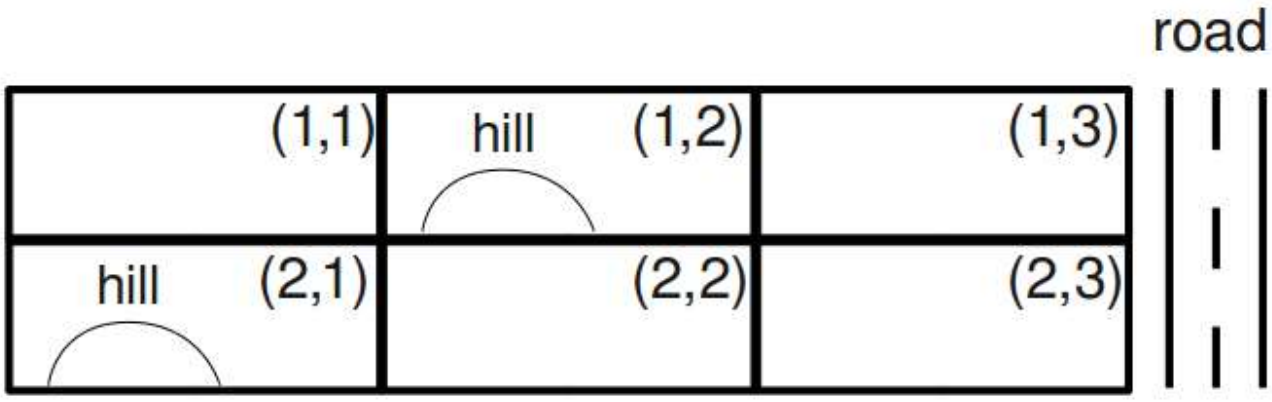
hw2_csps_q1_campus_layout

Question 1: Campus Layout

0.0/2.0 points (graded)

You are asked to determine the layout of a new, small college. The campus will have four structures: an administration structure (A), a bus stop (B), a classroom (C), and a dormitory (D). Each structure (including the bus stop) must be placed somewhere on the grid shown below.



The layout must satisfy the following constraints:

i. The bus stop (B) must be adjacent to the road.

ii. The administration structure (A) and the classroom (C) must both be adjacent to the bus stop (B).

iii. The classroom (C) must be adjacent to the dormitory (D).

iv. The administration structure (A) must not be adjacent to the dormitory (D).

v. The administration structure (A) must not be on a hill.

vi. The dormitory (D) must be on a hill or adjacent to the road.

vii. All structures must be in different grid squares.

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Here, *adjacent* means that the structures must share a grid edge, not just a corner.

Keep Constraints Always Visible

We recommend you work out the solutions to the following questions on a sheet of scratch paper, and then enter your results below.

Part 1: Unary Constraints

(a) Which of the constraints above are unary constraints?

- [x] i ✔
- [ ] ii
- [ ] iii
- [ ] iv
- [x] v ✔
- [x] vi ✔
- [ ] vii
- [ ] None of the above

Unary constraints are constraints that involve a single variable. i only contrains (B), v only constrains (A), and vi only constrains (D). All the other constraints involve more than one variable.

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(b) Select the domains of all variables after unary constraints have been applied.

A	B	C	D
☑ (1,1) ✔	☐ (1,1)	☑ (1,1) ✔	☐ (1,1)
☐ (1,2)	☐ (1,2)	☑ (1,2) ✔	☑ (1,2) ✔
☑ (1,3) ✔	☑ (1,3) ✔	☑ (1,3) ✔	☑ (1,3) ✔
☐ (2,1)	☐ (2,1)	☑ (2,1) ✔	☑ (2,1) ✔
☑ (2,2) ✔	☐ (2,2)	☑ (2,2) ✔	☐ (2,2)
☑ (2,3) ✔	☑ (2,3) ✔	☑ (2,3) ✔	☑ (2,3) ✔

i limits (B) to (1,3) or (2,3), because those are the only positions adjacent to the road. v removes (1,2) and (2,1) from the domain of (A) because those two positions have hills vi removes (1,1) and (2,2) from the domain of (D) because those two positions are neither on a hill, nor adjacent to the road. (C) has no unary constraints, and thus can still be any value after unary constraints are applied.

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Part 2: Arc Consistency

Let's start from the table above (the answer to Part 1) and enforce arc consistency. Initally, the queue contains all arcs (in alphabetical order).

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Let's examine what happens when enforcing A → B. After enforcing unary constraints, the domains of A and B are:

A	B
(1,1)	
(1,3)	(1,3)
(2,2)	
(2,3)	(2,3)

(c) Which of the following contains the correct domains after enforcing A → B? Pay attention to which variable's domain changes and which side of the arc it's on.

i

A	B
(1,1)	
	(1,2)
(1,3)	(1,3)
(2,2)	
(2,3)	(2,3)

ii

A	B
(1,3)	(1,3)
(2,2)	
(2,3)	(2,3)

iii

A	B
(1,1)	
(1,3)	
(2,2)	
(2,3)	(2,3)

iv

A	B
(1,1)	
(1,3)	(1,3)
(2,2)	
(2,3)	

- i
- ii ✔
- iii
- iv

After an arc is enforced, every value in the domain of the tail has at least one possible value in the domain of the head such that the two values satisfy all constraints with each other. If a value in the tail's domain does not satisfy this, that value can be removed, because it is guaranteed not to be a part of a solution without backtracking on some previously selected variable. In this case, (1,1) in A's domain is not adjacent to either (1,3) or (2,3), so B has no [Generating Speech Output] ,1) can be removed from A's domain.

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(d) Starting from the answer to Part 1 (in which unary constraints are enforced), select the domains of all variables after A → B is enforced.

A	B	C	D
☐ (1,1)	☐ (1,1)	☑ (1,1) ✔	☐ (1,1)
☐ (1,2)	☐ (1,2)	☑ (1,2) ✔	☑ (1,2) ✔
☑ (1,3) ✔	☑ (1,3) ✔	☑ (1,3) ✔	☑ (1,3) ✔
☐ (2,1)	☐ (2,1)	☑ (2,1) ✔	☑ (2,1) ✔
☑ (2,2) ✔	☐ (2,2)	☑ (2,2) ✔	☐ (2,2)
☑ (2,3) ✔	☑ (2,3) ✔	☑ (2,3) ✔	☑ (2,3) ✔

These are the same as part 1, except with (1,1) removed from A's domain due to enforcing A->B.

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(e) You should verify that enforcing consistency for A → C, A → D, B → A, B → C, B → D, and C → A do not change the domains of any variables. After enforcing these arcs, the next is C → B.

Continuing from the previous parts, select the domains of all variables after C → B is enforced.

A	B	C	D
☐ (1,1)	☐ (1,1)	☐ (1,1)	☐ (1,1)
☐ (1,2)	☐ (1,2)	☑ (1,2) ✔	☑ (1,2) ✔
☑ (1,3) ✔	☑ (1,3) ✔	☑ (1,3) ✔	☑ (1,3) ✔
☐ (2,1)	☐ (2,1)	☐ (2,1)	☑ (2,1) ✔
☑ (2,2) ✔	☐ (2,2)	☑ (2,2) ✔	☐ (2,2)
☑ (2,3) ✔	☑ (2,3) ✔	☑ (2,3) ✔	☑ (2,3) ✔

(1,1) and (2,1) are removed from C, because if either value is assigned to C, there is no possible value in B's domain that satisfies all of the constraints. A and D's domains do not change.

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(f) What arcs got added to the queue while enforcing C → B? Remember that the queue contained C → D, D → A, D → B, and D → C prior to enforcing C → B.

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- [ ] A → B
- [x] A → C ✔
- [ ] A → D
- [ ] B → A
- [x] B → C ✔
- [ ] B → D
- [ ] C → A
- [ ] C → B
- [ ] C → D
- [ ] D → A
- [ ] D → B
- [ ] D → C
- [ ] None

When a domain changes after enforcing an arc, all arcs that end at that variable must be re-added to the queue: A→C, B→C. This is done because some values in other variables' domains might have relied on the removed values to be consistent, so they have to be checked again.

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(g) Continuing from the previous parts, select the domains of all variables after enforcing arc consistency until the queue is empty. Remember that the queue currently contains C → D, D → A, D → B, D → C, and any arcs that were added while enforcing C → B.

A	B	C	D
☐ (1,1)	☐ (1,1)	☐ (1,1)	☐ (1,1)
☐ (1,2)	☐ (1,2)	☑ (1,2) ✔	☑ (1,2) ✔
☑ (1,3) ✔	☑ (1,3) ✔	☑ (1,3) ✔	☑ (1,3) ✔
☐ (2,1)	☐ (2,1)	☐ (2,1)	☑ (2,1) ✔
☑ (2,2) ✔	☐ (2,2)	☑ (2,2) ✔	☐ (2,2)
☑ (2,3) ✔	☑ (2,3) ✔	☑ (2,3) ✔	☐ (2,3)

Repeat the same process as parts c and e above for each arc in the queue. In this case the only value that gets removed from any domain while enforcing the arcs is (2,3) from D due to enforcing D→A.

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Part 3: Search with Arc Consistency

(h) If arc consistency had resulted in all domains having a single value left, we would have already found a solution. Similarly, if it had found that any domain had no values left, we would have already found that no solution exists. Unfortunately, this is not the case in our example (as you should have found in the previous part). To solve the problem, we need to start searching. Use the MRV (minimum remaining values) heuristic to choose which variable gets assigned next (breaking any ties alphabetically).

Which variable gets assigned next?

- A
- B ✔
- C
- D

B only has 2 possible values, while A and D have 3, and C has 4.

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(i) The variable you selected should have two values left in its domain. We will use the least-constraining value (LCV) heuristic to decide which value to assign before contuing with the search. To choose which value is the least-constraining value, enforce arc consistency for each value (on a scratch piece of paper). For each value, count the total number of values remaining over all variables.

Which value has the largest number of values remaining (and therefore is the least constraining value)?

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- (1,1)
- (1,2)
- (1,3)
- (2,1)
- (2,2)
- (2,3) ✔

Assigning (1,3) to B leaves only 2 other values: A or D with value (2,3) and C with value (1,2). Assigning (2,3) to B leaves 3 other values: A with value (1,3), C with value (2,2) and D with value (2,1) Since 3 > 2, (2,3) is the least constraining value.

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(j) After assigning a variable, backtracking search with arc consistency enforces arc consistency before proceeding to the next variable.

Select the domains of all variables after assignment of the least-constraining value to the variable you selected and enforcing arc consistency. Note that you already did this computation to determine which value was the LCV.

A	B	C	D
(1,1)	(1,1)	(1,1)	(1,1)
	1,2)	(1,2)	(1,2)

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☑ (1,3) ✔	☐ (1,3)	☐ (1,3)	☐ (1,3)
☐ (2,1)	☐ (2,1)	☐ (2,1)	☑ (2,1) ✔
☐ (2,2)	☐ (2,2)	☑ (2,2) ✔	☐ (2,2)
☐ (2,3)	☑ (2,3) ✔	☐ (2,3)	☐ (2,3)

These domains were determined while finding the least constraining value from part (i).

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(k) Is the answer to the previous part a solution to the CSP?

- ◉ Yes ✔
- ○ No

Since each variable has exactly one value in its domain after enforcing arc consistency, the answer is a solution to the CSP.

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