Advanced Algorithms	10/19, 2018
Exercise 04	
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1 MAX-SAT

Consider a conjunctive normal form (CNF) formula on Boolean variables x_1, x_2, $\ldots$, x_n, that is, a formula defined as AND of a number m of clauses, each of which is the OR of some literals appearing either positively as x_i or negated as $\bar{x}_i$. Suppose that each clause c_j has some weight w_j. The goal is to find an assignment of TRUE/FALSE values to the literals with the objective of maximizing the total weight of the satisfied clauses.

(A) Consider a clause that has $k \geq 1$ literals. Argue that the simple randomized algorithm that sets each variable at random (true or false, each with probability half) satisfied this clause with probability $(1 - 2^{-k})$.

(B) Consider the linear program with objective

$$\textit{maximize} \sum_{j=1}^{m} w_j z_j$$

$$\textit{subject to } \forall j \in \{1, 2, \ldots, m\} : \sum_{i \in S_j^+} y_i + \sum_{i \in S_j^-} (1 - y_i) \geq z_j$$

$$\forall j \in \{1, 2, \ldots, m\} : z_j \in [0, 1]$$

$$\forall i \in \{1, 2, \ldots, n\} : y_i \in [0, 1]$$

Here, S_j^+ denotes the set of variables that appear in the j^{th} clause positively, and S_j^- denotes the set of variables that appear in the j^{th} clause in a negated form. Explain how this is a relaxation of an integer linear program for our objective. Moreover, let (y^*, z^*) denote the optimal solution of this LP. Show that the natural randomized rounding algorithm that sets each x_i to be True with probability y_i^* provides the following guarantee: if the j^{th} clause has k literals, it is satisfied with probability at least $(1 - (1 - \frac{1}{k})^k) z_j^*$.

(C) Notice that the first algorithm handles well large clauses and the second algorithm handles well the smaller clauses. Put the two together to get a 3/4 approximation algorithm for the MAX-SAT problem.

(D) In part (B), we considered a linear randomized rounding process. Consider a non-linear round which rounds variable x_i to be true with probability $f(y_i^*)$ where $f : [0, 1] \to [0, 1]$ is an arbitrary function such that $f(y) \in [1 - 4^{-y}, 4^{y-1}]$. Prove that this non-linear rounding directly gives a 3/4 approximation algorithm.

(E) Find a CNF such that there is a 3/4 gap between the value of the solution of LP described in part (B) and the optimal Boolean assignment to the variables. Hint: find a CNF with 4 clauses, each of weight 1, such that the LP has value 4 but any assignment satisfies at most 3 clauses. This implies that the 3/4 factor is the integrability gap of this LP formulation and no rounding technique for it will give an approximation better than 3/4.