CS472 Foundations of Artificial Intelligence
Fall 1999
Assignment 1

Due Monday, September 20 at the beginning of class.

1. **Human Reasoning (15 pts.)**

   Consider the following cryptarithmetic problem:

```
    DONALD
  + GERALD
  --------
    ROBERT

with  D = 5
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   Find the substitution of digits for letters such that the resulting sum is arithmetically correct. Each letter must stand for a different digit.

   (a) **(7 pts.)** Humans can solve this puzzle relatively easily. Describe the reasoning process involved in finding a solution for this puzzle and give the solution. Describe the assignment of the first 5 digits you assign in detail.

   (b) **(2 pts.)** Is the solution unique? If so, why? If not, give 2nd solution.

   (c) **(3 pts.)** What's the size of the brute force search space? (I.e., the raw number of possible full digit assignments.) Estimate how many of those states you explored in answering part (a).

   (d) **(3 pts.)** Why is it difficult to replicate the kind of human reasoning used to solve this problem in a computer program? Also, in what sense is the reasoning similar to the constraint satisfaction problem (CSP) approach? Be as specific as possible in discussing what aspects could be done automatically using constraint propagation and what aspects would be quite difficult to do automatically.

2. **A* (10 pts.)** Algorithm A* does not terminate until a goal node is selected for expansion. However, a path to a goal node might be reached long before that node is selected for expansion. Why not terminate as soon as a goal node has been found? Illustrate your answer with an example. (Draw a graph.)

3. **Uninformed search (25 pts.)** Consider the search tree in Figure 1, where nodes are states, arcs are operators labeled with costs, S is the initial state, and G is the goal state, and the following strategies:

   No avoidance Repeated states are not avoided.

   No self-loop Do not return to the state you just came from.

   No cycles Do not create paths with cycles in them.

   No repeats Do not generate (*i.e.* add to list) any state that has been generated before.

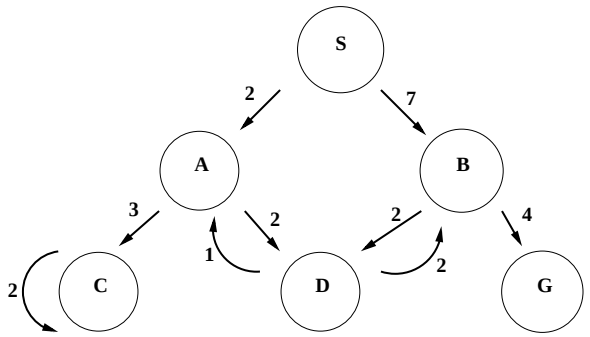

Figure 1: Graph for search question.

By employing each of the above strategies, list the states expanded by the following uninformed search strategies until the goal G is reached or 12 states have been listed. Break ties alphabetically by the state label. Present you answer in a table as shown below.

Strategy	No avoidance	No self-loop	No cycles	No repeats
Breadth-first				
Uniform cost				
Depth-first				
Iterative deepening				

4. **Heuristic Search (15 pts.)**

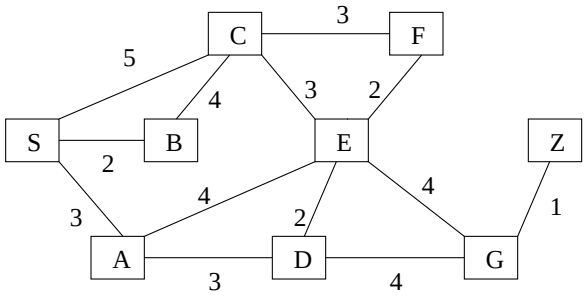

Figure 2: Graph for Heuristic Search question.

See the graph in Figure 2. The start state is S and the goal state is Z. The numbers on the arcs indicate the cost of traversing that arc. Whenever the search algorithm requires a heuristic estimating function, use the following:

n	S	A	B	C	D	E	F	G	Z
h(n)	8	7	6	5	4	3	2	1	0

(a) (5 pts.) Using the graph in Fig. 1 and **uniform-cost search**: (1) list the nodes in the order they would be expanded; (2) list the nodes that lie along the final correct path to the goal.

(b) (5 pts.) Same as (a), but using **greedy search**.

(c) (5 pts.) Same as (a), but using **A* search**.

5. **Problem Encodings (15 pts.)**

   (a) **(10 pts.)** Encode the N-queens problem as a Boolean satisfiability problem. How many clauses do you need to encode the constraints of the problem? Give the clauses.
   Hint: Use N^2 variables. Each variable corresponds to a square on the board. A variable has truth value *True* iff its corresponding square contains a queen.

   (b) **(3 pts.)** Consider randomly generated 3-SAT instances with the ratio of clauses to variables equal to 10. What can you say about the difficulty of solving such instances. Compare with the difficulty of solving randomly generated instances at the ratio of 4.3.

   (c) **(2 pts.)** Consider a SAT instance encoding a problem in VLSI design. Assume the ratio of clauses to variables of that instance is 10. What can you say about the hardness of the instance?

6. **Constraint Satisfaction Problems (CSP) (20 pts.)** Outline a formulation of the "Missionaries and cannibals" as a constraint satisfaction problem. (For the problem description, see Russell & Norvig.) Describe the variables and constraints of the problem. Hint: Consider a formulation in which you limit the maximum length of the solution, i.e., solutions up to k steps. You should define the main variables, say X_k, *i.e* the variables that represent the operator to pick at step k, their domains, as well as the different variables that define the states, indexed by time ($t = 0, 1, \ldots, k$). The constraints should be such that you can only pick operators that lead to legal states. Write down the constraints in terms of the state variables and the operator variables.