Written by (anonymous ID):

Corrected by (anonymous ID):

Written examination
TIN174/DIT410, Artificial Intelligence

Tuesday 2 May 2017, 8:30–12:30

Examiner: Peter Ljunglöf

Solution suggestions

This examination consists of six questions. A correctly answered question gives you 2 points, the total number of points is 12.

Grades: To get grade 3/G/pass you need at least 66% correct, i.e., 8 points.

This is only for students from previous years:

To get Chalmers grade 4 you need at least 10 points.
To get GU grade VG/distinction you need at least 11 points.
To get Chalmers grade 5 you need all 12 points.

Tools: Paper and pencil.

No extra books, papers or calculators.

Notes: Answer every question directly on the question paper, and write your ID number at the top of every paper.

If you have any extra papers with associated calculations, you should hand in them too.

Write legibly, and explain your answers!

http://existentialcomics.com/comic/15

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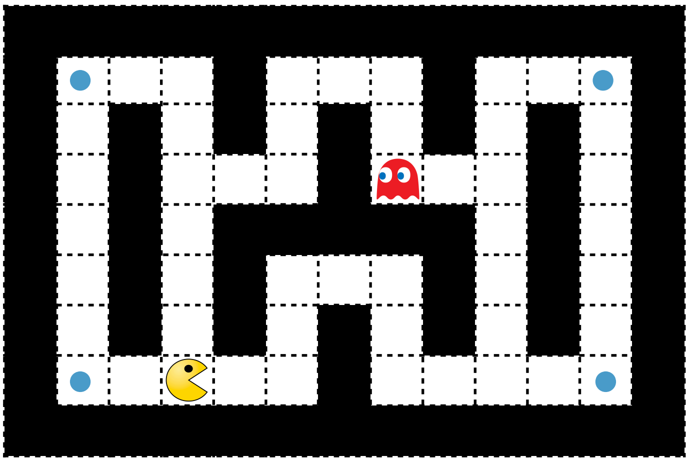
1. Pacman!

We all know and love Pacman. This time Pacman only has one enemy ghost, and only four "food dots" to eat. Every turn Pacman and the ghost moves simultaneously, one step in any of the four directions up, down, left or right. They cannot enter a wall, and Pacman fails if they end up on the same square (or pass over each other). Pacman wins when all four food dots are eaten.



a) Give a suitable representation of the states in this search problem.

correct?

The position of Pacman, the position of the ghost, and a boolean for each fruit.

This means, a tuple $(x_p, y_p, x_g, y_g, f_1, f_2, f_3, f_4)$, where x_i and y_i are integers and f_i are booleans.

b) Which of the following heuristic functions are admissible for this problem?

correct?

Check all that apply:

- [ ] The Manhattan distance between Pacman and the ghost
- [x] The Manhattan distance between Pacman and the closest food dot
- [x] The Manhattan distance between Pacman and the food dot the furthest away
- [ ] The sum of all Manhattan distances between Pacman and each food dot

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2. Data structures and search algorithms

The generic search algorithm uses a *frontier* of nodes that are waiting to be expanded. At each iteration, one node is removed from the frontier, and its neighbors are added to the frontier.

a) For each of the following search algorithms, which data structure is suitable for implementing the frontier?

correct?

Search algorithm	*Frontier data structure*
Depth-first search	*Stack (i.e., LIFO – last in first out)*
Breadth-first search	*Queue (i.e., FIFO – first in first out)*
Uniform-cost search	*Priority queue (ordered by $g(n)$ – the cost so far)*
A* search	*Priority queue (ordered by $f(n) = g(n) + h(n)$)*
Greedy best-first search	*Priority queue (ordered by $h(n)$ – the estimated cost to the goal)*

Note: I gave 1/2 point if you had four correct and one incorrect answer.

b) Which of the following A* searches will always return an optimal solution?

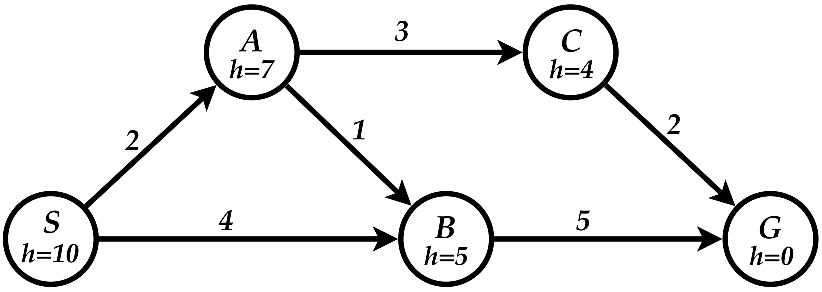
correct?

Check all that apply:

- ✅ A* tree search with admissible heuristics — tree search requires admissibility
- ✅ A* tree search with consistent heuristics — consistency implies admissibility
- ☐ A* tree search with any heuristics
- ☐ A* graph search with admissible heuristics — graph search requires consistency
- ✅ A* graph search with consistent heuristics
- ☐ A* graph search with any heuristics

3. Search graph with non-admissible heuristics

The following is a search graph with a non-admissible heuristics.



a) Which solution is the optimal one, and what is its cost?
Which solution will A* find, and what is its cost?

correct?

Solution	*Path*	*Cost*
Optimal	*SACG*	*7*
A* search	*SABG (alphabetical tiebreaking)* *SBG (tiebreaking B, G before A)*	*8* *9*

If both B and G are selected before A in tiebreaking, then SBG will be expanded before SA.

b) Which solution will *uniform-cost search* find, and what is its cost?
Which solution will *greedy best-first search* find, and what is its cost?

correct?

Solution	*Path*	*Cost*
Uniform-cost	*SACG*	*7*
Greedy best-first	*SBG*	*9*

Uniform-cost always returns the optimal solution, greedy best-first only cares about the heuristics.

Note: I gave 1/2 point if you got one correct and one incorrect.

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4. Magic squares

Read the background information about magic squares in the tear-off sheet.

Method for constructing a magic square of order 3 (modified from Wikipedia)

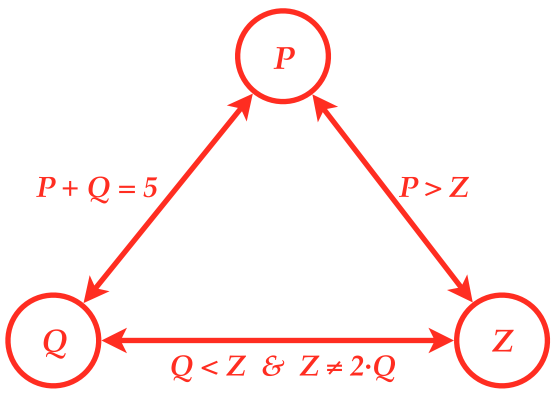
In the 19th century, Édouard Lucas devised the general formula for order 3 magic squares. Consider the table on the right, made up of positive integers p, q and z.

These 9 numbers will form a magic square with sum $3(p+q)$, so long as $0 < q < z < p$ and $z \neq 2q$.

$p+q-z$	$p+2q+z$	p
$p+z$	$p+q$	$p+2q-z$
$p+2q$	$p-z$	$p+q+z$

a) Formulate Édouard Lucas' magic square construction formula as a CSP over the variables P, Q and Z. Let the magic square sum be $3(p+q) = 15$, and let the initial domains be $\{1…9\}$. All constraints can be formulated as binary constraints. Draw the constraint graph and write the constraints next to the edges.

correct?



b) What are the resulting domains after the graph is made arc consistent?

correct?

Variable	Final domain
P	{ 4 }
Q	{ 1 }
Z	{ 3 }

Note that you must treat Q<Z and Z≠2Q as one and the same arc, otherwise you will not reach arc consistency.

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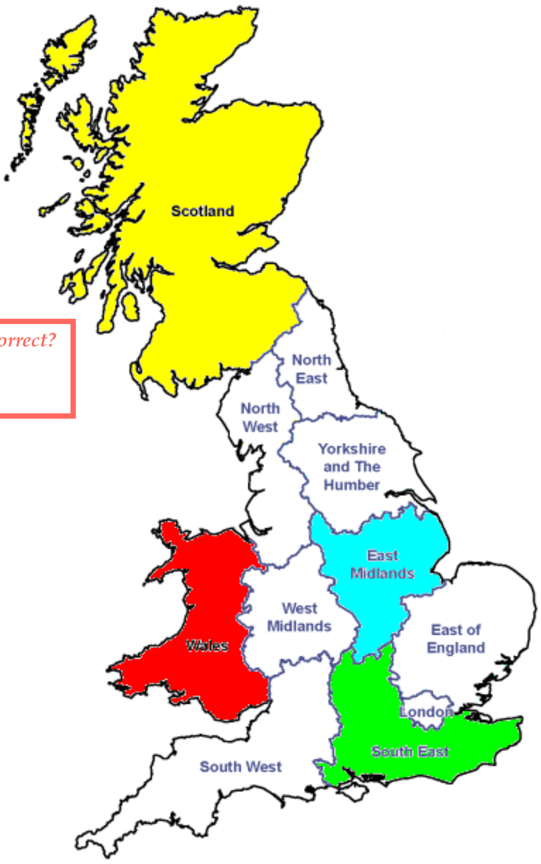
5. The colours of Britain

The Britain map to the right is partly coloured, but it really wants to be in full colour. As usual, neighbouring regions are not allowed to be in the same colour, and you have only four available colours.



a) Which region(s) does the *Minimum Remaining Values** heuristic suggest that you colour next? (*i.e, *choose the variable with the fewest legal values*)

correct?

Check all that apply:

- ☐ North East — 3 legal values
- ☑ North West — 1 legal value
- ☐ Yorkshire and The Humber — 3 values
- ☑ West Midlands — 1 legal value
- ☐ South West — 2 legal values
- ☐ East of England — 2 legal values
- ☐ London — 3 legal values

Note: I gave 1/2 point if you only answered one of the two possible.

b) Assume that we want to colour "Yorkshire and The Humber" next. Which colour(s) does the *Least Constraining Value** heuristic suggest that you try first? (*i.e., *prefer the value that rules out the fewest choices for neighbouring variables*)

correct?

Check all that apply:

- ☑ Yellow — 1 value for North West + 3 values for North East
- ☐ Red — 1 value for North West + 2 values for North East
- ☐ Blue — *illegal*
- ☐ Green — 0 values for North West + 2 values for North East

Note: I gave 1/2 point if you also included "Red".

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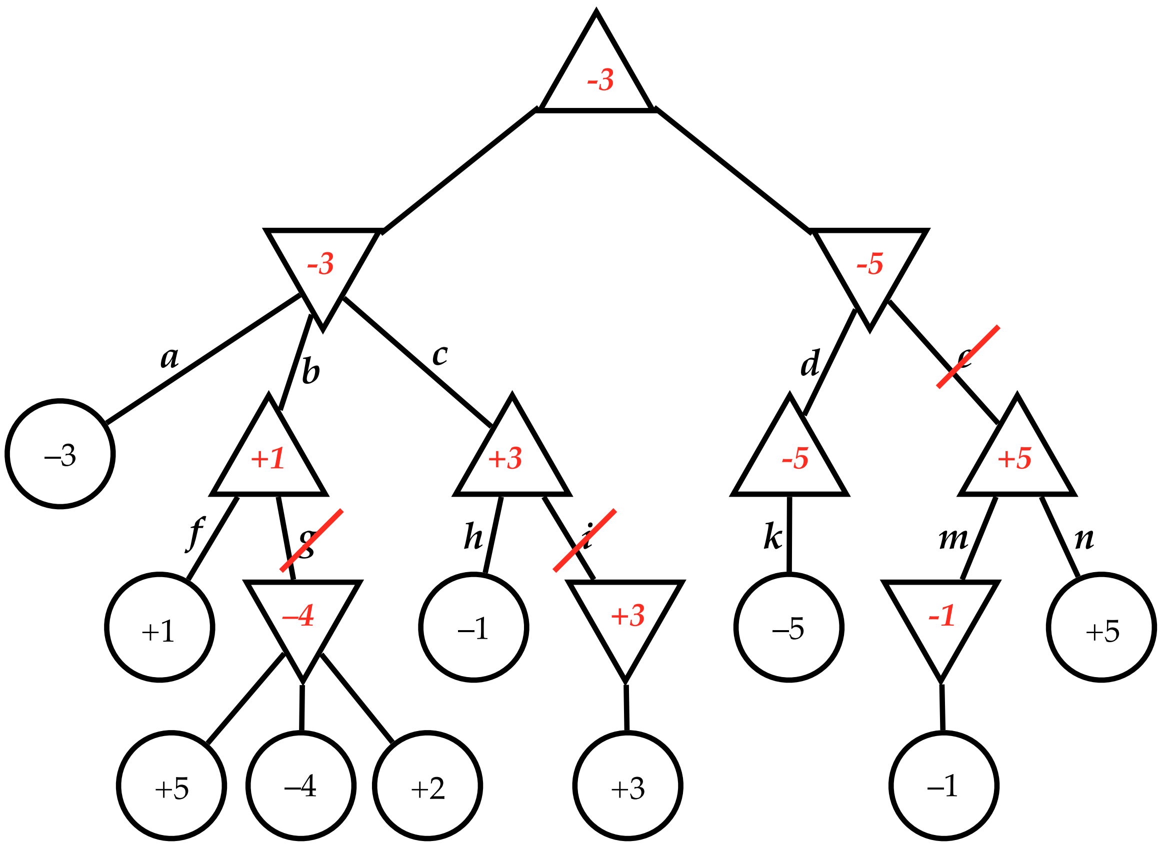
6. Minimax and alpha-beta pruning

Assume the following minimax game tree, where ◯ are leaf nodes, △ are maximising nodes, and ▽ are minimising nodes.



a) Perform the minimax algorithm on the game tree above, and write the resulting min/max values inside the empty nodes.

correct?

b) Suppose you had used alpha-beta pruning, which branches would have been cut off from the game tree? Check all that apply:

correct?

☐ *a* ☐ *b* ☐ *c* ☐ *d*

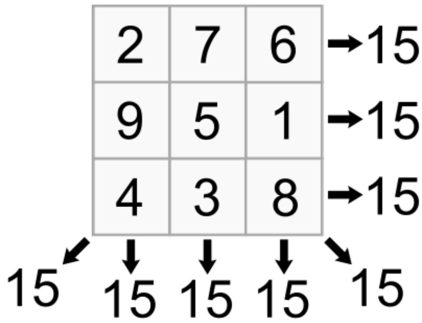
☑ *e* ☐ *f* ☑ *g* ☐ *h*

☑ *i* ☐ *k* ☐ *m* ☐ *n*

Note: I gave 1/2 point if you answered "m" or "n" instead of "e".

Tear-off sheet for question 4: Magic squares

Excerpt from the Wikipedia article "Magic square":



In recreational mathematics, a magic square is a $n \times n$ square grid (where n is the number of cells on each side) filled with distinct positive integers in the range 1, 2, ..., n^2 such that each cell contains a different integer and the sum of the integers in each row, column and diagonal is equal. The sum is called the magic constant or magic sum of the magic square. A square grid with n cells on each side is said to have order n.

In regard to magic sum, the problem of magic squares only requires the sum of each row, column and diagonal to be equal, it does not require the sum to be a particular value. Thus, although magic squares may contain negative integers, they are just variations by adding or multiplying a negative number to every positive integer in the original square.

Magic squares are also called normal magic squares, in the sense that there are non-normal magic squares which integers are not restricted in 1, 2, ..., n^2. However, in some places, "magic squares" is used as a general term to cover both the normal and non-normal ones, especially when non-normal ones are under discussion. Moreover, the term "magic squares" is sometimes also used to refer to various types of word squares.

Magic squares have a long history, dating back to at least 650 BC in China. At various times they have acquired magical or mythical significance, and have appeared as symbols in works of art. In modern times they have been generalized a number of ways, including using extra or different constraints, multiplying instead of adding cells, using alternate shapes or more than two dimensions, and replacing numbers with shapes and addition with geometric operations.