Solve problems 1, 5, 6, and any one out of 2, 3, 4

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PhD Qualifi Exam for Spring 2007–Theory Area

Spring 2007, CS Department, IIT
Your random number______________7

There are 6 questions in this exam. For every question, please write your answer in a clean and concise way. If you are asked to write an algorithm for a question, you have to write the pseudo-code of your algorithm and also put explanation about your pseudo-code.

1. Let $G = (V, E; r)$ be a weighted connected graph. For any edge $e \in E$, the value $r(e)$ is referred to as the *reliability* of e. For any path P in G, the *reliability* of P is, by definition, the minimum among. reliability of the edges occurring in P. The *reliability* $r_G(s,t)$ of two vertices s and t is equal to the maximum reliability of P where P ranges over all $s-t$ paths.
   (a) Give an algorithm with running time $O(m + n \log n)$ to compute $r_G(s,t)$ for any $s, t \in V$.
   (b) Prove that if T is a longest spanning tree (i.e., $\sum_{e \in E(T)} r(e)$ is the largest among all spanning trees), then $r_T(s,t) = r_G(s,t)$ for all $s, t \in V$.

2. Let $G = (V, E)$ be a connected graph, and T be a *depth-first spanning tree* (DFS tree) of G. For each $v \in V$, denote by $T(v)$ the sub-tree of T induced by the descendants of v (including v itself), and by $G - v$ the subgraph of G induced by $V \setminus \{v\}$. Prove that G is biconnected (i.e., for each node $v \in V$, the graph $G - v$ is connected) if and only if the root of T has exactly one child and for each node v other than the root and its (unique) child, there is an edge between a node in the subtree $T(v)$ and a proper ancestor of v other than the parent of v. (*Hint*: you may use the fact that each edge of G is between a vertex and one of its descendants.)

3. Let $G = (V, E)$ be an undirected graph with $|V| = n$, and s be a fixed node in G. The *depth* of a node v is the distance between v and s. Denote by R the maximum distance of all the nodes from s. For $0 \le i \le R$, the *layer* i of G consists of all nodes of depth i. The following procedure computes a special BFS tree T referred to as *canonical BFS tree* and an associated ranking *rank* of the nodes constructed layer-by-layer in the bottom-up manner. Initially, T is empty and $rank(v) = 0$ for each node v at the layer R. The ranks and the children of all nodes at each other layer i are computed iteratively: Initialize U to be the set of nodes at layer i, and W to be the set of nodes at layer $i+1$. Repeat the following iteration while W is non-empty. Compute the maximum rank r of the nodes in W, and find a node $v \in U$ which is adjacent to the largest number of nodes in W with rank r. If v is adjacent to only one node in W with rank r, then $rank(v) = r$; otherwise, $rank(v) = r + 1$. Put all neighbors of v in W as the children of v in T. Remove v from U, and remove all neighbors of v from W. When W is empty, set $rank(v) = 0$ for each node $v \in U$. Figure 1 gives an example of the ranking and the canonical BFS tree constructed in this way. Prove that (1) for each $v \in V$, $rank(v) \le \lfloor \log n \rfloor$; and (2) if u_1 and u_2 are two nodes at the same layer, v_1 and v_2 are their child respectively at layer $i+1$, and all of them have the same rank, then neither u_1 and v_2 nor u_2 and v_1 are adjacent in G.

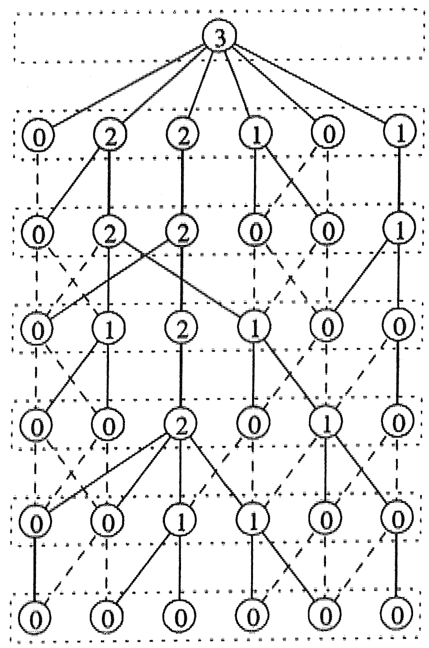

Figure 1: The ranking of V and the canocial BFS tree consisting of solid edges.

4. Let $D = (V, A; c)$ be a weighted digraph. A cycle cover of a graph D is a collection of vertex-disjoint cycles such that every vertex of G is a part of a cycle. The weight of a cycle cover is the total weight of edges in this cycle cover. Construct a weighted bipartite $H = (X \cup Y, E; c')$ as follows: Let $V = \{v_1, v_2, \cdots, v_n\}$. Then $X = \{x_1, x_2, \cdots, x_n\}$ and $Y = \{y_1, y_2, \cdots, y_n\}$ are two disjoint copies V. For each edge $v_i v_j \in A$, add an edge $x_i y_j$ to E with weight $c'(x_i y_j) = c(v_i v_j)$. Prove that D contains a cycle cover of weight C if and only if H contains a perfect matching of weight C. (Recall that a perfect matching in H is a set of n node-disjoint edges.)

5. Suppose S is a sequence of numbers divided into m consecutive sub-sequences $S_1, S_2, \cdots, S_m$, each of which is sorted. In order to sort S, we may and are only allowed to merge adjacent sub-sequences into a larger sorted sub-sequence. The the number of comparisons of merging two sorted sub-sequences into a larger sorted sub-sequence is the total length of the two sub-sequences minus one. Give a dynamic programming algorithm to find the best order to combine the sub-sequences so as to have the smallest total number of comparisons.

6. Assume that you only know the following problems are NP-complete: SAT/CNF-SAT, 3-SAT, Vertex Cover, Clique, Independent Set, Hamiltonian Path/Cycle, Subset Sum. Consider the following **MINIMUM BIN PACKING** problem. Given a finite U of items with a size $s(u) \in Z^+$ for each $u \in U$ and a positive integer bin capacity B, seek a partition of U into the smallest number of disjoint sets $U_1, U_2, \cdots, U_m$ satisfying that $\sum_{u \in U_j} s(u) \leq B$ for each $1 \leq j \leq m$. Prove that the decision version of **MINIMUM BIN PACKING** is NP-complete.