CS 521: Data Structures and Algorithms 1
Fall 2011-2012 (Homework 3)

1. (15 Pts.) The square of a directed graph $G = (V, E)$ is the graph $G^2 = (V, E^2)$ such that $u, v \in E^2$ if and only G contains a path with at most two edges between u and v. Describe efficient algorithms for computing G^2 from G for both the adjacency-list and adjacency-matrix representations of G. Analyze the running times of your algorithms.

2. (15 Pts.) The **incidence matrix** of a directed graph $G = (V, E)$ with no self-loops is a $|V| \times |E|$ matrix $B = (b_{ij})$ such that

$$b_{ij} = \begin{cases} -1 & \text{if edge } j \text{ leaves vertex } i, \\ 1 & \text{if edge } j \text{ enters vertex } i, \\ 0 & \text{otherwise.} \end{cases}$$

   Describe what the entries of the matrix product BB^T represent, where B^T is the transpose of B.

3. (15 Pts.) The **transpose** of a directed graph $G = (V, E)$ is the graph $G^T = (V, E^T)$, where $E^T = \{(v, u) \in V \times V : (u, v) \in E\}$. Thus, G^T is G with all its edges reversed. Describe efficient algorithms for computing G^T from G, for both the adjacency-list and adjacency-matrix representations of G. Analyze the running times of your algorithms.

4. (10 Pts.) Professor ASh conjectures the following: Let $G = (V, E)$ be a connected, undirected graph with a real-valued weight function w defined on E. Let A be a subset of E that is included in some minimum spanning tree for G, let $(S, V - S)$ be any cut of G that respects A, and let (u, v) be a safe edge for A crossing $(S, V - S)$. Then, (u, v) is a light edge for the cut. Show that the professors conjecture is incorrect by giving a counterexample.

5. (15 Pts.) Given a graph G and a minimum spanning tree T, suppose that we decrease the weight of one of the edges in T. Show that T is still a minimum spanning tree for G. More formally, let T be a minimum spanning tree for G with edge weights given by weight function w. Choose one edge $(x, y) \in T$ and a positive number k, and define the weight function w' by

$$w'(u, v) = \begin{cases} w(u, v) & \text{if } (u, v) \neq (x, y), \\ w(x, y) - k & \text{if } (u, v) = (x, y). \end{cases}$$

   Show that T is a minimum spanning tree for G with edge weights given by w'.

6. (15 Pts.) Suppose that a graph G has a minimum spanning tree already computed. How quickly can we update the minimum spanning tree if we add a new vertex and incident edges to G?

7. (15 Pts.) Professor Ash proposes a new divide-and-conquer algorithm for computing minimum spanning trees, which goes as follows. Given a graph $G = (V, E)$, partition the set V of vertices into two sets V_1 and V_2 such that $|V_1|$ and $|V_2|$ differ by at most 1. Let E_1 be the set of edges that are incident only on vertices in V_1, and let E_2 be the set of edges that are incident only on vertices in V_2. Recursively solve a minimum-spanning-tree problem on each of the two subgraphs $G_1 = (V_1, E_1)$ and $G_2 = (V_2, E_2)$. Finally, select the minimum-weight edge in E that crosses the cut (V_1, V_2), and use this edge to unite the resulting two minimum spanning trees into a single spanning tree.
   Either argue that the algorithm correctly computes a minimum spanning tree of G, or provide an example for which the algorithm fails.

8. (**Extra Credit**) (25 Pts) Problem 23-1 on page 638 of CLRS text book, 3rd edition (this corresponds to problem 23-1 on page 575 of the 2nd edition of CLRS).