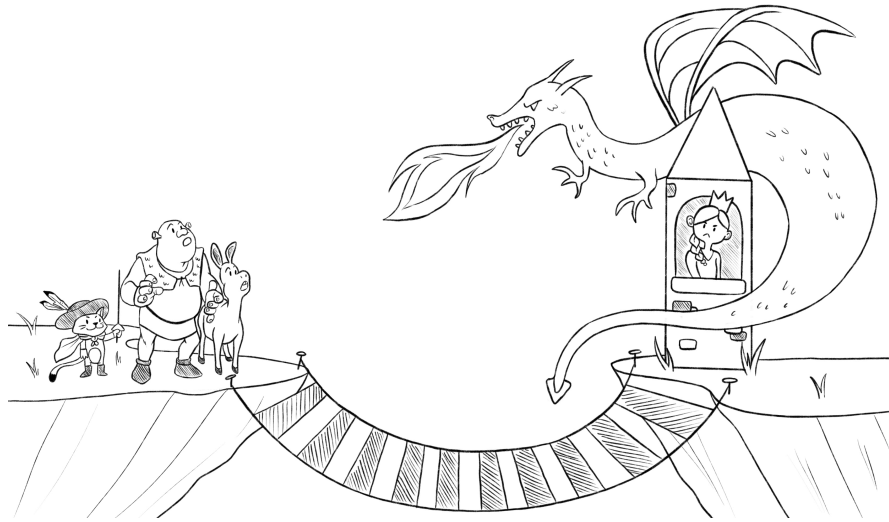


**Question 1. Search** [10 MARKS]

A fire-breathing dragon is holding Princess Fiona captive in its tower. To defeat it, she will need help from Shrek, Donkey, and Puss. The plan is as follows:

- Shrek, Donkey, and Puss will cross a bridge to reach the tower on the far side
- once Shrek, Donkey, and Puss are across the bridge, they will help Fiona defeat the dragon (which takes 3 minutes)
- once the dragon is defeated, Shrek, Donkey, Puss, and Fiona will cross back to the near side



The bridge appears unstable, so they decide that no more than two of them should cross at a time. Each of them can cross the bridge in different times.

Character	Crossing Time (mins.)
Shrek	8
Donkey	5
Puss	1
Fiona	2

When any two of them cross the bridge together, they must move at the slower one's pace.

Because it's night, a torch must be used when crossing the bridge. Unfortunately, they only have one torch that lasts for  $m$  minutes. This means that only after each crossing, someone will need to return back with the torch so that the others may cross.

If  $m$  is sufficiently large, we can model this situation as a search problem in which:

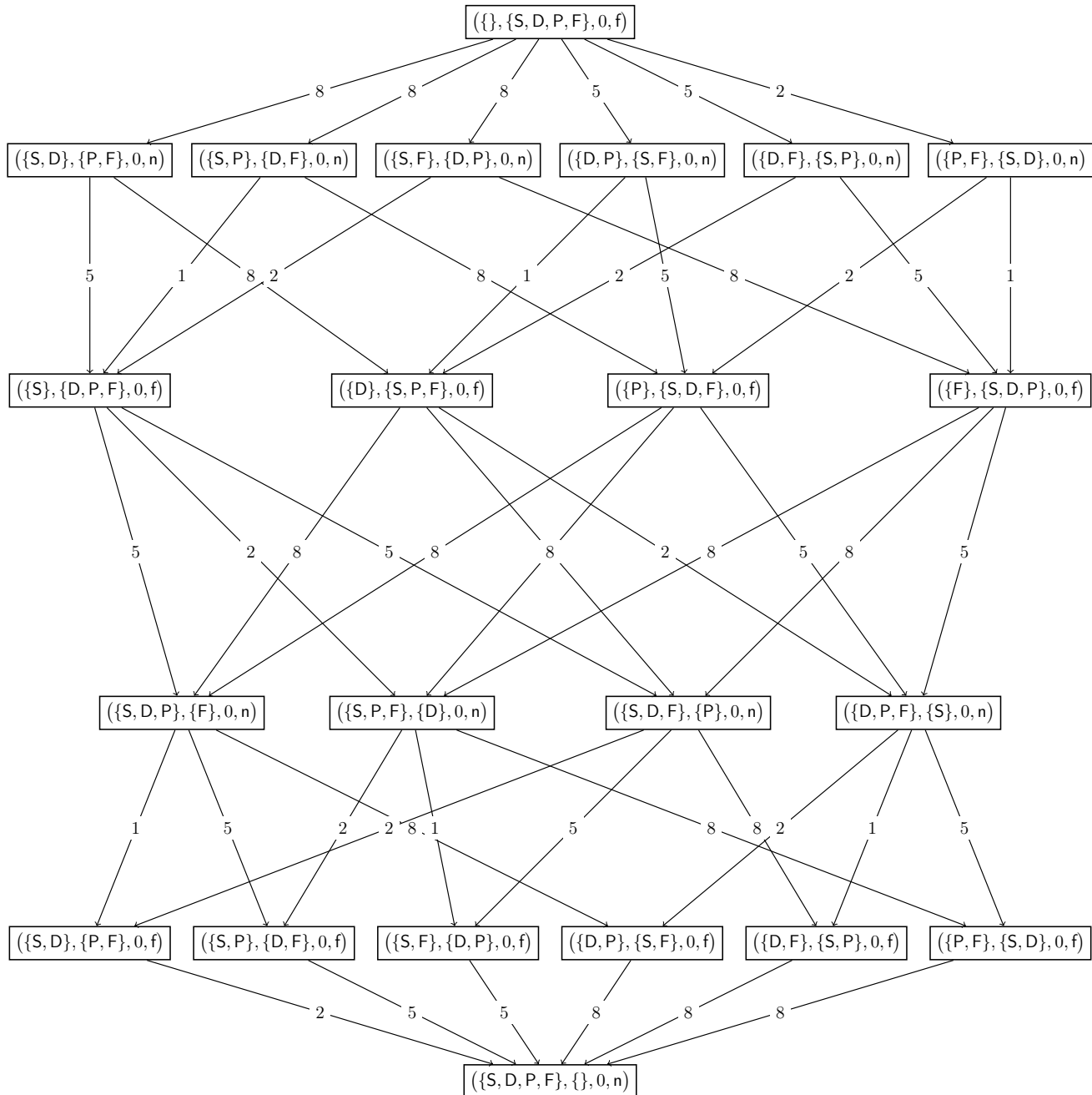
- S, D, P and F represent Shrek, Donkey, Puss, and Fiona respectively
- each state is a tuple  $(\mathcal{N}, \mathcal{F}, d, t)$ , where  $\mathcal{N}, \mathcal{F} \subseteq \{\text{S}, \text{D}, \text{P}, \text{F}\}$  represent the characters on the near and far sides of the bridge,  $d = \{0, 1\}$  represents whether the dragon is defeated ( $d = 0$ ) or not ( $d = 1$ ), and  $t \in \{\text{n}, \text{f}\}$  represents which side of the bridge the torch is on.
- $\mathcal{N} \cap \mathcal{F} = \emptyset$  since one cannot simultaneously be on the near and far side of the bridge
- the cost metric is the total time required for Shrek, Donkey, and Puss to cross to the far side, defeat the dragon with Fiona, and then cross back with her
- the initial state is  $(\{\text{S}, \text{D}, \text{P}\}, \{\text{F}\}, 1, \text{n})$

Our goal is to determine how long the torch must last, i.e.,  $m$ .

- (a) [6 MARKS] Draw a *directed, weighted, acyclic* search graph representing the ways that Shrek, Donkey, and Puss can cross to the far side of the bridge and then defeat the dragon. Do NOT include dead states (i.e., states that have no path to the goal). Remember that Fiona cannot cross until the dragon has been defeated. The initial state has been drawn.

$$\boxed{(\{\text{S}, \text{D}, \text{P}\}, \{\text{F}\}, 1, \text{n})}$$

- (b) [3 MARKS] The search graph below represents the different ways that Shrek, Donkey, Puss, and Fiona, can cross to the near side of the bridge after defeating the dragon. Circle any one path found by uniform-cost search. *Note: there may be more than one path, but you only need to circle one.*



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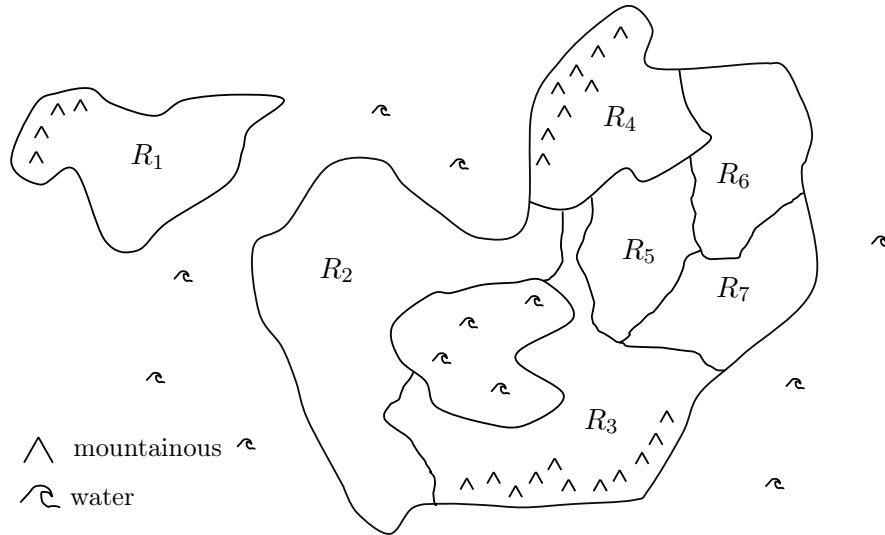
Duration: **3 hours**

(c) [1 MARK] What is the minimum number of minutes,  $m$ , that the torch must last?

$m \geq$

**Question 2. CSPs** [12 MARKS]

Avatar Aang has discovered a new piece of land, shown below:



The land is to be allocated amongst the four nations: the earth kingdom, the air nomads, the fire nation, and the water tribe. Each region,  $R_i$  must be allocated to exactly one nation,  $\{e, a, f, w\}$ .

Region	$R_1$	$R_2$	$R_3$	$R_4$	$R_5$	$R_6$	$R_7$
Surface Area (km <sup>2</sup> )	200	200	250	150	50	50	100
Borders Water?	Yes	Yes	Yes	Yes	No	Yes	Yes
Has Mountains?	Yes	No	Yes	Yes	No	No	No

Aang has a few requirements (represented as constraints):

- Rq. 1: All nations get the same total land area
- Rq. 2: No two regions that share a border are allocated to the same nation

Additionally, each nation has their own requirements (represented as domain restrictions):

- Rq. 3: Any region allocated to the water tribe must border a body of water.
- Rq. 4: Any region allocated to the earth kingdom must be mountainous.
- Rq. 5: Any region surrounded entirely by land must be allocated to the fire nation.
- Rq. 6: The air nomads do not want the island or any region that is less than 75 km<sup>2</sup>.

We can model this as a CSP in which  $R_1, \dots, R_7$  are the variables, their domains are given by Rqs. 3 - 6, and the constraints are defined by Rq. 1 and 2.

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Duration: **3 hours**

- (a) [2 MARKS] Indicate the domains of each variable based on Rqs. 3 - 6. Use e, a, f, and w to denote Earth, Air, Fire, and Water, respectively.

Region	$R_1$	$R_2$	$R_3$	$R_4$	$R_5$	$R_6$	$R_7$
Domain							

- (b) [2 MARKS] Provide binary not-equal constraints over  $\{R_i\}$  that collectively represent Rq. 2.

- (c) [8 MARKS] Perform back-tracking with forward-checking to find a solution to the CSP:

- assume Rq. 2 is modelled using binary not-equal constraints as in (b) and Rq. 1 is modelled as a 7-ary constraint over  $R_1, \dots, R_7$
- use the minimum remaining values (MRV) heuristic to choose the variable to assign; if there are ties, assign the variables in ascending numerical order, i.e.,  $R_1, \dots, R_7$
- assign values to variables in the order; e, a, w, f
- use DWO for domain wipe-outs (you do not need to fill in the current domains)

Itr.	Assignment	Current Domains						
		$R_1$	$R_2$	$R_3$	$R_4$	$R_5$	$R_6$	$R_7$
1								
2								
3								
4								
5								
6								
7								
8								

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Duration: **3 hours**



**Question 5. Knowledge: Reasoning** [5 MARKS]

Consider the following statements:

- S1:** All academics are always sleepy.
- S2:** Every graduate either chooses industry or academia.
- S3:** Anyone who chooses industry is smart.
- S4:** Anyone who is smart is also a good teacher.
- S5:** Chandra is a graduate and the university is his employer.
- S6:** Anyone who is always sleepy is not payed by their employer.
- Q:** If Chandra is not a good teacher, then the university will not pay Chandra.

We can express statements **S1** to **S6** and the negation of **Q** via first-order logic in **clausal form** using the following vocabulary:

- $ac(x)$  to represent that  $x$  is an academic / chose academia.
- $ind(x)$  to represent that  $x$  chose industry.
- $sl(x)$  to represent that  $x$  is always sleepy.
- $grad(x)$  to represent that  $x$  is a graduate
- $sm(x)$  to represent that  $x$  is smart
- $tch(x)$  to represent that  $x$  is a good teacher
- $emp(x, y)$  to represent that  $x$  is the employer of  $y$
- $pays(x, y)$  to represent that  $x$  pays  $y$
- **Chandra** to represent represents Chandra
- **Uni** to represents the university

The resulting clauses are shown below:

#	Clause
1	$\neg ac(x) \vee sl(x)$
2	$\neg grad(x) \vee ind(x) \vee ac(x)$
3	$\neg ind(x) \vee sm(x)$
4	$\neg sm(x) \vee tch(x)$
5	$grad(\text{Chandra})$
6	$emp(\text{Uni}, \text{Chandra})$
7	$\neg sl(x) \vee \neg emp(y, x) \vee \neg pays(y, x)$
8	$\neg tch(\text{Chandra})$
9	$pays(\text{Uni}, \text{Chandra})$



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Duration: **3 hours**

Prove that **S1** to **S6** entail **Q** using resolution by refutation. For the resolution step, use the format discussed in class (e.g.,  $R[7a, 8c]\delta$  denotes resolving the 1<sup>st</sup> literal of the 3<sup>rd</sup> clause with the 3<sup>rd</sup> literal of the 8<sup>th</sup> clause, under the substitution  $\delta$ ). You may not need all the rows.

#	Resolution Step	Resulting Clause
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		