CSL863: Randomized Algorithms
II semester, 2007-08

Homework # 1

Due before class on **Friday, February 8, 2008**

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1. Find an example of a random variable with a finite jth moment for $1 \leq j \leq k$ but an unbounded $k+1$st moment for some value of k.

2. A *fixed point* of a permutation $\pi : [n] \rightarrow [n]$ (where $[n]$ denotes the set $\{1, 2, \ldots, n\}$) is a value j for which $\pi(j) = j$. Find the variance of the number of fixed points of a permutation chosen uniformly at random from all permutations. Use this to upper bound (with high probability) the number of fixed points in a randomly chosen permutation.

3. Given a black box that generates integers uniformly at random from k, we give an algorithm for constructing a random permutation of $[n]$. For each $i \in [n]$, for any $n \leq k$, we determine an $f(i)$ as follows: $f(1)$ is picked at random from $[k]$ using the black box. For $f(i)$, $i > 1$, pick a random number r from $[k]$ using the black box. If r is distinct from all $f(j)$, $j < i$, then $f(i) = r$ otherwise pick another random number from $[k]$. The random permutation is the numbers sorted in the order of increasing $f(i)$.

   First show that this algorithm gives a permutation chosen uniformly at random from all permutations. What is the expected number of calls to the black box when $k = n$, and when $k = 2n$. Using a Chernoff bound, bound the probability of having to make more than $4n$ calls to the black box when $k = 2n$.

4. The randomized quicksort algorithm to sort a set S of n numbers is as follows:

- Pick a *pivot* i.e. an element r of S uniformly at random.
- Make a pass through S and create sets $S_1 = \{x \in S : x \leq r\}$ and $S_2 = \{x \in S : x > r\}$.
- Recursively sort S_1 and S_2
- Output the sorted version of S_1 followed by r followed by the sorted version of S_2.

Let us view the execution of Randomized quicksort as forming a tree where the root of each subtree is the pivot chosen for subset contained in that subtree. A node of this tree is called *good* if the pivot element in it divides the subtree rooted at that node into two sets each of size not more than 2/3 of the subset contained in the subtree.

(a) Show that the expected running time of this algorithm is $O(n \log n)$.

(b) Show that the number of good nodes in any path from root to leaf in this tree is not greater than $c \log n$ for some constant c.

(c) Show that with probability at least $1 - 1/n^2$ the number of nodes in any given root to leaf path is not more than $c' \log n$ for some other constant c'.

(d) Show that, with high probability, the number of nodes in the *longest* root to leaf path is no more than $c' \log n$.

(e) Use these answers to show that the running time of Randomized quicksort is $O(n \log n)$ with high probability.