Let x represent….

1……..
2…….
It is obvious that both 1 and 2 is about "This problem/game" and you are expected to answer for the matrix you created.

If you wrote as the answer what strongly dominance means (with formula etc), but didn't apply it to this problem, 1 point will still be given.

If the matrix is not correct but still have the same utility structure and you answer correctly the second part, you get full point (5 pts) for the 2. Part (i.e., no strongly dominant str.)

PROBLEM 8 SHORT QUESTIONS

1) In competitive multiagent environments it can avoid the pitfalls of predictability.
2) Algorithms exist that say yes to every entailed sentence but no alg. Exists that also say no to every nonentailed sentence (Textbook, p 325)

3)

$$\forall y\ (\forall x\ (taller(y,x) \lor wise(x)) \Rightarrow wise(y))$$

$$\forall y\ (\forall x\ \neg(taller(y,x) \lor wise(x)) \lor wise(y))$$

$$\forall y\ \forall x\ (\neg taller(y,x) \land \neg wise(x)) \lor wise(y))$$

$$\forall y\ \forall x\ (\neg taller(y,x) \lor wise(y)) \land (\neg wise(x) \lor wise(y))$$

$$(\neg taller(y,x) \lor wise(y)) \land$$

$$(\neg wise(x) \lor wise(y))$$

4) $A \land \neg B$

PROBLEM 9 (LOGIC) (10 points, 2 point each)

Translation from English to Logic.

1) There is a mouse that every cat chases.

$\exists y \, \forall x \quad Mouse(y) \wedge [Cat(x) \Rightarrow Chases(x, y)]$

2) For every flavor, there is some person who likes that flavor.

$\forall f \, \exists p \; Flavor(f) \Rightarrow [\, Person(p) \land Likes(p, f) \,]$

3) "There was no student who scored 100 on every quiz."

$\forall s \, \exists q \; Student(s) \rightarrow [\, Quiz(q) \wedge \neg Scored100(s, q) \,]$

4) There is a barber who shaves all men in town who do not shave themselves.

$\exists x \, \forall y \; Barber(x) \land Man(y) \land \neg Shaves(y, y) \Rightarrow Shaves(x, y)$

5) There exists a lawyer all of whose clients are doctors

$\exists \; p1 \; \forall \; p2 \; Occupation(p1, Lawyer) \land [Customer(p2, p1) \Rightarrow \_Occupation(p2, Doctor)]$

or

$\exists \; p1 \; Occupation(p1, Lawyer) \land [\forall \; \_p2 \; Customer(p2, p1) \Rightarrow \_Occupation(p2, Doctor)]$

OPPGAVE 1 (True/False questions) (20 pts, 2 pts for each correct answer, -1 for each wrong answer. Total points will not be less than zero) *Mark each of the following sentences either as True or False*

1. True or False: Greedy best-first search algorithm is guaranteed to find an optimal path.

   ANSWER: False. It takes the first path to goal it finds.

2. True or False: Uniform Cost algorithm is guaranteed to find the optimal solution when all step costs are greater than zero and the branching factor is finite.

   ANSWER: True

3. True or False: Let *b* be the branching factor of a search, *d* the depth of the solution, and m the maximum depth of the search space. Then the complexity of breadth-first search is b^m.
   Answer= false. It is b^d
4. True or false: $(A \Leftrightarrow B) \vDash (\neg A \vee B)$

   ANSWER: True

5. Linear planning is incomplete.
   Answer: True, Linear planning is incomplete. Think for example about Sussman's
   anomaly.

6. Simple "hill climbing" algorithm is perfect to solve constraint satisfaction problems.
   ANSWER: False. It can get stuck at local minima and fail to find a solution.

7. A sound logical reasoning process is not necessary in order to pass the Turing test.
   ANSWER: True. Humans don't always use sound logical reasoning

8. Depth-first tree search algorithm always expands at least as many nodes as an A* tree search algorithm with admissible heuristic does.

   ANSWER: False: a lucky DFS might expand exactly d nodes to reach the goal. A* largely dominates any graph-search algorithm that is guaranteed to find optimal solutions.

9. The set consisting of "mammal" and "non-mammal" categories is both a disjunctive and an exhaustive decomposition of the category "animal".

Answer: True.

10. Explainability is an ethical problem in AI which domain knowledge may help to solve. Answer: True

OPPGAVE 2 (First Order Logic) (15pts – 7-3-5)

The Knowledge base has the following sentences for which FOL representations are given below.

Everyone who loves all animals is loved by someone.
Anyone who kills an animal is loved by no one.
Sofie loves all animals.
Either Sofie or CarAccident killed the cat, who is named Kismet.

FOL representations:

1. $\forall x\ [\forall y\ [Animal(y) => Loves(x,y)]] => [\exists z\ Loves(z,x)]$
2. $\forall x\ [\exists y\ (Animal(y) \wedge Kills(x,y)] => \neg(\exists z\ Loves(z,x))$
3. $\forall x\ [Animal(x) => Loves(Sofie, x)]$
4. $Kills(Sofie,Kismet) \vee Kills(CarAccident,Kismet)$
5. $Cat(Kismet)$

Query: Did CarAccident kill the cat?

You are going to the answer the above query by using resolution by refutation.

1. First convert all FOL sentences into conjunctive normal form (CNF). Show every step in this process.
2. Write down any background knowledge that is needed to solve the problem
3. Apply resolution by refutation and show how the query is answered. Show each and every unification.

ANSWER TO PROBLEM – FOL

CNF:
Everyone who loves all animals is loved by someone.

In FOL
$\forall x\{[\forall y[Animal(y)=>Loves(x,y)]]=>[\exists z\ Loves(z,x)]\}$

Remove Implications
$\forall x\ \{[\neg[\forall y\ \{Animal(y)\ =>\ Loves(x,y)\}]]\ \vee\ [\exists z\ Loves(z,x)]\}$

$\forall x \{[\neg[\forall y \{\neg Animal(y) \vee Loves(x,y)\}]] \vee [\exists z\ Loves(z,x)]\}$
Move negation inward
$\forall x \{[\exists y \{\neg \neg Animal(y) \wedge \neg Loves(x,y)\}] \vee [\exists z\ Loves(z,x)]\}$
$\forall x \{[\exists y\ Animal(y) \wedge \neg Loves(x,y)] \vee [\exists z\ Loves(z,x)]\}$

Skolemize
$\forall x\{[Animal(F(x)) \wedge \neg Loves(x,F(x))] \vee [Loves(G(x),x)]\}$

Drop universal quantifier
$[Animal(F(x)) \wedge \neg Loves(x,F(x))] \vee [Loves(G(x),x)]$
Use distributive law (and get two clauses)
$(Animal(F(x)) \vee Loves(G(x),x))$ AND $(\neg Loves(x,F(x)) \vee Loves(G(x),x))$

Anyone who kills an animal is loved by no one.
Transfer to FOL
$\forall x \{[\exists y\ (Animal(y) \wedge Kills(x,y)] => \neg(\exists z\ Loves(z,x))$

Remove Implications
$\forall x \{\neg[\exists y\ (Animal(y) \wedge Kills(x,y)] \vee \neg(\exists z Loves(z,x))\}$

Move negations inwards
$\forall x \{[\forall\ y\ \neg Animal(y) \vee \neg Kills(x,y)] \vee (\forall z\ \neg Loves(z,x))\}$

Remove quantifiers
$\neg Animal(y) \vee \neg Kills(x,y) \vee \neg Loves(z,x)$

Sofie loves all animals.
FOL form
$\forall x\ [Animal(x) => Loves(Sofie, x)]$

Remove implications
$\forall x\ [\neg Animal(x) \vee Loves(Sofie, x)]$

Remove quantifier
$\neg Animal(x) \vee Loves(Sofie, x)$

Either Sofie or CarAccident killed the cat, who is named Kismet.

FOL
form
Kills(Sofie,Kismet) $\lor$Kills(CarAccident,Kismet), Cat(Kismet)

Bakground knowledge: All cats are animals: $\forall$x Cat(x) => Animal(x)

RESOLUTION:

Cat(Kismet) , ¬Cat(x) $\lor$ Animal(x)

Unify(Cat(Kismet), ¬Cat(x)) = { x/Kismet }

First line thus resolves to:

Animal(Kismet)

Kills(Sofie,Kismet) $\lor$ Kills(CarAccident,Kismet), ¬Kills(CarAccident,Kismet)
Resolves to:

Kills(Sofie,Kismet)

¬Animal(y) $\lor$ ¬ Kills(x,y) $\lor$ ¬ Loves(z,x), Animal(Kismet)
Unify(Animal(Kismet), ¬Animal(y)) = {y/Kismet}

Resolves to:

¬ Kills(x,Kismet) $\lor$ ¬ Loves(z,x),

¬ Loves(x,F(x)) $\lor$ Loves(G(x),x), ¬Animal(z) $\lor$ Loves(Sofie, z)

Unify(¬ Loves(x,F(x)) , Loves(Sofie, z)) = { x / Sofie, z / F(x)}

Resolvent clause is obtained by substituting the unification rule

Loves(G(Sofie),Sofie) $\lor$ ¬Animal(F(Sofie))

Animal(F(x)) $\lor$ Loves(G(x),x), Loves(G(Sofie),Sofie) $\lor$ ¬Animal(F(Sofie))

Unify(Animal(F(x)) , ¬Animal(F(Sofie)))= { x / Sofie}

Resolvent clause is obtained by substituting the unification rule

Loves(G(Sofie),Sofie)

¬ Kills(x,Kismet) $\lor$ ¬ Loves(z,x), Loves(G(Sofie),Sofie)

Unify(¬ Loves(z,x), Loves(G(Sofie),Sofie)) = { x / Sofie, z / G(Sofie)}

Resolvent clause is obtained by substituting the unification rule

¬ Loves(G(Sofie),Sofie)

¬ Loves(G(Sofie),Sofie), Loves(G(Sofie),Sofie)

Resolvent clause is empty. Proof succeeded

OPPGAVE 3 - A* search algorithm (13 pts, 1-4-4-4)

1. Apply A* algorithm for graphs on the graph in the following figure (Figure 1). Write down the nodes in the order they are expanded. A is the start node, and G is the goal node.
2. What is the returned path? Is it optimal? explain your answer on an example from the given graph in the figure.
3. Modify the pseudocode in the figure (Figure 2) for A* algorithm for graph search so that it guarantees to find the optimal solution with heuristic values given in Figure 1. Write down the pseudocode in a separate paper starting from the sentence just before your modification starts, and ending with the sentence right after your last change. That is, you don't need to write the whole pseudocode, only the part you modified, plus a single/one original sentence before and one after your modified sentences.
4. Assume that a search tree has heuristic values which enable the A* algorithm presented in the pseudocode (the unmodified version in figure 2) to find an optimal path to the goal. Would the A* algorithm still be guaranteed to find the minimal path to the goal if there are negative transition costs? This question is general, not about the problem presented in Figure 1.

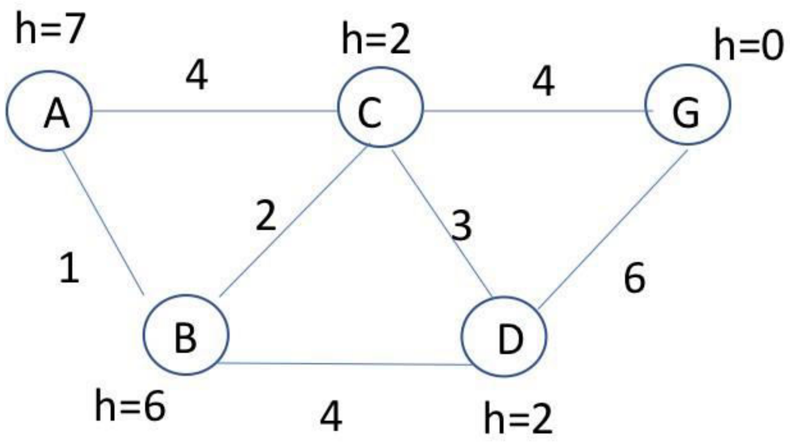


Figure 1 Graph for the question. A is the start node, and G is the goal node.

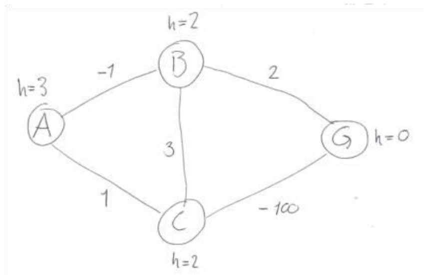
```
Start.g = 0;
Start.h = heuristic(Start)
FRONTIER = {Start}
CLOSED = {empty set}
    WHILE FRONTIER is not empty
        N = FRONTIER.popLowestF()
        IF state of N= GOAL RETURN N
        add  N to CLOSED
        FOR all children M of N not in CLOSED:
            M.parent = N
            M.g = N.g + cost(N,M)
            M.h = heuristic(M)
            add M to FRONTIER
        ENDFOR
    ENDWHILE
```

Figure 2 .Pseudocode for A algorithm.*

ANSWER to PROBLEM (A* alg.)

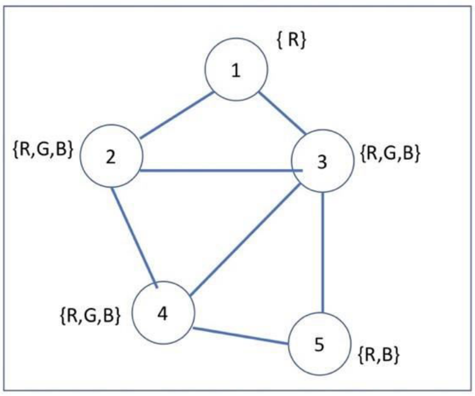
1. Expanded nodes: ACBDG.

2. Returned path: ACG. Not optimal. Because of B is not consistent. H(B) > h(C) + c(B,C) C is expanded with path cost 6, but then it appears as the child of B again with a path cost 5 (3+2) this time but since it is in “closed” is not re-expanded.
3. The pseudocode is changed so that a node in “closed” can be re-expanded (by putting it back into “frontier”. This can be done by removing the “not in CLOSED” part of Sentence 9. Alternatively, the path cost (M.g+M.h) of the new encounter of the node (M) is compared with path cost of M in the “closed” and it is put back to frontier only if its new path cost is smaller.
4. No. See the example below (cost 1 versus -99)



OPPGAVE 4 - CONSTRAINT SATISFACTION (12 pts, 2-4-2-4)

Consider the following constraint graph (in the figure) for a graph coloring problem where the constraints mean that the connected nodes cannot have the same color. The variables are shown inside the nodes while the domains are shown next to each variable node.



1. What are the domains after a full constraint propagation using an arc consistency algorithm?
2. Show the sequence of variable assignments during a pure backtracking search (don’t assume that propagation above has been done). Assume that the variables are examined in numerical order and the values are assigned in the order shown next to each node. Show assignments by writing the variable number and the letter for the value, e.g, 5R, 2G.
3. Describe how forward checking works.

4. This time you’ll apply backtracking search with forward checking. Use the same ordering convention for variables and values as above. Show the sequence of variable assignments during backward search with forward checking. Again,

show assignments by writing the number of variables followed by the letter for the value.

ANSWER to PROBLEM (Constaint Satisfaction)

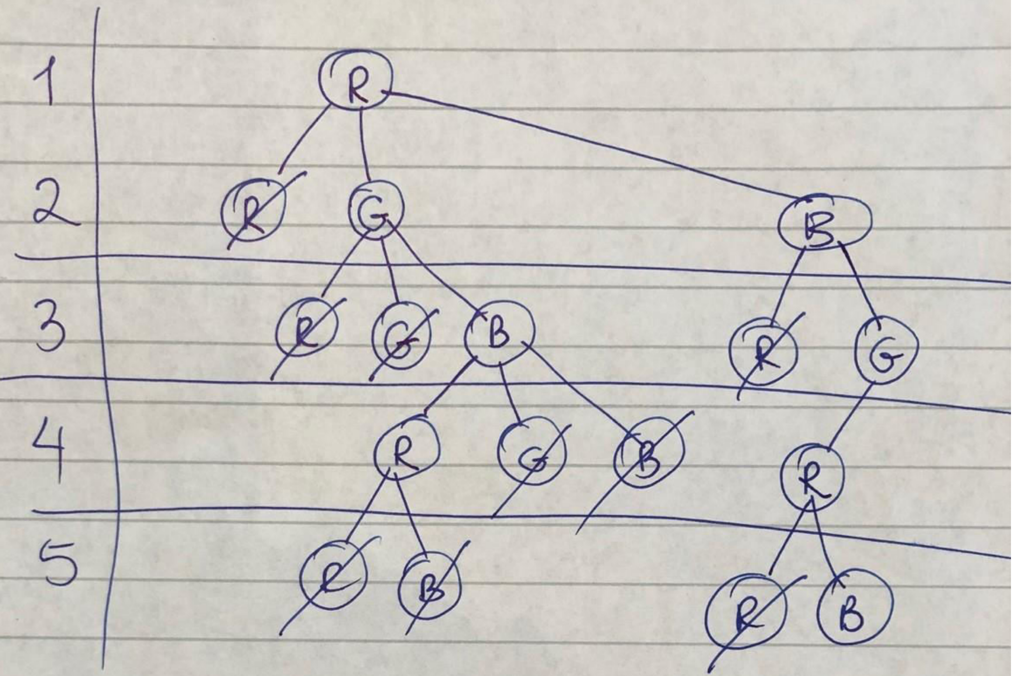
1. 1={R}
   2={G,B}
   3={G,B}
   4={R,G,B}
   5={R,B}

2. 1R, 2R, 2G, 3R,3G, 3B, 4R, 5R, 5B, 4G, 4B, 2B, 3R, 3G, 4R, 5R, 5B. The tried but not assigned values during backtracking search are shown in parentheses: 1R, (2R), 2G, (3R), (3G), 3B, 4R, (5R), (5B), (4G), (4B), 2B, (3R), 3G, 4R, (5R), 5B. The figure below shows all value considerations. Full 4 points have been given also to answers that don't include the inconsistent values (i.e., the ones in the parenthesis), i.e., 1R, 2G, 3B, 4R, 2B, 3G, 4R, 5B is also accepted as correct answer. So both 1R, 2R, 2G, 3R,3G, 3B, 4R, 5R, 5B, 4G, 4B, 2B, 3R, 3G, 4R, 5R, 5B . and 1R, 2G, 3B, 4R, 2B, 3G, 4R, 5B are accepted as correct answer.

The following and the next figure are in order to show/explain you, they are not required in the answer.

(2)

Pure BT (without inference)



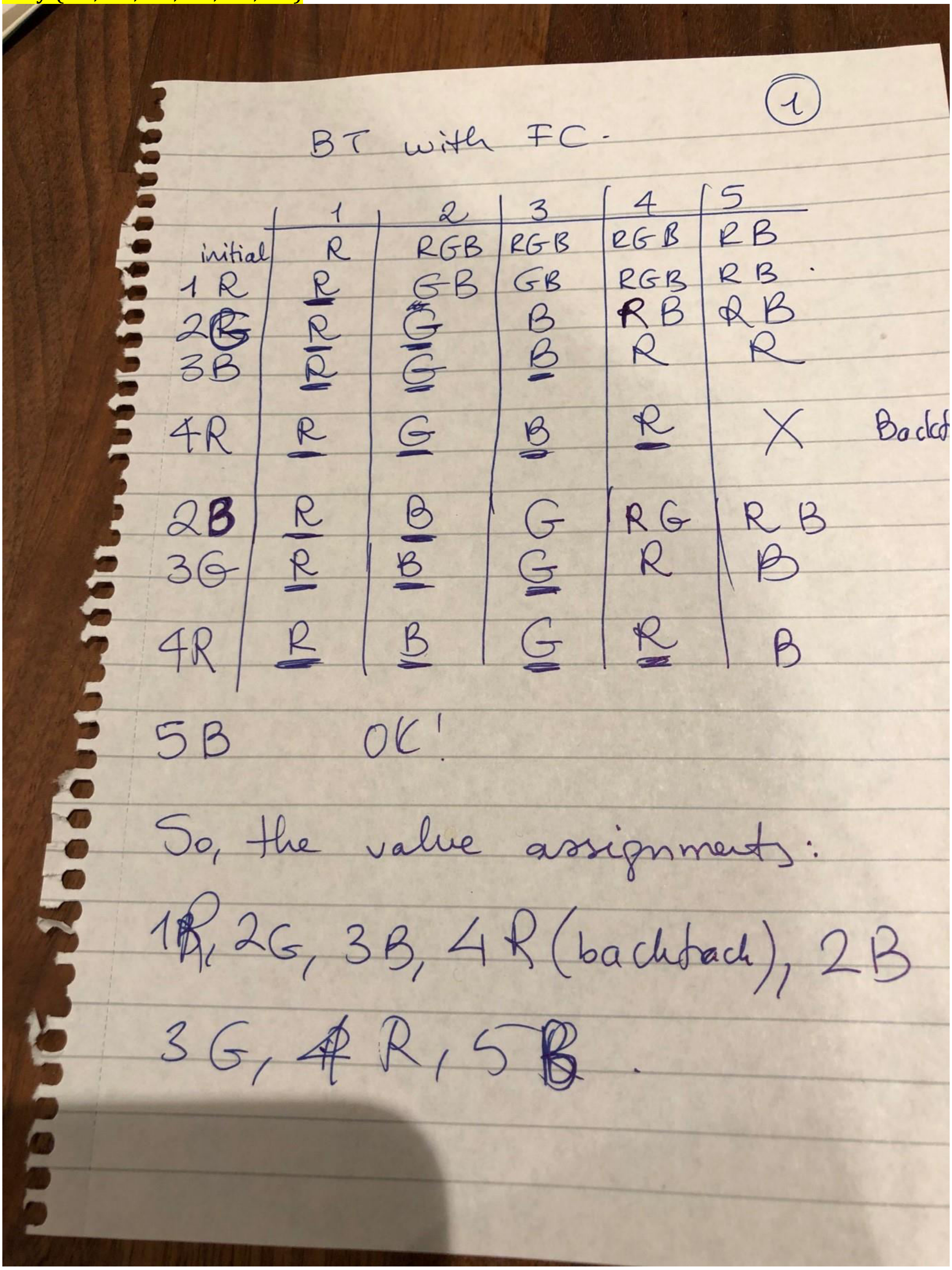
The considered values during search (i.e in search tree)

1R, (2R), 2G, (3R), (3G), 3B, 4R, (5R), (5B), (4G), (4B), 2B, (3R), 3G 4R (5R) 5B.

The value assignments shown in the paranthese are discovered to be inconsist during consistency checking.

3. Forward checking does check only 1 step(immediate neighbours not assigned yet) after assignment of a variable.

4. 1R, 2G, 3B, 4R, 2B, 3G, 4R, 5B. No point is given if the answer is the result path only (i.e., 1R, 2B, 3G, 4R, 5B)



BT with FC.

	1	2	3	4	5
initial	R	RGB	RGB	RGB	RB
1 R	R	GB	GB	RGB	RB
2G	R	G	B	RB	RB
3B	R	G	B	R	R
4R	R	G	B	R	X
2B	R	B	G	RG	RB
3G	R	B	G	R	B
4R	R	B	G	R	B

Backt

5B OK!

So, the value assignments:

1R, 2G, 3B, 4R (backtrack), 2B

3G, 4R, 5B.

OPPGAVE 5 – Game Theory (10 pts, equal points for each question))

Consider the game for which the payoff matrix is shown in the following figure.

		agent2 G	*agent2* NG
agent1	H	8, 0	3, 1
agent1	NH	4,4	2,3

Figure 3 Payoff Matrix.

1. Identify any *dominated* strategy. Explain your answer.
2. Find the *Nash equilibrium*. What are the equilibrium payoffs, i.e., values for each agent?
3. Are there any *pareto optimal* joint actions? If any exists, what are they?
4. Explain (in general, not for this particular problem) why a *social welfare maximizing* joint action profile is also pareto optimal.

Answer:

1. First notice, neither of Agent2's strategies are dominated since,

   u2 (H, G) = 0 < 1 = u2 (H,NG) and u2 (NH,G) = 4 > 3 = u2 (NH, NG)
   H strictly dominates NH for Agent1
   since,
   u1 (H, G) = 8 > 4 = u1 (NH, G)
   and u1 (H, NG) = 3 > 2 = u1 (NH, NG) .

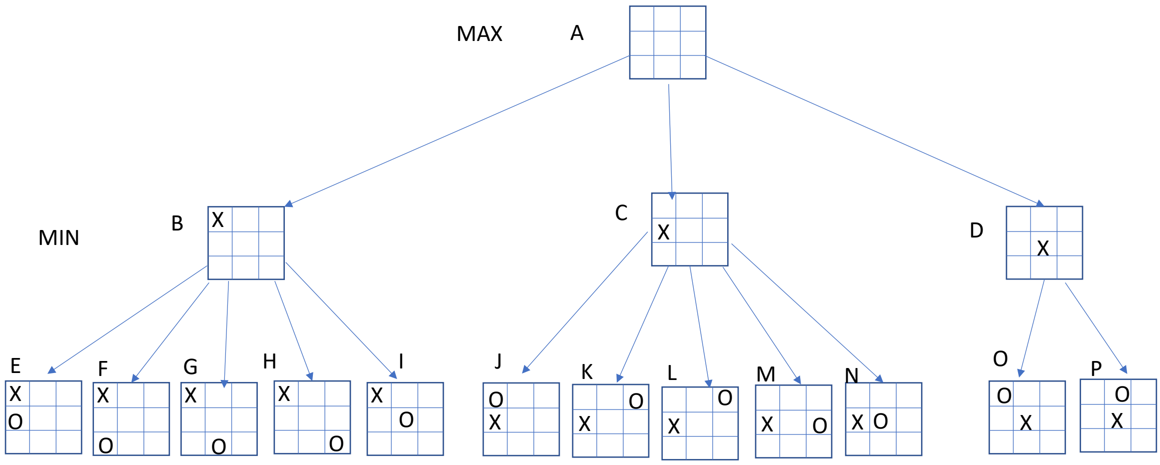
2. NE is (H, NG) which yields a payoff of (3, 1)

3. (H,G) and (NH, G) are pareto optimal

4. Social welfare maximizing profile means that the sum of utilities of all agents are highest for this action profile. This means that it is not possible to increase utilities of both agents at the same time.

OPPGAVE 6 - ADVERSARIAL SEARCH (10 pts, 3-3-4)

Consider a tic-tac-toe game on a 3x3 grid (see the figure below) where players MAX and MIN take turns marking the spaces in a 3×3 grid by placing their X's and O's, respectively. The player who succeeds in placing three of their marks in a horizontal, vertical, or diagonal row is the winner.



The values of the terminal nodes have not been provided. You will compute these values using an evaluation function *e*. Function *e* uses a heuristic that estimates the value of each terminal node according to the following formula:

e(node)= E1-E2 where

E1=sum of the number of rows, columns and diagonals that are possible winning situations for Max and,

E2= sum of the number of rows, columns and diagonals that are possible winning situations for Min.

The following figure shows examples for computing the values of some hypothetical nodes:

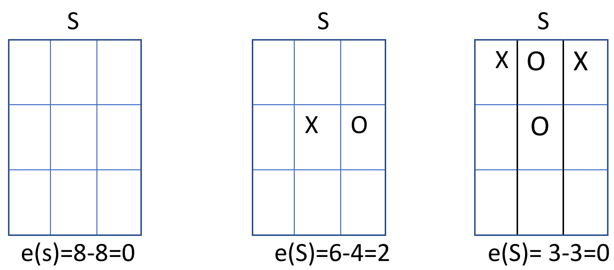


Figure : Example on estimation the values of terminal nodes

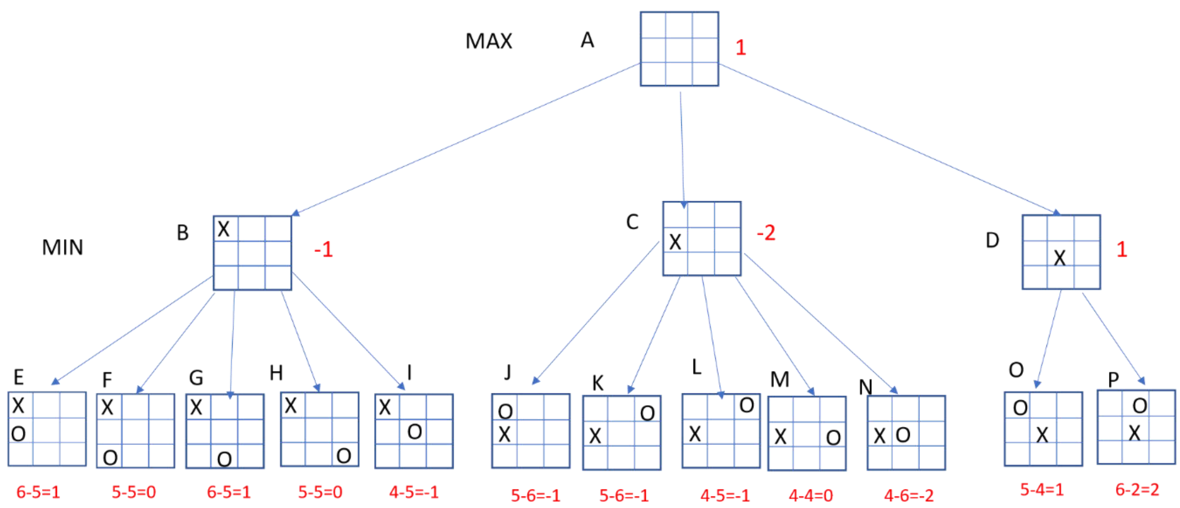
1. Compute and write down the values of each terminal node node, i.,e of E, ……, P.

2. Using the *Minimax* algorithm find and write down the values of the remaining nodes(A,…D) in the search tree. Which action will Max play in this game, the action whose outcome is B, C or D?

3. Is it possible to prune any nodes using the *Alpha-Beta pruning* algorithm? If there are any, write down the prunable node(s) - i.e., write the letter for the node.

ANSWER to ADVERSARIAL SEARCH

1. See figure for MINIMAX alg. Best action is the one with outcome D.
2. K,L, M,N can be pruned. Answers excluding K or excluding L are also correct since the two are equal.



OPPGAVE 7 - SHORT QUESTIONS (20 pts, 2 pts for each question. Plus 2 points for correct answer to the "bonus"/voluntary question.)

1. How is the goal information represented in simple reflex agents?

   Answer: the goal is implicit in the condition-action rule (goals are "designed in")

2. Is the PL sentence $((P \rightarrow Q) \land Q) \rightarrow P$ valid, unsatisfiable or satisfiable? Justify your answer.

   ANSWER: Satisfiable. When P=T and Q=T the sentence is true, but when P=F and
   Q=T the sentence is false.

3. Translate the following sentence into predicate logic:
   "Any person who has an umbrella is not wet"

   ANSWER: ∀ x [(IsPerson(x) => ∃ y (Has(x, y) ∧ IsUmbrella(y))) =>
   ¬ IsWet(x)] .

4. Translate the following sentence into predicate logic:
   "John has at least two daughters."

   ANSWER: ∃x, y Daughter(x, John) ∧ Daugher (y,John) ∧ ¬ (x=y)

5. Assume a Hill Climbing algorithm that aims to find the best state according to a heuristic cost function. Does it try to find the global minimum or the global maximum?

   Answer: Global minimum

6. It has been suggested that the first phase of *GraphPl0an* be used as a heuristic function for forward search in the following way: Given a state *s* and goal *g*, run the graph-construction phases of *GraphPlan* until all the components are represented and not mutex in the last layer. Let *n* be the number of action layers in the graph. We will let *n* be the heuristic value for s. Is this an admissible heuristic? Explain your answer.

   ANSWER: Yes, this is an admissible heuristic because it will always underestimate the distance to a solution (no solution can be nearer than the first layer where all of the solution propositions are no mutex)

7. If *GraphPlan* terminates with a successful, 3-action plan in the first iteration, what constraints are there on the order in which the actions must be executed?

   ANSWER: There are no constraints on what order the actions must be executed. They are all in the same layer, which indicates that they can be performed in parallel.

8. Does *Regression Planning* work in a forward or backward manner?

   ANSWER: Backward

9. You will represent the concept of "student" using a *frame-based* knowledge representation language. You want the age of a student to be computed on the basis of her birth year and the current year. How would you represent this in a slot of "student" frame?

   Answer: In the "age" slot, and as a demon, a procedure/function that computes the age.

Name: student		
isa: person		
age:	(calculate-age)	..: .. ...

10. Assume a version of the original vacuum cleaner agent in the textbook. 10% of the time the SUCK action of this one does not clean the floor if it is dirty and even may deposit dirt on the dirt on the floor if the floor is clean. Classify this environment with respect to each of the following dimensions:
    Sequential/Episodic, deterministic/stochastic, and dynamic versus static.
    Answer: sequential, stochastic, static

11. BONUS QUESTION: Assume that *Simulated Annealing* search algorithm starts from a state S_0 in the middle of a large plateau. That is, the values of all states on the plateau are exactly the same. Assume also that in the first step the random neighbor we picked is S_1, which has the same value as S_0. Will Simulated annealing move to S_1? Explain your answer mathematically (i.e. using a formula). No points will be given otherwise.

    ANSWER: True. Since P(S_0-> S_1) = exp($\Delta E/T$) and
    ΔE =|VALUE(S_0)-VALUE(S_1)|, we see that with probab. 1 we will move to S_1.

ANSWERS to TDT4136-2020 Fall exam

SEARCH

a)

- Initial_state: The initial state is the starting star system S
- States: The states are the set of all states reachable from the initial. state by a sequence of actions.
- Actions: The actions are the possible action available in a state. Given a state s, ACTIONS(s) returns all actions that can be performed in s. For instance ACTIONS(C) = {Go(S); Go(B); Go(H); Go(G)}

• Path_cost: The path cost is the sum of costs of the individual actions along the path. They are shown on the graph. For instance COST(In(S);GO(B)) = 1
• Transition_model: Given a state and action, this returns the resulting planet: RESULT(In(B); Go(C)) = In(C)
• Goal_test: The goal test checks whether a given state is the goal state. Here the goal is the singleton set {In(G)}

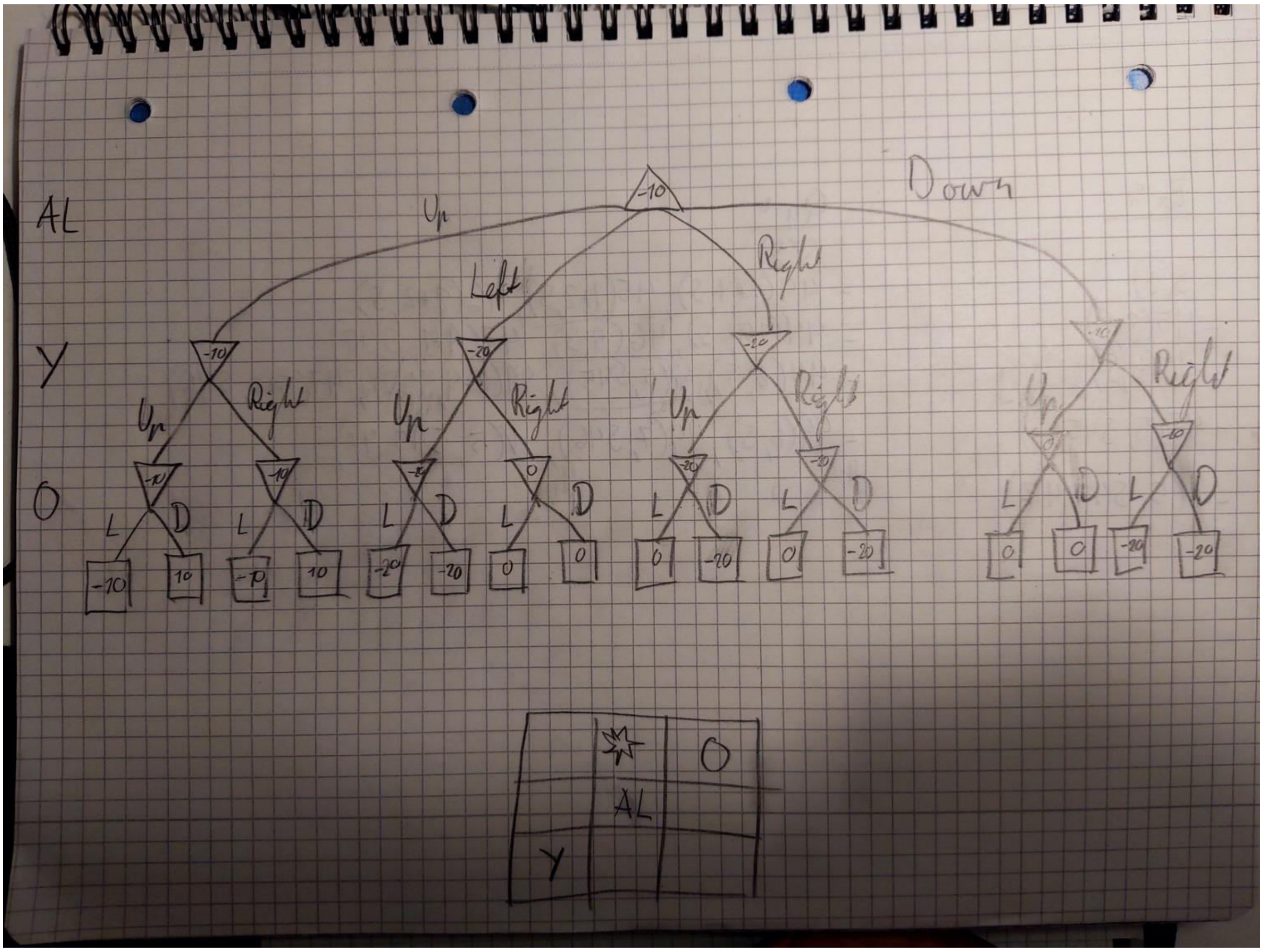
b)

Explored	**Frontier**
	S(5)
S(5)	C(4,SC), B(5,SB)
S(5), C(4, SC)	H(6, SCH), G(8, SCG), B(5, SB)
S(5), C(4, SC), B(5, SB)	H(6, SCH), G(8, SCG)
S(5), C(4, SC), B(5, SB), H(6, SCH)	~~G(8, SCG)~~, G(6, SCHG)
S(5), C(4, SC), B(5, SB), H(6, SCH), **G(6, SCHG)**	

c)

• Path found: SCHG, cost = 6. Not optimal.
• Reason: Heuristic is inconsistent.
• Fix: Change e.g h(C) = 3, then A* will find SBCHG which has a cost of 5 and is optimal.

d)



e). See Figure 2 below.
a: No nodes are pruned.
b: Search the tree from a right to left manner instead.
This corresponds to rearranging the nodes so that the three looks like. See figure 3

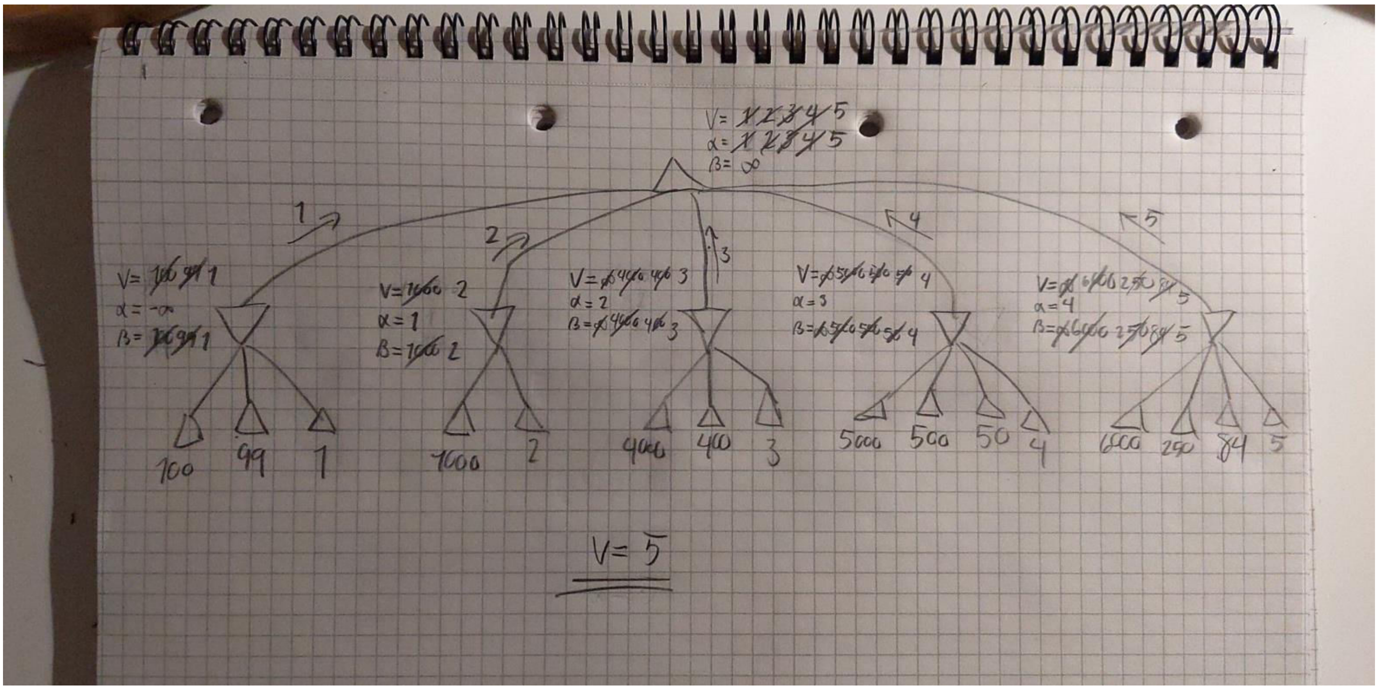


Figure 2

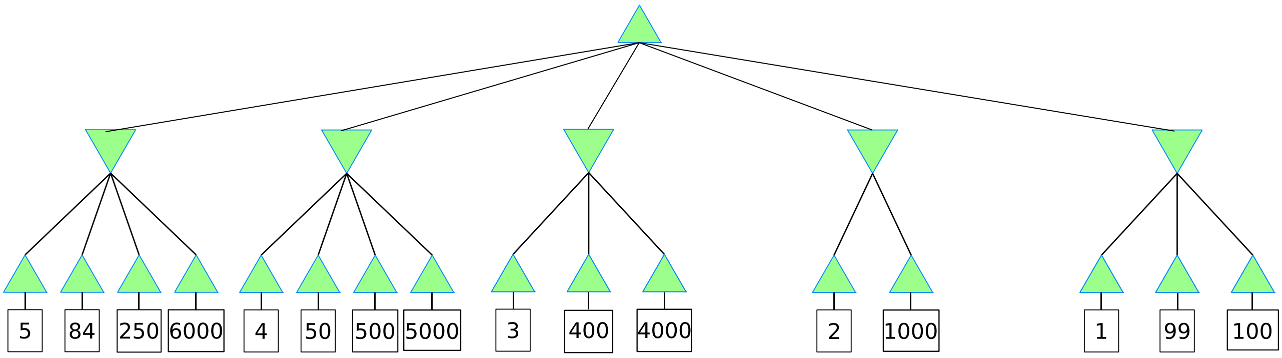


Figure 3

f). Found solution is not optimal, optimal solution would be SCDG

Explored	Frontier	Current Node
	S	
S	A(S), B(S), C(S)	S
S, A(S)	B(S), C(S)	A(S)
S, A(S), B(S)	C(S), D(S, B), E(S, B)	B(S)
S, A(S), B(S), C(S)	D(S, B), E(S, B)	C(S)
S, A(S), B(S), C(S), D(S, B)	E(S, B), G(S, B, D)	D(S, B)

Path found: SBDG
It is NOT the optimal path.
The optimal path is: SBEG

LOGIC

1) In this case it doesn't really matter which representation one picks, both can represent the board with the same amount of symbols. Because it doesn't matter I just picked propositional logic.

$Sparkles_{x,y} =$ Square (X, Y) has sparkles
$Diamonds_{x,y}$ = Square X Y has diamonds
$RedGlow_{x,y}$ = Square X Y has a red glow
… and so on for Lava and Player
Board state is then: $Sparkles_{1,1} \wedge Diamonds_{1,2} \wedge RedGlow_{1,2} \wedge Sparkes_{1,3} \wedge Lava_{1,3} \wedge RedGlow_{2,1} \wedge Sparkles_{2,2} \wedge Sparkles_{2,3} \wedge RedGlow_{2,3} \wedge Lava_{1,3} \wedge RedGlow_{3,2} \wedge Player_{3,2} \wedge Sparkles_{3,2} \wedge Diamonds_{3,3}$

2)

1) $\forall x\ \forall y\big(Square(y) \wedge Square(x) \wedge Adjacent(x,y) \wedge \mathrm{Has}(\mathrm{y}, \mathrm{Diamonds}) \Rightarrow Sparkles(x)\big)$
2) $\forall x\ \forall y\big(Square(y) \wedge Square(x) \wedge Adjacent(x,y) \wedge Has(y, \mathrm{Lava}) \Rightarrow RedGlow(x)\big)$
3) $\forall x(Square(x) \wedge Has(x, Player) \wedge Has(x, Lava) \Rightarrow GameOver)$
4) $\neg\exists y\big(Diamond(y) \wedge \neg Has(Player, y)\big) \Rightarrow GameWon$
5) $\forall x \forall z\big(Square(x) \wedge Player \wedge Diamond(z) \wedge Has(x, Player) \wedge Has(x,z) \Rightarrow Has(Player, z)\big)$
6) $\forall x\left(\Big(Square(x) \wedge CanMove(Player, x) \wedge \exists y\big(Square(y) \wedge Adjacent(y,x) \wedge Has(y, RedGlow)\big)\Big) \Rightarrow \exists y\big(Square(y) \wedge Adjacent(y,x) \wedge Has(y, Sparkles)\big)\right)$

7) $\forall x \forall y \big(Square(x) \wedge Square(y) \wedge CanMove(Player, x) \wedge Has(x, Player) \Rightarrow Adjacent(x, y) \big)$

3) No, the player can not win. This is because of rule 6. The player can never move to (2, 1) because it has a red glow but does not sparkle, which means that the player can never move to (2, -1)

4)
a, b, d already in CNF
c: $\forall x\ \forall y \big(Person(x) \wedge Afraid(x, y) \Rightarrow \neg\ Close(x, y) \big)$
gives $\forall x \forall y \big(\neg Person(x) \vee \neg Afraid(x, y) \vee \neg\ Close(x, y) \big)$ because implication is equivalent to this
gives $\neg Person(x_1) \vee \neg Afraid(x_1, y_1) \vee \neg\ Close(x_1, y_1)$ by removing universal quantifiers.
E: Same steps as c gives

$$\neg Close(x\_2, y\_2)\ \vee \neg Close(y\_2, z\_2)\ \vee Close(x\_2, z\_2))$$

F: Same steps as c gives

$$\neg Close(x_3, y_3) \vee Close(x_3, y_3)$$

G: Same steps as c gives

$$\neg CanMine(x_4, Diamonds) \vee Close(x_4, Diamonds)$$

"Richard does not mine diamonds" is

$$\neg CanMine(Richard, Diamonds)$$

So refutation is:
H: $CanMine(Richard, Diamonds)$
H and G gives I: Close(Richard, Diamonds)
B and D gives J: $\neg Afraid(Richard, y_1) \vee \neg Close(Richard, y_1)$
A and J gives K: $\neg Close(Richard, Lava)$
K and E gives L: $\neg Close(Richard, y_2) \wedge \neg Close(y_2, Lava)$
L and I gives M: $\neg Close(Diamonds, Lava)$
M and D gives empty, concluding proof by resolution refutation.

5)
Here RedGlow = RG, Diamonds = D
a. Valid, RedGlow may be false
b. Neither, RedGlow can't be false and true at the same time
c. Valid, RedGlow is always either true or false
d. Valid, equivalent to c
e. Satisfiable, true when RedGlow and Diamonds have same truth value
f. Satisfiable, true when RedGlow and Diamonds do not have same truth value
g. Satisfiable, equivalent to $(\neg RedGlow \wedge \neg Diamonds) \vee (RedGlow \wedge Diamonds) \vee RedGlow$ which is true f.ex. when RedGlow is true and false when RedGlow is false and Diamonds is true.

Constraint Satisfaction Problem:

1. Domains based on the favorite colours and plant types of persons :
   Peter: {LG-Calat1, LG-Calat2, LG-Phil1}
   Anette: { V-Calat3, B-Phil2, DG-Calat3 }
   Rudolf: {V-Phil1, V-Calat1, B-Phil2 }
   Daisy: { V-Calat1, B-Phil2}
   Femke: { V-Phil1, V-Calat1, V-Calat2, V-Calat3, DG-Phil1, DG-Calat1, DG-Calat2, DG-Calat3, Y-Phil1, Y-calat1, Y-Calat2, Y-Calat3}

2. Search tree for "backtracking with forward checking".

   Assign P: LG-Calat1 do inference:
   Some domains change because person P now has "reserved" LG colour and Calat1 plan. Nobody else can take them. Below are all the domains:

   A={V-Calat3, B-Phil2, DG-Calat3} ,
   R={V-Phil1, B-Phil2}
   D has a constraint with P. Plant(P)= Plant(D). Then
   D={-) Empty. Backtrack.

   Assign Per: **LG-Calat2**
   Anette: { V-Calat3, B-Phil2, DG-Calat3 }
   Rudolf: {V-Phil1, V-Calat1, B-Phil2 }
   Daisy: { V-Calat1}
   Femke: { V-Phil1, V-Calat1, , V-Calat3, DG-Phil1, DG-Calat1, DG-Calat3, Y-Phil1, Y-calat1, Y-Calat3}

   Assign Anette= V-Calat3. Do forward check
   Rudolf: {B-Phil2 }
   Daisy: { } Empty. Stop backtrack

   Assign Anette= B-Phil2
   Rudolf: { } Empty domain. backtrack

   Assign Anette= DG-Calat3
   Rudolf: {V-Phil1, V-Calat1, B-Phil2 }
   Daisy: { V-Calat1, B-Phil2 }
   Femke: { V-Calat1 }. Must have same plant category as Anette, i.e., Calat.

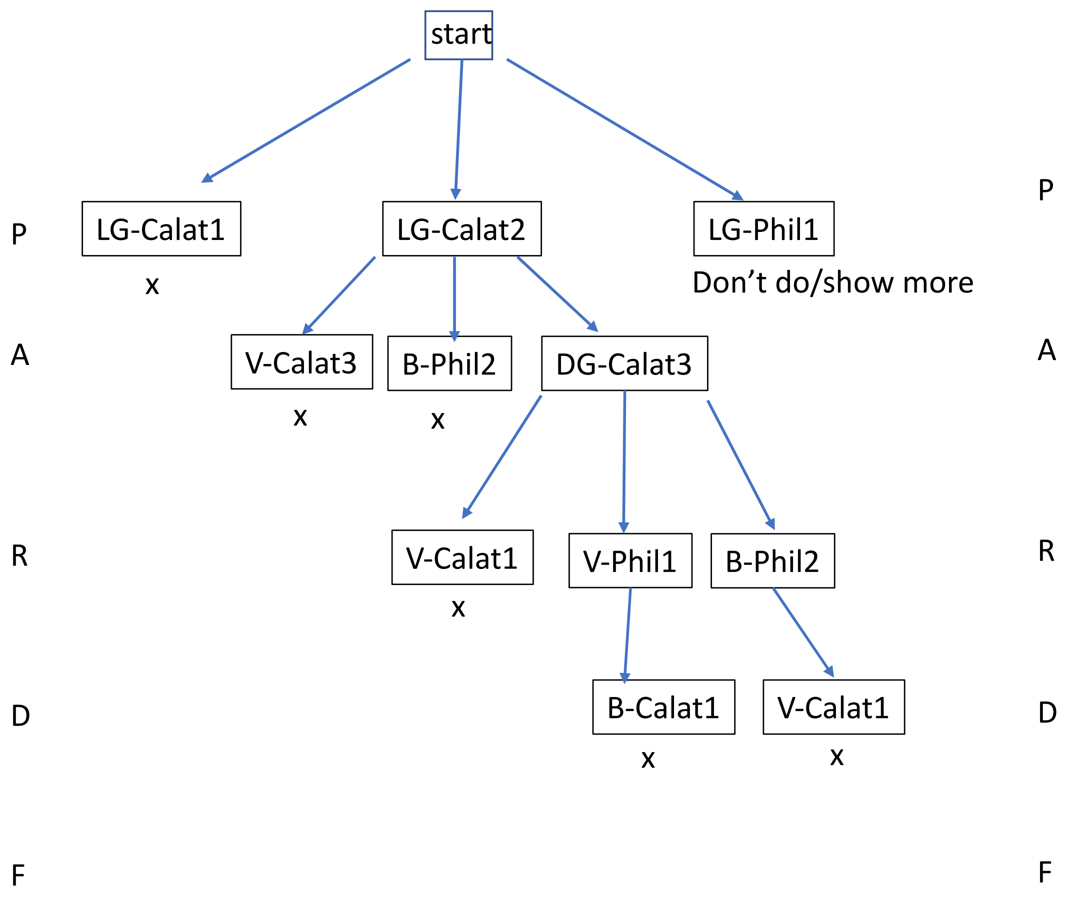
   Assign Rudolf= V-Calat1
   Daisy: {- }Empty, backtrack

Assign Rudolf= V-Phil1
Daisy: { B-Calat1} must have same same plant category as P, which is Calat
Femke: { Y-Calat1} . must have same plant category as Anette

Assign Daisy= B-Calat1
Femke: { -} Empty, Backtrack

Assign Rudolf= B-Phil2
D: {V-Calat1}
Femke: {Y-calat1, Y-Calat1} same category as Anette.

Assign D= V-Calat1
Femke: {-} Empty backtrack



3. Search tree for "**backtracking search with forward checking and propagating through domains that are reduced to singleton domains.**"

Assign P: LG-Calat1.
Do inference: Some domains change because person P now has "reserved" LG colour and Calat1 plan. Nobody else can take them. Below are all the domains:

A={V-Calat3, B-Phil2, DG-Calat3} ,
R={V-Phil1, B-Phil2}
D has a constraint with P. It cannot have Calat1 but must have a Calat plant because Plant-category(P) = Plant-category(D). Then
D={ -}. Empty domain. Backtrack.

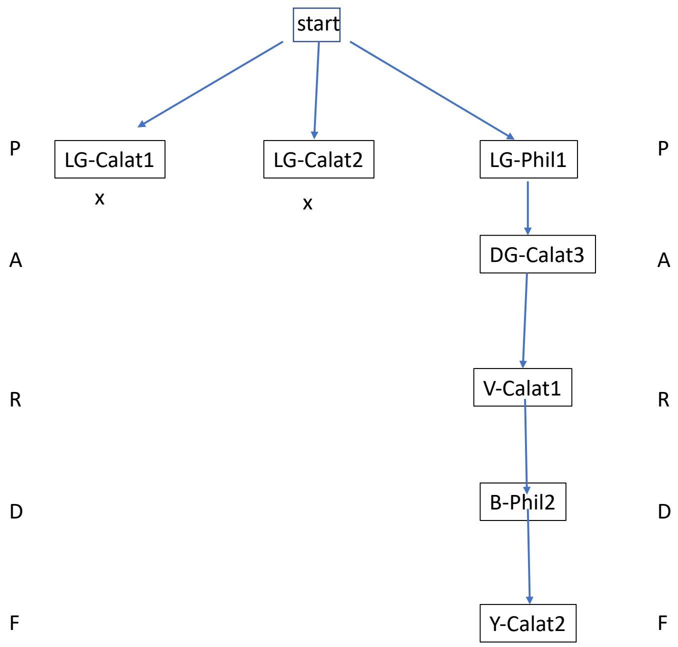
Assign P= LG-Calat2
Anette: { V-Calat3, B-Phil2, DG-Calat3 }
Rudolf: {V-Phil1, V-Calat1, B-Phil2 }
Daisy: { **V-Calat1**}. Singleton domain, propagate - Constraint on plant category with P.

Anette: { B-Phil2, DG-Calat3 }
Rudolf: {**B-Phil2** } Singleton domain, propagate

Anette: {**DG-Calat3**}. Singleton propagate
Femke cannot have LG, V, B, DG. Cannot have Calat2,Calat1,Calat3, and Phil2. Must have the same plant category as Anette which is Calat.
Femke:{Empty} Backtrack

Assign **P= LG-Phil1**
Anette: {V-Calat3, B-Phil2, DG-Calat3 }
Rudolf: {V-Calat1, B-Phil2}
Daisy: **{ B-Phil2**}-since must have plant in same category as Peter

Anette: { V-Calat3, DG-Calat3 }
Rudolf: {**V-Calat1}** singleton
Anette: {**DG-Calat3** }. Cannot have V because of Rudolf propagation.
Femke: {Y-Calat2}



PlANNING

1)
   a) Flaw1. Precondition Smooth(B) of paint(B) is not satisfied
   Flaw2. putOn(A,B) threatens paint(B) –because it makes A not free
   Flaw3. putOn(A,B) threatens paint(A) - –because it makes B not free
   Flaw4. putOn(A,B) threatens sand(A) - because it makes A not free
   So, need for ordering links.
   b) Flaw 1: add action. Sand(B)
   Flaw 2: paint B must be executed before putOn(A,B), i.e., an ordering link is added
   Flaw 3: paint B must be executed before putOn(A,B), i.e., an ordering link is added
   Flaw 4: putOn(A,B) comes after sand(A) as well as newly added sand(B)
   c) (sand(A) OR sand(B)) ; (Paint(A) OR paint(B)) ; putOn(A,B)

2) No constraints, they can be executed in parallel.
3) Both return TAK as the plan. Its postconditions (C and D) satisfies the goal $C \wedge D$.

GAME THEORY :

1) The Nash equilibrium is when all students chose the same integer. No student will have an incentive to move away from that number because moving to any other number will end up in zero payoff. There is no other Nash because any student who has chosen a less-often-chosen number would benefit from switching to the most-often one. Also if there are two numbers that are most often, students who have chosen these will benefit from switching to the other most-often number.

2) All strategy profiles except (B,B) are pareto optimal. (B,A) is also social optimum.
3) We eliminate a and b because c dominates them. Then on the remaining matrix, we can eliminate S and R as they both are dominated by T. Then the solution is (c,T).

SHORT QUESTIONS

1) LOCAL SEARCH QUEST

(a) Eval(a)= 1- # attacking pairs(a)= 1-5= -4
Eval(b) = 1-# attacking pairs(b)= 1-9= -8

(b) See textbook p.126, Figure 4.5. Simulated Annealing algorithm. The alg decides to move if Delta-E> 0. If smaller, then moves with probability $e^{(\text{Delta-E/T}).}$
Delta E= (1-9)-(1-5)= -4. Moves with probability 1/e.

2) Ethical Issues

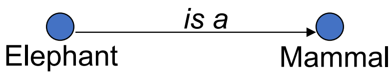
This is an open question and I wanted to see how students think/reason. Any justified answer is accepted. Student connect consequentialism to the whole agent notion, rationalism, search strategies, more specific search problems such as adversarial search, as well as game theory. The connection with the game theory and the utilities is particularly interesting.

3) PEAS and Characteristics of the Environment

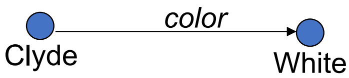
Environment: partially observable, deterministic (but may be stochastic if the sensor is not good and the robot may be blown away by the mine), continuous, static, sequential (mines are most probably places with a some distance between them. If one found, then the next one will be at least in 30 cm distance). The answers may differ based on the assumptions. So, various answers are accepted here.

4) Translation from Semantic Networks to Logic

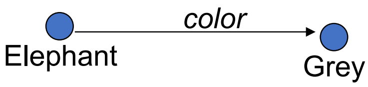
Translate the sematic network representations shown in the figure to logic representations. The following is the outset. I accepted also variations such as Isa(elephant,mammal), color(elephant, grey) type of answers without quantification.



(x)(elephant(x) -> mammal(x))



color(clyde, white)



(x)(elephant(x) -> color(x, grey))

ANSWERS

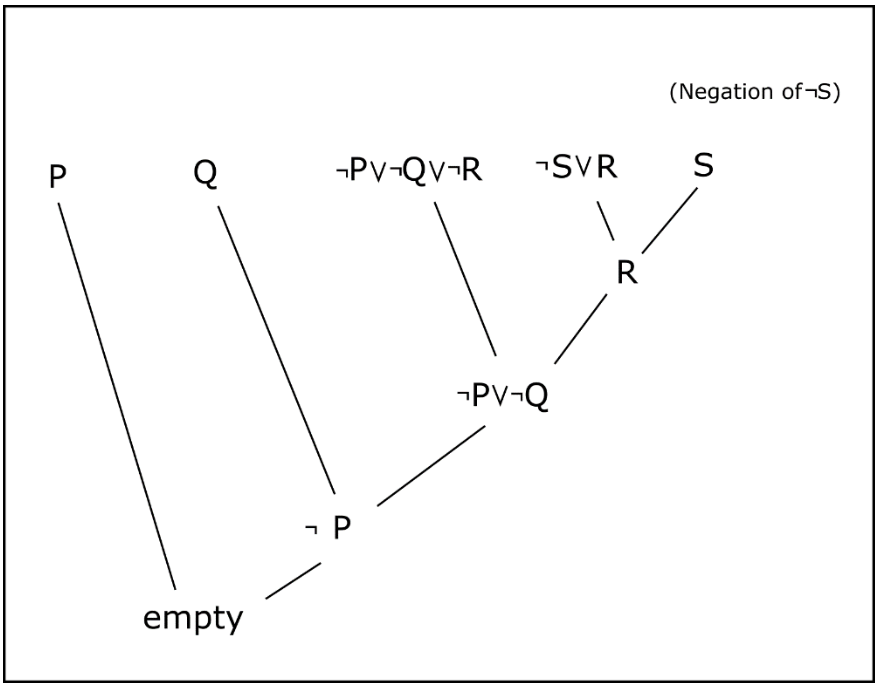
PROBLEM 1 – LOGIC

a)

1. $P \wedge Q$ given (premise)
2. P (from 1, decomposing a conjunction)
3. Q (from 1)
4. $P \rightarrow \neg(Q \wedge R)$ given
5. $\neg(Q \wedge R)$ (from 2,4)
6. $\neg$ Q $\vee$ $\neg R$ (from 5)
7. $\neg R$ (from 3,6)
8. $S \rightarrow R$ given
9. $\neg S$ (from 7,8)

b) Draw the truth table and see there is one row where 1,2, and 3 is true and $\neg$ S is also true there.

c)



d) First, we need to convert the definition of Green into CNF.

- $\forall x$: Green(x) $\leftrightarrow$ Bikes(x) $\vee$ [$\exists y$: Drives(x, y) $\wedge$ Electric(y)]

  Break the double-implication into 2 conjoined implications

- $\forall x$: [Green(x) $\rightarrow$ Bikes(x) $\vee$ [$\exists y$: Drives(x, y) $\wedge$ Electric(y)]] $\wedge$

  [[Bikes(x) $\vee$ [$\exists y$: Drives(x, y) $\wedge$ Electric(y)]] $\rightarrow$ Green(x)]

  Convert implications to disjunctions

- $\forall x$: [¬Green(x) $\vee$ Bikes(x) $\vee$ [$\exists y$ Drives(x, y) $\wedge$Electric(y)]] $\wedge$

  ¬[Bikes(x) $\vee$ [$\exists y$ Drives(x, y) $\wedge$ Electric(y)] $\vee$ Green(x)

  Move negations inward

- $\forall x$: [¬Green(x) $\vee$ Bikes(x) $\vee$ [$\exists y$: Drives(x, y) $\wedge$ Electric(y)]] $\wedge$

  ¬Bikes(x) $\wedge$ ¬[$\exists y$ Drives(x, y) $\wedge$ Electric(y)] $\vee$ Green(x)

  Continue moving negations inward

- $\forall x$: [¬Green(x) $\vee$ Bikes(x) $\vee$ [$\exists y$ Drives(x, y) $\wedge$ Electric(y)]] $\wedge$

  ¬Bikes(x) $\wedge$ [$\forall y$ ¬Drives(x, y) $\vee$ ¬Electric(y)] $\vee$ Green(x)

  Skolemizing produces an F(x) in place of the existential-quantified y:

- $\forall x$: [¬Green(x) $\vee$ Bikes(x) $\vee$ [Drives(x, F(x)) $\wedge$ Electric(F(x))]] $\wedge$
  ¬Bikes(x) $\wedge$ [$\forall y$: ¬Drives(x, y) $\vee$ ¬Electric(y)] $\vee$ Green(x)

  Remove the universal quantifications, since all remaining variables are universally quantified.

- [¬Green(x) $\vee$ Bikes(x) $\vee$ [Drives(x,F(x)) $\wedge$Electric(F(x))]] $\wedge$

  ¬Bikes(x) $\wedge$ [¬Drives(x, y) $\vee$ ¬Electric(y)] $\vee$ Green(x)

  Distribute the disjunction in the first half

- [¬Green(x) $\vee$Bikes(x) $\vee$Drives(x,F(x))] $\wedge$
  [¬Green(x) $\vee$ Bikes(x) $\vee$ Electric(F (x))] $\wedge$
  ¬Bikes(x) $\wedge$ [¬Drives(x, y) $\vee$ ¬Electric(y)] $\vee$ Green(x)

  Distribute the disjunction in the second half to produce a conjunction of 4 disjuncts (CNF).

- [¬Green(x) ∨ Bikes(x) ∨Drives(x,F(x))] ∧

  [¬Green(x) ∨ Bikes(x) ∨ Electric(F (x))] ∧

  [Green(x) ∨ ¬Bikes(x)] ∧
  [¬Drives(x, y) ∨ ¬Electric(y) ∨ Green(x)]

  Next, combine these 4 clauses with the other givens and add in the negation of the goal sentence: Green(Sophie). Then keep applying the resolution rule until θ = False is derived, indicating the contradiction.

  1. ¬Green(x) ∨Bikes(x) ∨Drives(x,F(x)) Given
  2. ¬Green(x) ∨Bikes(x) ∨Electric(F(x))] Given
  3. Green(x) ∨ ¬Bikes(x)] Given
  4. ¬Drives(x, y) ∨ ¬Electric(y) ∨Green(x) Given

  5. Electric(Tesla) Given

  6. Drives(Sophie,Tesla) Given
  7. ¬Green(Sophie) (Assuming negation of target sentence)
  8. ¬Drives(x, Tesla) ∨ Green(x) (Resolving 4 and 5 with θ = {y/Tesla})

  9. Green(Sophie) (Resolving 6 and 8 with θ = {x/Sophie})

  10. (Resolving 7 and 9 with θ = {})

  Notice that only 1 of the 4 clauses derived from the definition of Green was used to prove the target sentence.

PROBLEM 2 --INFORMED AND UNINFORMED SEARCH

a) Uniform cost:

Expanded nodes: SADBCE G2

Solution path: S D C G2

Path cost: 13. Optimal path. Uniform cost search is optimal when there are no negative path costs.

b) Breadth first:
Expanded: S A G1. (goal check is when childs are generated)
S. Path: S A G1

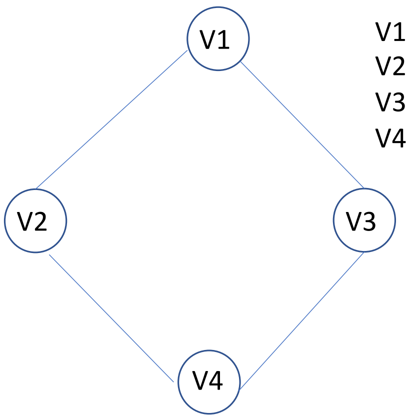
Path cost: 14. Not optimal. BFS is cost optimal only when the steps costs are identical

c) Depth first
Expanded nodes: S A B C F D E G3
Solution cost: 45

d) A*
Expanded nodes: S A B D C E G2
Solution path: S D C G2
Path cost: 13. Optimal.

PROBLEM 3 ---CSP CROSS WORD PUZZLE

a)



V1: 1-across
V2: 2-down
V3: 3-down
V4: 4-accross

b) C1: V1 has 5 letters

C2: V2 has 3 letters

C3: V3 has 3 letters

C4: V4 has 4 letters

C5: 3rd letter of V1 is the same letter as the first letter of V2

C6: 5th letter of V1 is the same letter as the first letter of V3

C7: 2nd letter of V4 is the same letter as 3rd letter of V2

….

….

c) Domains, according to node consistency:

V1 ----Domain1={ astar, happy, hello, hoses}

V2 ----Domain2={ live, load, loam, peal, peel, save, talk, anon, nerd, tine }

V3 ----Domain3={ ant, oak, old, run, ten}

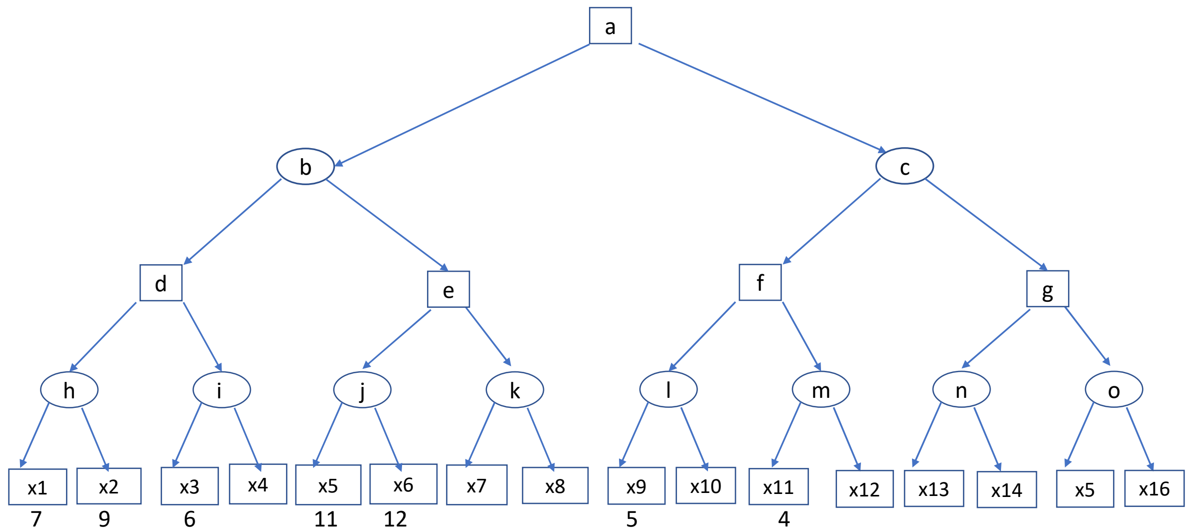
V2 ----Domain2={ live, load, loam, peal, peel, save, talk, anon, nerd, tine}

d)

Arc consistency Queue	**Current considered arc**	**Domains of arc variables before arc consistency check**	**Domains of arc variables after arc consistency check**
V1V2, V1V3, V2V1, V2V4, V3V1, V3V4, V4V2, V4V3	V1V2	V1:{astar, happy, hello, hoses} V2:{live, load, loom, peal, peel, save, talk, anon, nerd, tine}	V1:{astar, happy, hello, hoses} V2:{live, load, loom, peal, peel, save, talk, anon, nerd, tine}
V1V3, V2V1, V2V4, V3V1, V3V4, V4V2, V4V3	V1V3	V1:{astar, happy, hello, hoses} V3:{ant, oak, old, ten, run}	V1:{astar, hello} V3:{ant, oak, old, ten, run}
V2V1, V2V4, V3V1, V3V4, V4V2, V4V3	V2V1	V2:{live, load, loom, peal, peel, save, talk, anon, nerd, tine} V1:{astar, hello}	V2:{live, load, loom, talk, tine} V1:{astar, hello}
V2V4, V3V1, V3V4, V4V2, V4V3, V1V2	V2V4	V2:{live, load, loom, talk, tine} V4:{live, load, loom, peal, peel, save, talk, anon, nerd, tine}	V2:{load, loom, tine} V4:{live, load, loom, peal, peel, save, talk, anon, nerd, tine}
V3V1, V3V4, V4V2, V4V3, V1V2	V3V1	V3:{ant, oak, old, ten, run} V1:{astar, hello}	V3:{oak, old, run} V1:{astar, hello}
V3V4, V4V2, V4V3, V1V2, V1V3	V3V4	V3:{oak, old, run} V4:{live, load, loom, peal, peel, save, talk, anon, nerd, tine}	V3:{oak, old, run} V4:{live, load, loom, peal, peel, save, talk, anon, nerd, tine}
V4V2, V4V3, V1V2, V1V3, V2V4	V4V2	V4:{live, load, loom, peal, peel, save, talk, anon, nerd, tine} V2:{load, loom, tine}	V4:{load, loom, save, talk, anon} V2:{load, loom, tine}
V4V3, V1V2, V1V3, V2V4, V3V4	V4V3	V4:{load, loom, save, talk, anon} V3:{oak, old, run}	V4:{load, talk, anon} V3:{oak, old, run}
V1V2, V1V3, V2V4, V3V4	V1V2	V1:{astar, hello} V2:{load, loom, tine}	V1:{astar, hello} V2:{load, loom, tine}
V1V3, V2V4, V3V4	V1V3	V1:{astar, hello} V3:{oak, old, run}	V1:{astar, hello} V3:{oak, old, run}
V2V4, V3V4	V2V4	V2:{load, loom, tine} V4:{load, talk, anon}	V2:{load, loom, tine} V4:{load, talk, anon}
V3V4	V3V4	V3:{oak, old, run} V4:{load, talk, anon}	V3:{oak, old, run} V4:{load, talk, anon}

a) H=7,i<=6, d=7, j=11, e>=11, b= 7, c<=5, f<=5, l <=5, m<=4. solution=7

b) x4, k, x10, x12, and g are pruned



PROBLEM 5--- GAME THEORY

a) N={A1, A2}, Domains of A1=A2 ={0,10,20,30,40,50}, and the payoff fns are are specified by the following matrix

A1, Agent2	0	10	20	30	40	50
0	40, 0	0, 30	0, 30	0, 30	0, 30	0, 30
10	40, 0	30, 0	0,20	0, 20	0, 20	0, 20
20	40, 0	30, 0	20, 0	0, 10	0, 10	0, 10
30	40, 0	30, 0	20, 0	10, 0	0, 0	0, 0
40	40, 0	30, 0	20, 0	10, 0	0, 0	0, -10
50	40, 0	30, 0	20, 0	10, 0	0, 0	-10 , 0

b) There is no weakly dominant strategy eq. as neither player has a weakly dominant action. Notice that for both players, actions 30 and 40 weakly dominate every other action. But not wach other.

c) D) There is no strictly dominated action for either player and and hence all the action profiles survive IESD actions

d) We can eliminate the weakly dominated actions in the following order:

A:0

A2:0

A1: 50

A2: 50

A1:10

A2: 10

A1: 20

Which leads to the following set of outcomes {30,40} x {20,30,40}. However, tehre are other orders of elimination which lead to different outcomes.

e) The game is not dominance solvable.