Course "**Fundamentals of Artificial Intelligence**"
EXAM TEXT

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1

In the following FOL formulas, let P, Q, R, and $>$, $\leq$, $<$, $\geq$ denote predicates,
f, g, h, F_1, F_2, F_3 and $+, -, \cdot, /$ denote functions,
x, y, z, x_1, x_2, x_3 denote variables,
A, B, C, C_1, C_2, C_3 and $0, 1, 2, 3, 4$ denote constants.

For each of the following facts, say if it is true or false.

(a) The FOL formula $\forall x_1 \forall x_2 . P(x_1, x_2)$ is equivalent to $\forall x_1 \forall x_2 . P(x_2, x_1)$

(b) The FOL formula $(2 > 4)$ is unsatisfiable.

(c) The FOL formula $\forall x_1 \exists x_1 . Q(x_1)$ is equivalent to $\exists x_1 . Q(x_1)$

(d) The FOL formula $(\forall x_1 . \neg P(x_1)) \leftrightarrow (\neg \forall x_1 . P(x_1))$ is valid

[SCORING [0...100]:

- +25pts for each correct answer
- -25pts for each incorrect answer
- 0pts for each unanswered question

]

2

Consider (normal) modal logics. Let $\mathsf{Engine} = \mathsf{F355355v8}$, $\mathsf{IsFast}(\mathsf{Engine})$, $\mathsf{IsFast}(\mathsf{F355355v8})$, $\mathsf{IsIdle}(\mathsf{Engine})$, $\mathsf{IsOff}(\mathsf{Switch})$ be possible facts, let $\mathsf{Joe}, \mathsf{Eve}$ be agents and let $\mathbf{K}_{\mathsf{Joe}}, \mathbf{K}_{\mathsf{Eve}}$ denote the modal operators "Joe knows that..." and "Eve knows that..." respectively.
For each of the following facts, say if it is true or false.

(a) If $\mathsf{Engine} = \mathsf{F355355v8} \wedge \mathbf{K}_{\mathsf{Joe}}\mathsf{IsFast}(\mathsf{Engine})$ holds, then $\mathbf{K}_{\mathsf{Joe}}\mathsf{IsFast}(\mathsf{F355355v8})$ holds.

(b) If $\mathbf{K}_{\mathsf{Eve}}\mathsf{Engine} = \mathsf{F355355v8} \wedge \mathbf{K}_{\mathsf{Eve}}\mathsf{IsFast}(\mathsf{Engine})$ holds, then $\mathbf{K}_{\mathsf{Eve}}\mathsf{IsFast}(\mathsf{F355355v8})$ holds.

(c) If $\neg\mathbf{K}_{\mathsf{Joe}}\mathsf{IsIdle}(\mathsf{Engine})$ holds, then $\mathbf{K}_{\mathsf{Joe}}\neg\mathsf{IsIdle}(\mathsf{Engine})$ holds

(d) If $\mathbf{K}_{\mathsf{Joe}}\mathsf{IsIdle}(\mathsf{Engine})$ and $\mathbf{K}_{\mathsf{Joe}}(\mathsf{IsIdle}(\mathsf{Engine}) \rightarrow \mathbf{K}_{\mathsf{Eve}}\mathsf{IsIdle}(\mathsf{Engine}))$ hold, then $\mathbf{K}_{\mathsf{Joe}}\mathbf{K}_{\mathsf{Eve}}\mathsf{IsIdle}(\mathsf{Engine}))$ holds

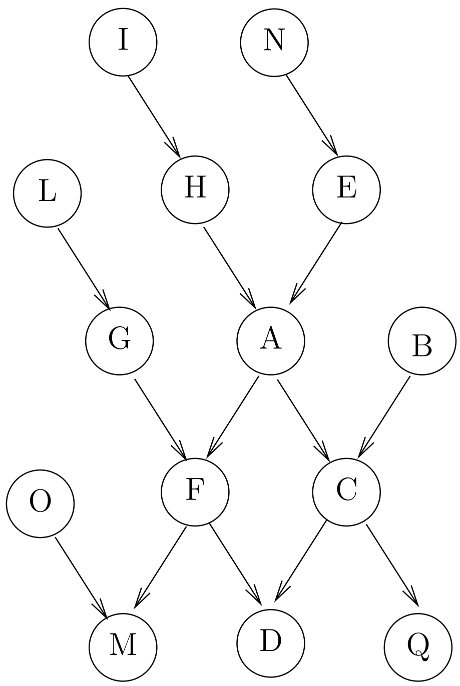
[SCORING [0...100]:

- +25pts for each correct answer
- -25pts for each incorrect answer
- 0pts for each unanswered question

]

3

Consider the following DAG of a Bayesian network.



For each of the following facts, say if it is true or false.

(a) For $\mathbf{P}(H|F)$, G is irrelevant.

(b) For $\mathbf{P}(G|A)$, C is irrelevant.

(c) $\mathbf{P}(C|ABHF) = \mathbf{P}(C|AB)$

(d) $\mathbf{P}(F|GACDOMHQ) = \mathbf{P}(F|GACDOM)$

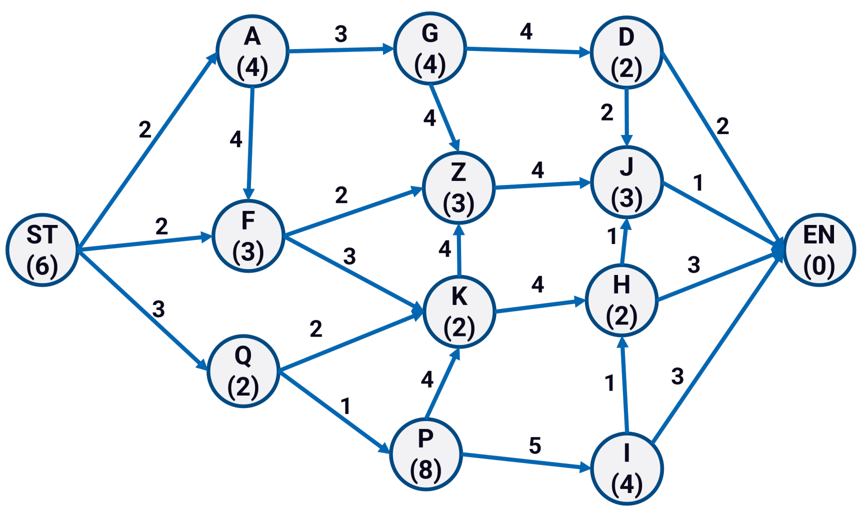
[SCORING [0...100]:

- +25pts for each correct answer
- -25pts for each incorrect answer
- 0pts for each unanswered question

]

4

Consider applying the DFS algorithm for exploring the graph shown below by using the early goal test strategy.
The start node is ST and the end node is EN.
The algorithm explores the graph by adopting the following criteria to fill the queue: heuristic value, alphabetical order.



For each of the following facts, say if it is true or false.

(a) The algorithm explores all the nodes.

(b) The EN node is explored.

(c) The solution found is the optimal one.

(d) The node Q is explored before H is generated.

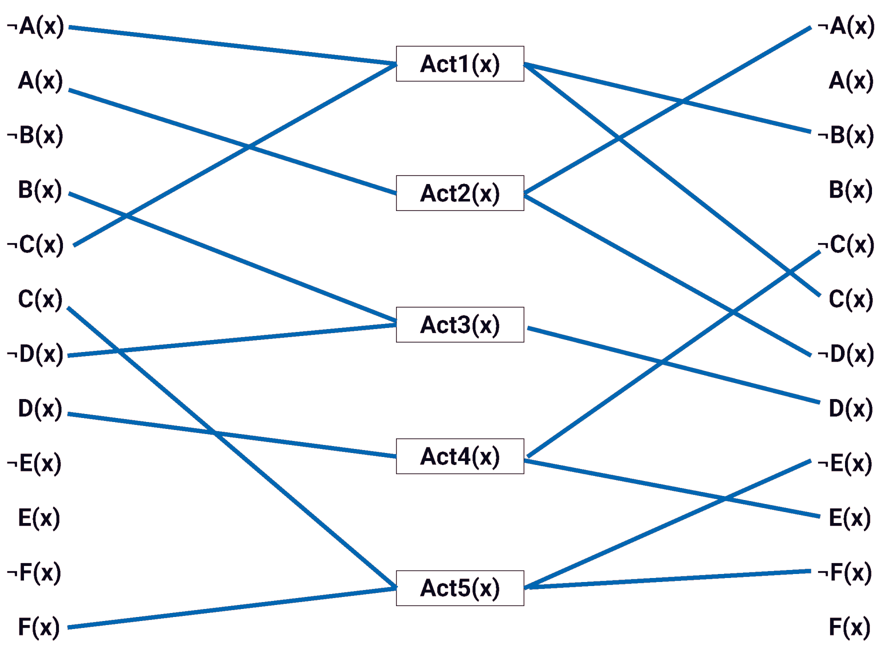
[SCORING [0...100]:

- +25pts for each correct answer
- -25pts for each incorrect answer
- 0pts for each unanswered question

]

5

Consider the graph shown below.



For each of the following facts, say if it is true or false.

(*a*) There is at least one mutex between Act2 and Act5.

(*b*) The mutex between Act2 and Act4 is an interference.

(*c*) There are no mutex between A(x) and D(x).

(*d*) The mutex between the persistence of A(x) and Act5 is an inconsistent effect.

[SCORING [0...100]:

- +25pts for each correct answer
- -25pts for each incorrect answer
- 0pts for each unanswered question

]

6

(a) Describe as Pseudo-Code the Uniform-Cost Search (UCS) stategy (graph version).

(b) When is the goal test applied to a node?

1 when the node is selected for expansion

2 when the node is first generated

(Say if 1. or 2.)

[SCORING: [0...100], 75 pts for a correct answer to question (a), 25 pts for correct answer to question (b); no penalties for wrong answers.]

7

Consider the following propositional formula φ:

$$((\neg A_3 \land \neg A_2) \leftrightarrow (\quad A_5 \land \neg A_4))$$

1. Using the CNF_{label} conversion, produce the CNF formula $CNF_{label}(\varphi)$.
2. For each of the following sentences, only one is true. Say which one.
   (i) φ and $CNF_{label}(\varphi)$ are equivalent.
   (ii) φ and $CNF_{label}(\varphi)$ are not necessarily equivalent. $CNF_{label}(\varphi)$ has a model if and only φ has a model.
   (iii) There is no relation between the satisfiablity of φ and that of $CNF_{label}(\varphi)$.

[SCORING: [0...100], 75pts for correct answer 1, 25pts for correct answer 2. No penalties for wrong answers..]

8

For each of the following FOL formulas, compute its CNF-Ization.
Use symbols $C_1, C_2, C_3, ...$ for Skolem constants and symbols $F_1, F_2, F_3, ...$ for Skolem functions.

(a) $\forall x.[\exists y.\forall z.P(x, y, z) \rightarrow \exists y.\forall z.Q(x, y, z)]$

(b) $\exists x.[\forall y.\exists z.P(x, y, z) \rightarrow \forall y.\exists z.Q(x, y, z)]$

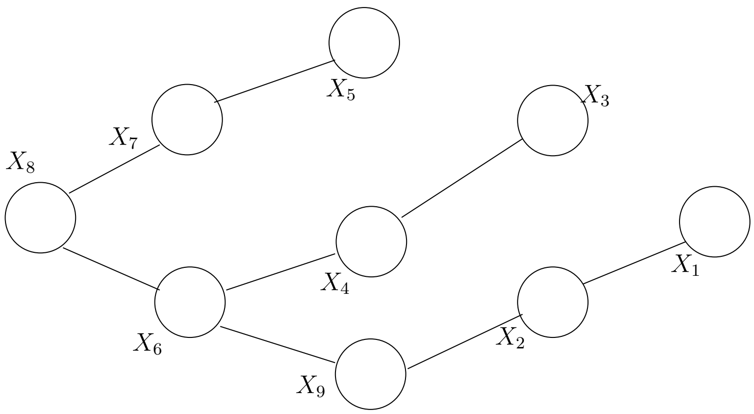
(c) $\exists x.[\forall y.P(x, y) \leftrightarrow \exists z.Q(x, z)]$

(d) $\forall x.[\exists y.P(x, y) \leftrightarrow \exists z.Q(x, z)]$

[SCORING: [0...100], 25 pts for each correct answer, no penalties for wrong answers.]

9

Consider the following tree-structured map-coloring problem, with domain $D \stackrel{\text{def}}{=} \{\text{Red}, \text{Green}, \text{Blue}\}$, with the following initial domain restrictions:



$X_1 = \{$ Red , , $\}$
$X_2 = \{$ Red , Green , $\}$
$X_3 = \{$, Green , $\}$
$X_4 = \{$ Red , Green , $\}$
$X_5 = \{$, , Blue $\}$
$X_6 = \{$ Red , Green , Blue $\}$
$X_7 = \{$, Green , Blue $\}$
$X_8 = \{$ Red , Green , Blue $\}$
$X_9 = \{$, Green , Blue $\}$

Using the Tree-Structured Algorithm, and considering the following node ordering: $\{X_8, X_7, X_5, X_6, X_4, X_3, X_9, X_2, X_1\}$,

(a) show the ordered progression of domain restrictions induced by the algorithm.

(b) As a consequence of the above process, state if the problem is solvable or not. If yes, show one solution. If not, explain why it is not.

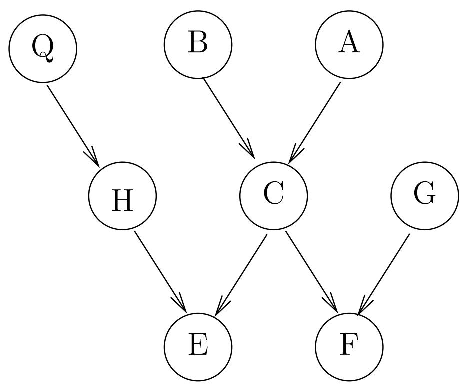
(c) Let n, d be ths number of nodes and the (maximum) domain size respectively. What is the worst-case complexity of this algortithm?

Notation: to represent the current domain of a node X_i, substitute with a blank " " any value in $\{\text{Red}, \text{Green}, \text{Blue}\}$ which cannot be assigned. (Ex: in current graph: $X_5 : \{\ ,\ ,\text{Blue}\}$)

[SCORING: [0...100], 50 pts for correct answer to question (a), 25pts each for correct answer to (b) and (c). No penalties for wrong answers..]

10

Consider the following Bayesian network:



where, for every node X, Y, Z:

- $P(x) \stackrel{\text{def}}{=} 0.6$, if X has no parent
- $P(x|Y) \stackrel{\text{def}}{=}$ (table below) if X has only one parent Y

Y	$P(x\|Y)$
T	0.4
F	0.3

- $P(x|Y,Z) \stackrel{\text{def}}{=}$ (table below)

Y	Z	$P(x\|Y,Z)$
T	T	0.7
F	T	0.6
T	F	0.2
F	F	0.1

if X has one left parent Y and one right parent Z.

Compute the conditional distribution $\mathbf{P}(\mathbf{A}|\mathbf{C})$.
Notation: uppercase letters are used for propositional variables representing random events, whereas the corresponding lowercase letters represent truth assignments to such propositional variables.
Ex: $a \stackrel{\text{def}}{=} (A = \mathsf{true})$, $\neg a \stackrel{\text{def}}{=} (A = \mathsf{false})$.

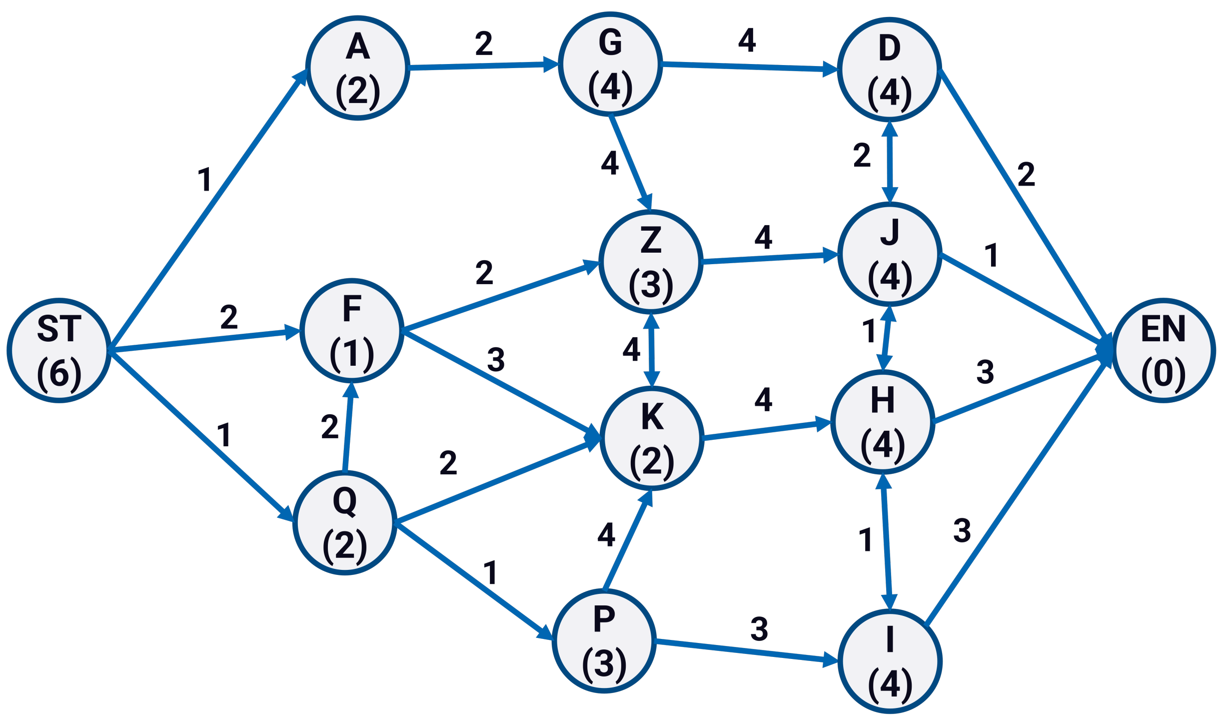
[SCORING: [0...100], 50 pts for correct symbolic formulas solving the problem; other 50 pts for correct computation of values; no penalties for wrong answers.]

11

The graph shown represents the states space of a hypothetical search problem where:

- States are denoted by letters.
- Arcs are labeled with the cost of traversing them.
- The estimated cost to a goal (i.e., the h function) is reported inside nodes (so that lower scores are better).

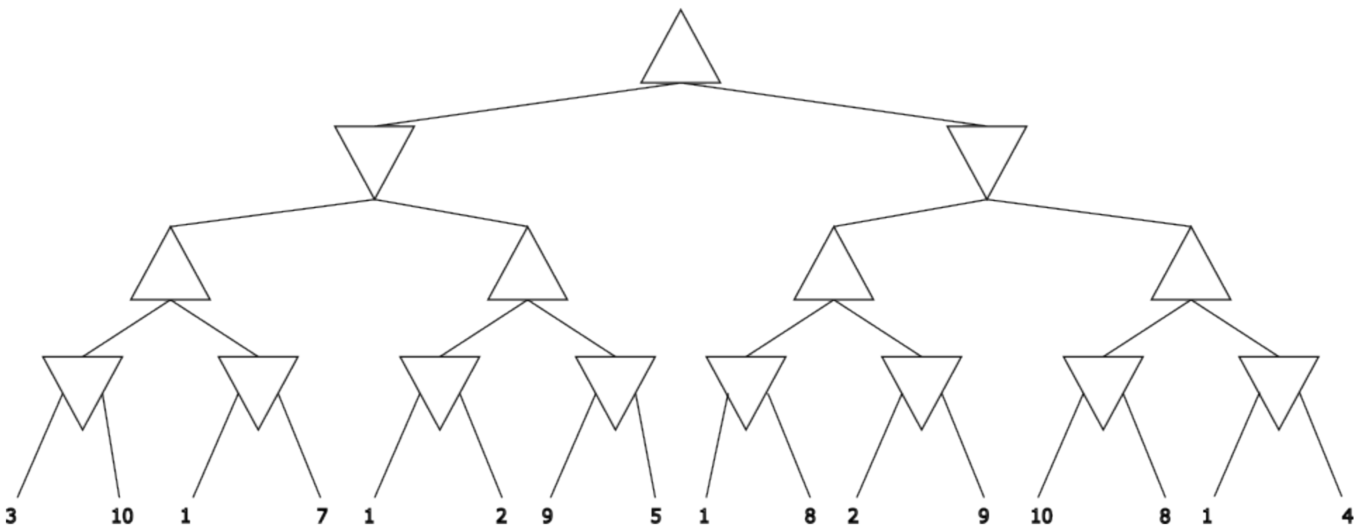
Considering ST as the initial state and EN as the goal state, please apply the **A*** search algorithm and report each step of the resolution process. Then, explain if the heuristic adopted is admissible or not. In the case of possible equal choices please proceed with the selection in alphabetical order. The solution format has to be provided as shown during the laboratory session.



[SCORING: [0...100], 80 pts for the correctness of the algorithm resolution, 20 pts for the correct heuristic explanation, -20 pts for every error within the resolution process..]

12

Solve the following adversarial search problem using Alpha/Beta search:



For each visited non-terminal node, write:

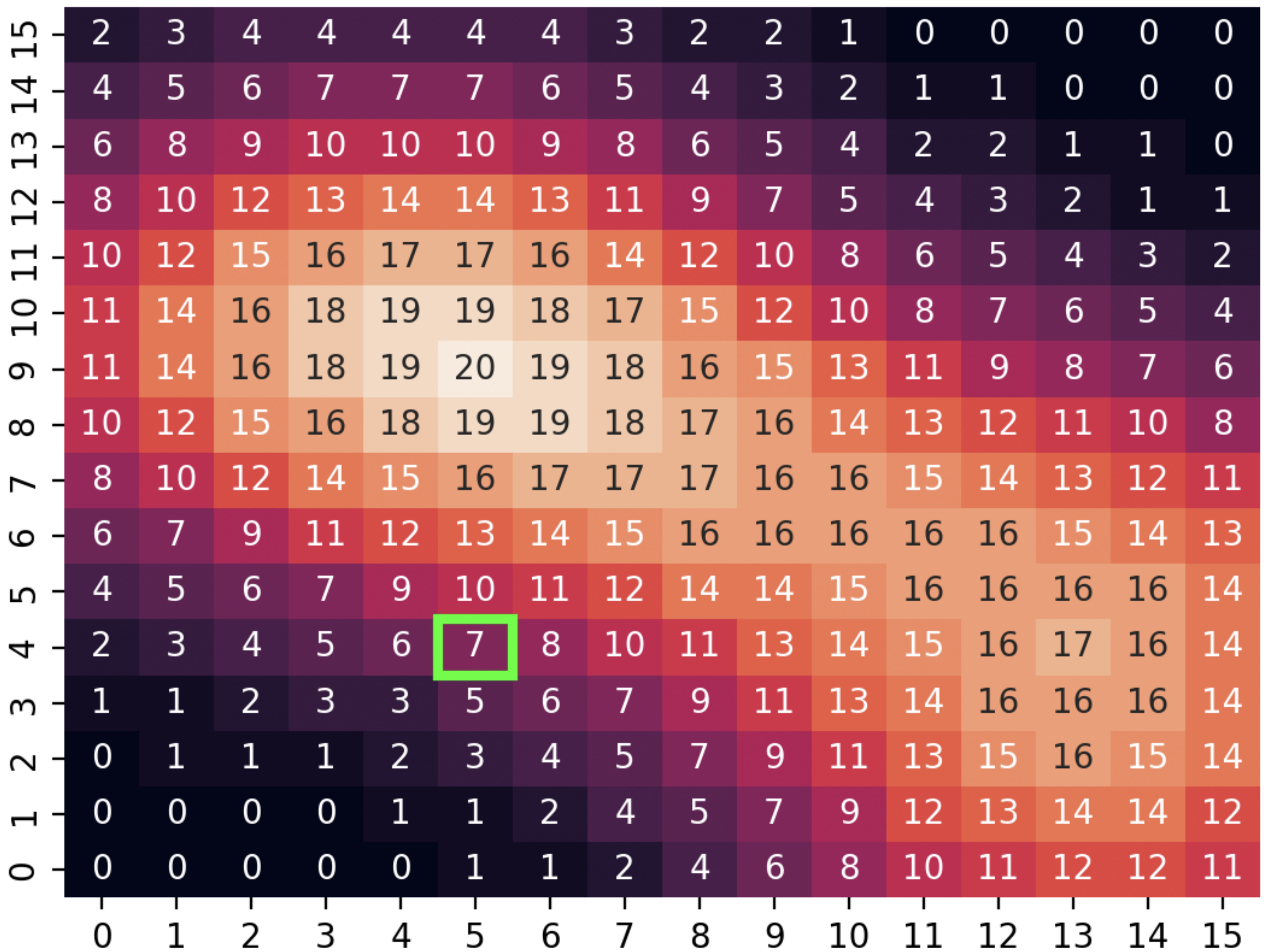
- its return value (inside the triangle)
- its α and β values **right before returning** (outside the triangle)

Additionally, **clearly cross** the pruned subtrees (not visited by the algorithm).

[SCORING: [0...100], 100pts for a fully correct solution, -10pts for each error in the resolution process. The score cannot go below 0..]

13

Consider the landscape of the following *maximization* problem:



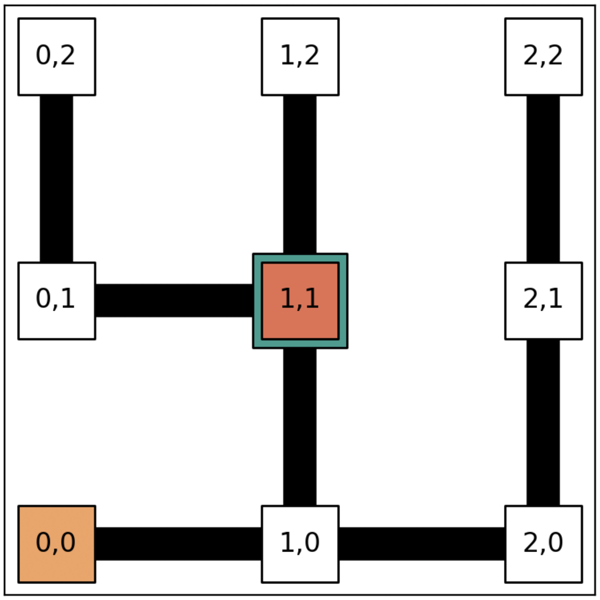
with starting solution: $(5, 4)$

Compute the sequence of solutions generated with *steepest* Hill Climbing. In case of a tie, the coordinates with higher values (lexicographic order) are picked (e.g. $(1,0) > (0,1) > (0,0)$).

[SCORING: [0...100], 100pts for a fully correct solution, -20pts for each error in the resolution process. The score cannot go below 0..]

14

Consider the following state graph, with undirected edges having uniform cost:



Start: (1,1)
Goal: (0,0)
Action order (when equal est. cost):
North, East, South, West

Compute the sequence of visted nodes by an agent using $LRTA^*$.

[SCORING: [0...100], 100pts for a fully correct solution, -10pts for each error in the resolution process. The score cannot go below 0..]

15

Consider the following actions with durations / dependencies:

a	d(a)
A	5
B	2
C	3
D	10
E	2
F	9
G	8
H	2
I	1

$A \prec C$
$A \prec F$
$B \prec C$
$C \prec E$
$D \prec E$
$E \prec G$
$E \prec H$
$F \prec I$
$H \prec I$

Using the Critical Path method:

- Compute the earliest / latest possible start time (ES/LS) for each action.
- Indicate which actions are in the critical path and the minimum makespan.

[SCORING: [0...100], 100pts for a fully correct solution. -10pts for each error in the resolution process. The score cannot go below 0..]