CONSTRAINT SATISFACTION - ANSWERS

There questions were carefully designed to test essential skills in constraint satisfaction. It allows the examiner to test the full range of ability. Here are justifications for my major decisions:

- Justification for no choices:
  Questions 1 and 2 test the students' ability to formulate constraint satisfaction problems. Together they allow students to contrast different formulations (which is important, and demanding, as part of learning outcome 2).
  Question 3 tests their knowledge of the techniques learned in the module, plus their ability to use them in appropriate situations.
  Together these questions test all the learning outcomes that can be tested in examinations. The learning outcomes tested by these questions are all essential to this module. Therefore, I see no incentive for giving students a choice.

- Justification for having two questions that start with problem formulation:
  Students are told repeatedly that problem formulation is the most important part of this module. It is also elaborated as the first and second learning outcomes. If one cannot formulate the problem as a constraint satisfaction problem, one cannot apply any of the techniques learned from this module. This is why every past exam papers on this topic contained about two questions in problem formulation. This paper is no exception.

- Bookwork vs non-bookwork:
  None of the questions in this paper is 100% bookwork. Having said that, if students remember what "bandwidth ordering" is, they would find it easier to understand questions 1 and 2.

Answer to Question 1

This is **non-bookwork**:

- The minimal bandwidth ordering problem was introduced in the module. So students should know what it is. That is why only a concise definition is given in the question.
- However, students have never been asked to formulate this problem as a constraint satisfaction problem.

(a) Marks will be given to any valid formulation. Here is one possible formulation:
Let V = x1, x2, …, xn
Variables: p1, p2, …, pn represent the position of x1, x2, …, xn in an ordering
Domains: all variables have domains {1, 2, …, n}
Constraints: p1, p2, …, pn all take different values [15%]

(b) A constraint graph is a graph (V, E) for a constraint satisfaction problem (Z, D, C) in which every variable in Z corresponds to a node in V. An edge (x, y) is in E whenever the variables corresponding to x and y are involved in at least one constraint. The constraint graph is a complete graph – every node is adjacent to every other node. [5%]

(c) The size of the search space is *n to the power n*, or *n factorial* if the constraints are taken into consideration. [5%]

(d) The objective function *f* is the maximum of all i – j, where (pi, pj) is an edge in E. The objective is to minimize *f*. [5%]

(e) Not much in constraint satisfaction is effective in this problem. The only constraint is all-different, so some constraint propagation is possible. That is arguably the most relevant technique in this problem, but not terribly effective in pruning the search space, because everytime a label is committed to only one value is pruned from the remaining variables. [10%]

Answer to Question 2

(a) Marks will be given to any valid formulation. Here is one possible formulation:
Let V = x1, x2, …, xn
Variables: p1, p2, …, pn represent the position of x1, x2, …, xn in an ordering
Domains: all variables have domains {1, 2, …, n}
Constraints: This is different from the Minimal Bandwidth Ordering Problem.
Constraint 1: p1, p2, …, pn all take different values
Constraint 2: whenever (xi, xj) is an edge in E, $pi - pj \leq k$ [15%]

(b) Lookahead algorithms would perform better in the Bandwidth Decision Problem. This is because everytime a value is assigned to pi, values can be propagated with Constraint 2. So more values are likely to be removed.
- The smaller k is, the more effective constraint propagation could be.
- Compared to the situation in the Minimal Bandwidth Ordering Problem, more constraint propagation is possible. This makes constraint satisfaction more relevant. [15%]

Answer to Question 3

This question will test the students' understanding of the techniques. It also tests the students' breadth of knowledge in constraint satisfaction.

The answers may not be long. To give the right answer, students have to thoroughly understand the techniques.

(i) *Problem reduction* is most relevant. This can either be used for preprocessing or look ahead search. The hope is that problem reduction can help us to detect deadends early, hence save search time. [10%]

(ii) Everything else being equal, the *minimum domain first* heuristic, which is sometimes referred to as the *fail-first-principle*, is most relevant. [10%]

(iii) In this problem, the cost of constraint checks dominates the algorithm. Therefore, constraint checks should be minimized. The most relevant algorithm to use is *BackMarking*, which reduces the amount of constraint checks. [10%]

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