Final Exam

600.464/664 Artificial Intelligence
Spring 2020

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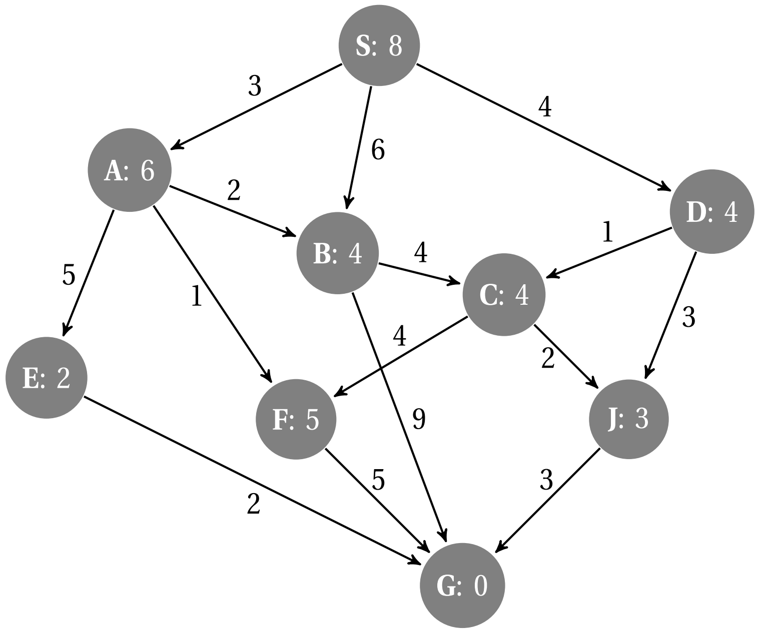
Instructions

- Please be sure to write your name in the space above!
- Please show ALL relevant work for your answers and provide explanations when prompted. Failure to do either will result in loss of credit.
- You may upload a edited pdf file (preferably), a scan of printout with hand-written answers, or any other document with answers.
- The exam is due by midnight on Gradescope.

Informed Search *10 points*

Consider the search space below, where **S** is the start node and **G** satisfies the goal test. Arcs are labeled with the cost of traversing them and the heuristic cost to the goal is reported inside nodes (so lower scores are better).

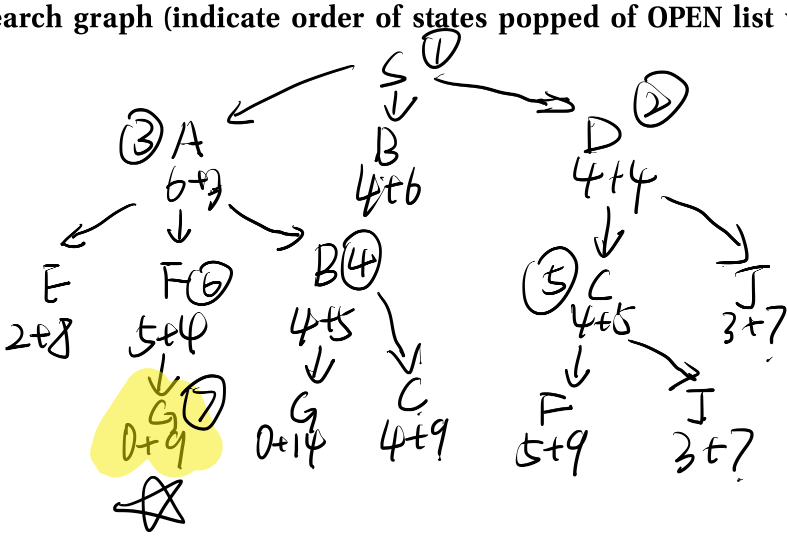


1. (10 points) For A* search, indicate which goal state is reached at what cost and list, in order, all the states popped off of the OPEN list. You use a search graph to show your work. Do not expand paths that revisit states at higher cost.

   Note: When all else is equal, nodes should be removed from OPEN in *alphabetical* order.

   Path to goal (cost): 9

   Search graph (indicate order of states popped of OPEN list with numbers):



First Order Logic *15 points*

2. (5 points) Convert the following sentences into first-order predicate calculus logic:

If a team wins a game, it is happy.

$\forall x \forall y \ \ Team(x) \land Game(y) \land Win(x,y) \Rightarrow Happy(x)$

If a team plays a game, is better than the opponent, and is in good form, it wins the game.

$\forall x \forall y \forall z, \ Team(x) \land Game(y) \land Opponent(x,z) \land Better(x,z) \land GoodForm(x) \Rightarrow Win(x,y)$

The Blue Jays play a game against the Tigers.

$\exists x \exists y : BlueJay(x) \land Tigers(y) \land Game(x,y) \land Opponent(x,y)$

The Blue Jays are better than the Tigers.

$\exists x \exists y \ \ BlueJays(x) \land Tigers(y) \land Better(x,y)$

The Blue Jays are in good form.

$\exists x \ BlueJays(x) \land GoodForm(x)$

3. (5 points) Convert all rules to Conjunctive Normal Form (CNF). You do not need to restate rules that are already in CNF.

(1) $\neg Team(x) \lor \neg Game(y) \lor \neg Win(x,y) \lor Happy(x)$

(2) $\neg Team(x) \lor \neg Game(y) \lor \neg Opponent(x,z) \lor \neg Better(x,z) \lor \neg GoodForm(x) \lor Win(x,y)$

(3) $Game(BlueJays) \land Game(Tigers) \land Opponent(BlueJays, Tigers)$

(4) $Better(BlueJays, Tigers)$

(5) $Good(BlueJays)$.

4. (5 points) Carry out a resolution proof of the statement *The Blue Jays are happy.*

Assume $\neg Happy(BlueJays)$.

Then (1) $\neg Team(x) \lor \neg Game(y) \lor \neg Win(x,y) \lor Happy(x)$ $\qquad \neg Happy(BlueJays)$.

(2) $\neg Team(x) \lor \neg Game(y) \lor \ldots$ (see above) $\qquad \neg Team(x) \lor \neg Game(y) \lor \neg Win(x,y)$

$\neg Team(x) \lor \neg Game(y) \lor Opponent(x,z) \lor \neg Better(x,z) \lor \neg GoodForm(x)$

(3) $Game(BlueJays)$ .... (see above)

(4) $Better(BlueJays, Tigers)$ $\qquad \neg Better(x,z) \lor \neg GoodForm(x)$

(5) $\neg GoodForm(BlueJays)$ $\qquad \neg GoodForm(x)$

$\boxed{X}$

Constraint Satisfaction *15 points*

Consider the following Mini Sodoku puzzle.
(numbers are assigned values, letters are names for cells)

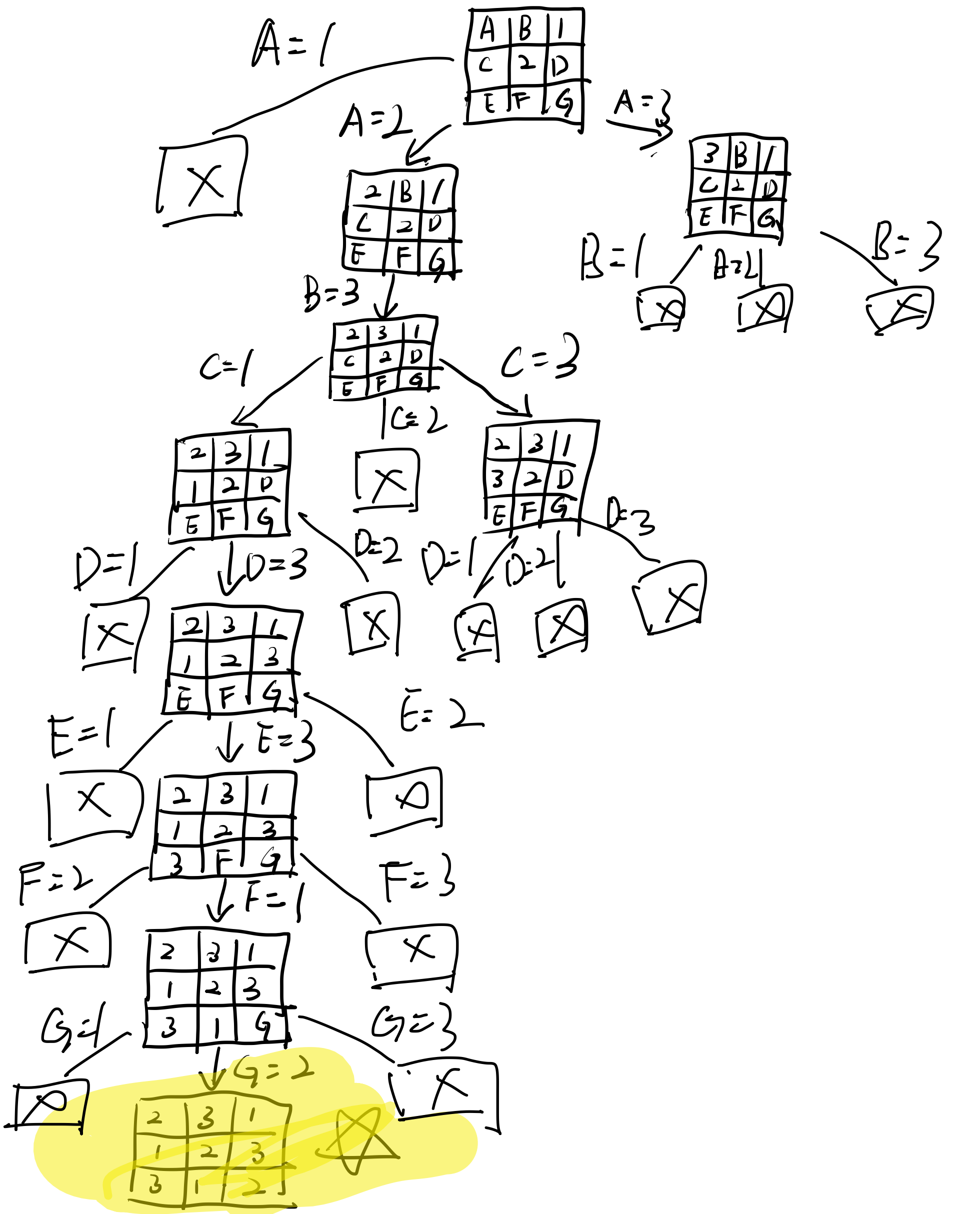
A	B	**1**
C	**2**	D
E	F	G

Recall the rules of Sudoku:

- Each cell is assigned a number (in Mini Sudoku, the numbers are 1, 2, and 3).
- No row can have the same number twice.
- No column can have the same number twice.

These rules can be specified by constraints. You do not need to formally write these constraints down.

5. (8 points) Carry out backtracking search. Explore the search space in the alphabetic order of the cell names, and assign values in numerical order (i.e., first assign 1, then 2, then 3). Draw the search tree. Stop and backtrack at leaves where constraints allow no valid variable assignment.



6. (7 points) Now, use the minimum remaining values (MRV) heuristic. Fill in the following table. Start with a row that specifies the remaining possible values for each variable. Then commit one variable to a value following the MRV heuristic (in case of ties follow alphabetical order).

Step		A	B	C	D	E	F	G
	remaining values	2, 3	3	1, 3	3	1, 2, 3	1, 3	2, 3
1	assigned value		3					
	remaining values	2		1, 3	3	1, 2, 3	1	2, 3
2	assigned value	2						
	remaining values			1, 3	3	1, 3	1	2, 3
3	assigned value				3			
	remaining values			1		1, 3	1	2
4	assigned value			1				
	remaining values					3	1	2
5	assigned value					3		
	remaining values						1	2
6	assigned value						1	
	remaining values							2
7	assigned value							2

Planning **15 points**

An evil robot has almost completed his evil plan for the total destruction of the human race. He has two nasty chemicals called A and B which are currently stored in containers 1 and 2 respectively. All he has to do now is mix them together in container 3. His designer, an equally evil computer scientist, has equipped the evil robot with a propositional planning system that allows him to reason about the locations of particular things and about moving a thing from one place to another.

7. (5 points) Explain how this problem might be represented within a propositional planning system. Give specific examples of the way in which the start state and goal can be represented.

See it on next page.

8. (5 points) Describe in detail an algorithm that can be used to find a plan using this form of representation.

See it on next page.

9. (2 points) Give a specific example of a successor-state axiom using the representation you suggested.

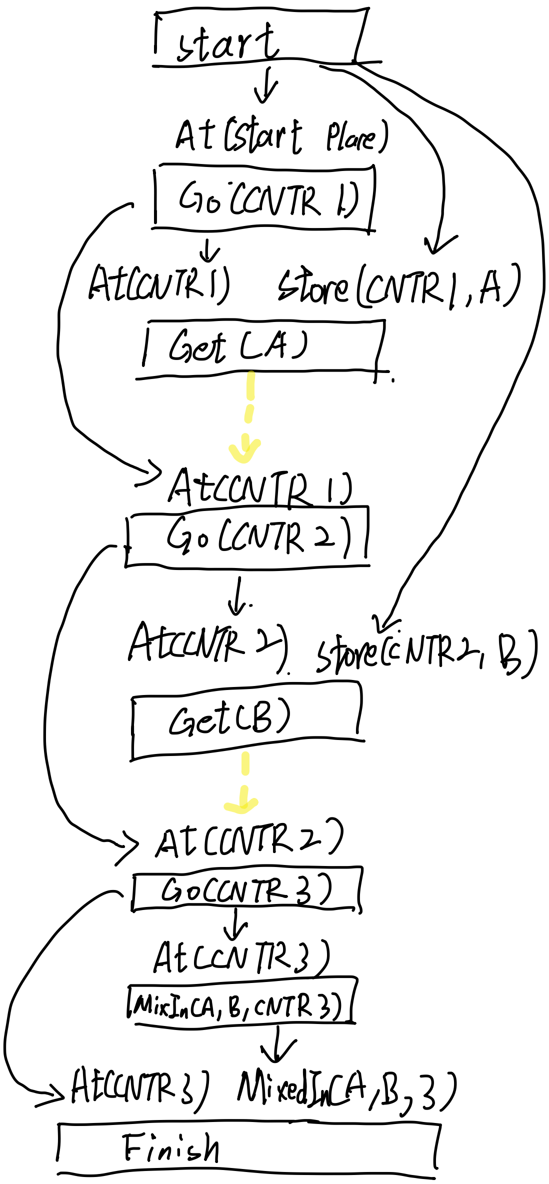
$Go(CNTR2) \rightarrow [\neg Get(B) \leftrightarrow \neg Store(CNTR2,B) \vee (\neg Get(A) \wedge Store(CNTR2,B))]$

10. (3 points) Explain why in this particular planning problem it might be necessary to include one or more precondition axioms and give an example of such an axiom using your representation.

The precondition axiom is necessary because it is the condition to decide action and make action possible. The precondition axiom is also used to determine which fluent will be true.

Example: Store(CNTR1, A), Store(CNTR2, B)

7.



In my representation, index is for Container, which is 1, 2, 3, ChemType is the type of Chemistry, which is A or B.

Then the representation can be as follow:

Action: Go(CNTR index)
Get(ChemType)

Precondition: Store(CNTR index, ChemType)
At(CNTR index)

Effect: MixedIn(A, B, 3)

The start state: At(Start Place)
Store(CNTR 1, A)
Store(CNTR 2, B)

The End state: At(CNTR 3)
MixedIn(A. B, 3)

8. The picture above is how the algorithm works. Here's the pseudocode of the algorithm.

```
function POP(initial, goal, operators) returns plan
    plan ← MAKE-MINIMAL-PLAN(initial, goal)
    loop do
        if SOLUTION?(plan) then return plan
        Sneed, c ← SELECT-SUBGOAL(plan)
        CHOOSE-OPERATOR(plan, operators, Sneed, c)
        RESOLVE-THREATS(plan)
```

```
end
```

```
function SELECT-SUBGOAL(plan) returns Sneed, c.
  pick a plan step Sneed from STEPS(plan)
      with a precondition c that has not been achieved
  return Sneed, c
```

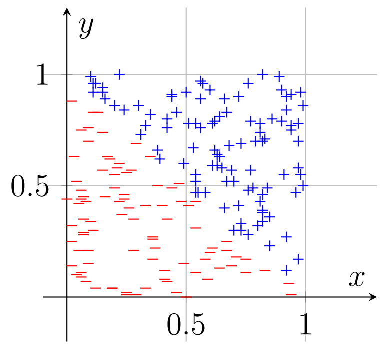
```
procedure CHOOSE-OPERATOR(plan, operators, Sneed, c)
  choose a step Sadd from operators or STEPS(plan) that
  has c as an effect
  if there is no such step then fail
  add the casual link Sadd -c-> Sneed to LINKS(plan)
  add the ordering constraint Sadd < Sneed to ORDERINGS(plan)
  if Sadd is a newly added step from operators then
      add Sadd to STEPS(plan)
      add Start < Sadd < Finish to ORDERINGS(plan)
```

```
procedure RESOLVE-THREATS(plan)
  for each Sthreat that threatens a link Si -c-> Sj in
  LINKS(plan) do
  choose either
      Demotion: Add Sthreat < Si to ORDERINGS(plan)
      Promotion: Add Sj < Sthreat to ORDERINGS(plan)
  if not CONSISTENT(plan) then fail
end
```

Combining the pesudocode and the problem, I get a graph as I give in Q7.

Machine Learning *15 points*

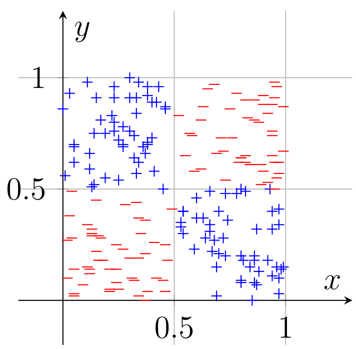
Consider the following plot of data points.



11. (5 points) Write down the formula for a linear classifier function $f(x, y) \rightarrow value$ where positive output *values* correspond to the sign **+** and negative *values* correspond to the sign **–**. The classifier should classify all training examples corrrectly.

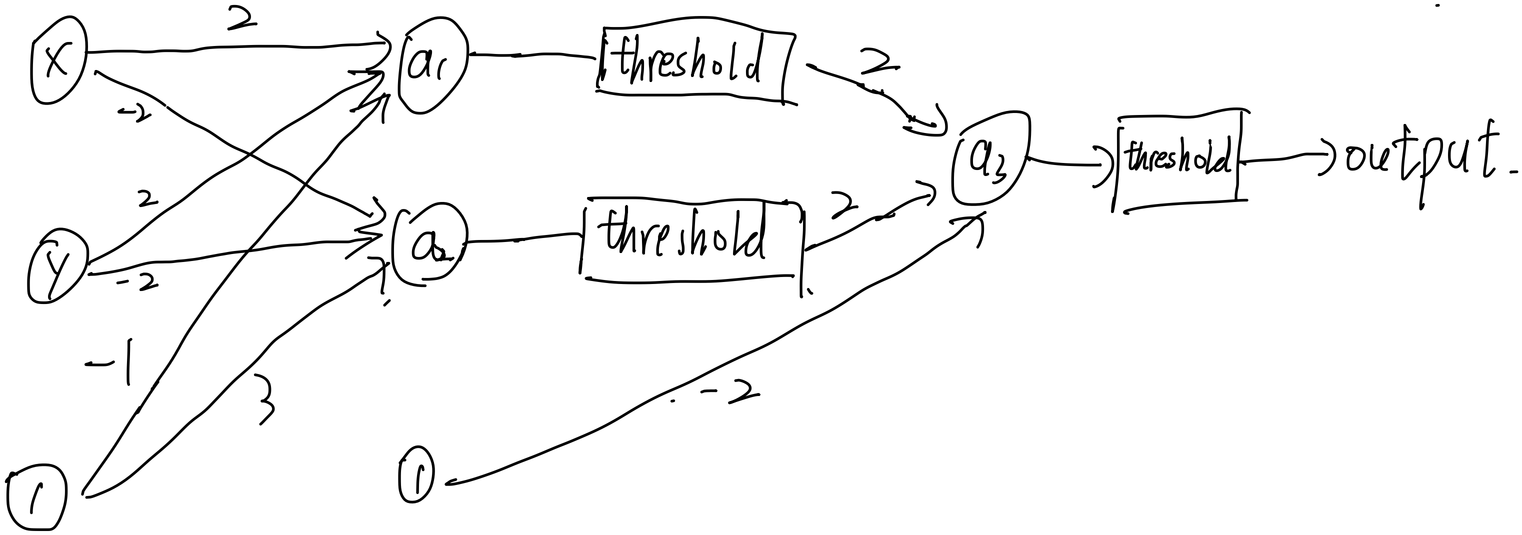
$f(x, y) = x + y - 1$

Now consider the following plot of data points.



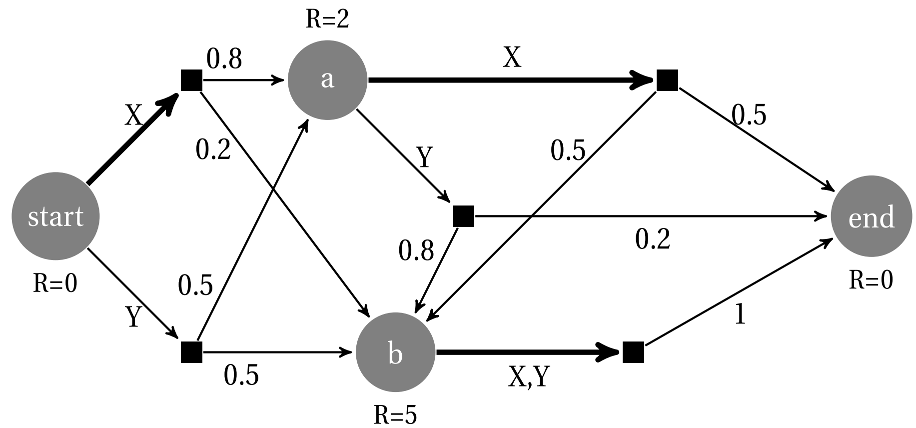
12. (10 points) Draw a neural network with weight values that classifies all values correctly. You may use the following activation function.

$$\text{threshold}(z) = \begin{cases} 1 & \text{if } z \geq 1 \\ -1 & \text{else} \end{cases}$$



Reinforcement Learning **15 points**

Consider the *non-deterministic* reinforcement environment drawn below. States are represented by circles, and actions by squares. The Probability of a transitions is indicated on the arc from actions to states. *Immediate* rewards are indicated above and below states. Once the agent reaches the **end** state the current episode ends.



13. (15 points) Consider two possible policies: always take action **X** or always take action **Y**. For each policy, compute the answers to the following questions.

    (a) What paths could be taken?

    (b) What is each path's probability?

    (c) What is each path's reward?

    (d) What is the utility of each state?

(1) Only take X

a) Path	b) probability	c) Reward
start → a → end	0.8×0.5=0.4	2
start → b → end	0.2×1=0.2	5
start → a → b → end.	0.8×0.5×1=0.4	7

(d) start 0.8+1+2.8=4.6
a 1+3.5=4.5
b 0+5=5
end 0

(2) Only take Y

a) Path	b) Probability	c) Reward
start → b → end	0.5	5
start → a → end	0.5×0.2=0.1	2
start → a → b → end	0.5×0.8=0.4	7

(d) start 2.5+0.2+2.8=5.5
a 0.4+5.6=6
b 5
end 0

Natural Language Processing *15 points*

We plan to build a database of which persons were hired at which company from the corpus of news paper articles.

The database table looks like follows:

Name	Position	Company
Joe Johnson	sales representative	IBM
Frida Feldman	lawyer	Microsoft
...	...	...

Consider the following sentences

- *Albert Altman was hired by Apple as a software developer.*
- *Booking.com hired Brianna Bayer as an accountant.*
- *Comcast hired as their new CEO Catherine Carter.*

14. (3 points) For each sentence, write a string pattern matching expression that extracts the relevant information (use any pattern matching formalism you like).

sentence1: [Name] was hired by [Company] as a/an [Position]

sentence2: [Company] hired [Name] as a/an [Position]

sentence3: [Company] hired as their new [Position] [Name]

15. (3 points) Annotate each sentence with dependency relationships with appropriate labels.

① Albert Altman was hired by Apple as a software developer,

Albert Altman	was	hired	by	Apple	as	software developer
PRO	AUX	VB	ADP	PRO	SCONJ	NP
subject(passive)	aux		agent	object	prep	object
hired	hired		hired	by	hire	as

② Booking.com hired Brianna Bayer as an accountant.

Booking.com	hired	Brianna Bayer	as	accountant
PRO	VB	PRO	SCONJ	NP
subject		object	prep	object
hired		hired	hired	as

③ Comcast hired as their new CEO Catherine Carter.

Comcast	hired	as	their new CEO	Catherine Carter
PRO	VB	SCONJ	NP	PRO
subject		prep	object	appos
hired		hired	as	their new CEO.

16. (5 points) Define informally a pattern over dependency structures that allows you to extract the relevant information from all the example sentences for the database table.

In active voice, The subject of hire (VB) is [Company].
The object of hire (VB) is [Name].

In passive voice, The subject of hire (VB) is [Name].
The object of hire (VB) is [Company].

The object who has a dependency on 'as' (SCONJ) is [Position].

17. (4 points) Hiring information may be expressed in many different ways in natural language. Below is a list of general problems in natural language processing. Give an example sentence that contains relevant hiring information for out database that demonstrates why each of these problems poses a challenge for our simple extraction patterns.

- Synonymy

  There are a lot of word have similar meaning to 'hire'.
  eg. Amazon employs Tom as a lawyer.

- Hypernymy

  Hypernymy may cause incomplete information.
  eg. Tom was hired as a lawyer by an IT company.

- Co-reference

  The name and the company may be a pronoun appeas in context.
  eg. Jerry told us that he was hired by Amazon. The 'he' here is Tom who appears in context.

- Semantic inference

  Some sentence can be inferred to hiring.
  eg. Tom get an offer from Amazon.