MCMT Homework 9

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Exercise 9.1

Let Y_t denote the number of coordinates that have been selected after t rounds. Define the distinguishing statistic $f : \{0,1\}^n \to R$ by $f(x) = \sum_{i=1}^n x_i$.

1. The probability that one coordinate is not selected in t steps is $p = (1-\frac{1}{n})^t$. The expectation of the number of coordinates that are not selected in t steps is $\mathrm{E}(n - Y_t) = np = n(1-\frac{1}{n})^t$. So $\mathrm{E}(Y_t) = n - n(1-\frac{1}{n})^t$.

2. Let $I_i(t)$ be the indicator that i-th coordinate has been selected at t-th step.

   $\mathrm{E}(I_i(t)I_j(t)) = 2(1-(1-\frac{1}{n})^t) - (1-(1-\frac{2}{n})^t) = 1 - 2(1-\frac{1}{n})^t + (1-\frac{2}{n})^t$.

   $\mathrm{E}(I_i(t))\mathrm{E}(I_j(t)) = (1-(1-\frac{1}{n})^t)^2$.

   $\mathrm{Cov}(I_i(t), I_j(t)) = \mathrm{E}(I_i(t)I_j(t)) - \mathrm{E}(I_i(t))\mathrm{E}(I_j(t)) = (1-\frac{2}{n})^t - (1-\frac{1}{n})^{2t} \leq 0$.

   $\mathrm{Var}(Y_t) = \mathrm{Var}(\sum_i I_i(t)) = \sum_i(\mathrm{Var}(I_i(t))) + \sum_{i\neq j}\mathrm{Cov}(I_i(t), I_j(t)) \leq \sum_i(\mathrm{Var}(I_i(t))) \leq np(1-p) \leq \frac{n}{4}$.

3. $\mathrm{E}_0(X_{ti}|Y_t) = \frac{Y_t}{n}\frac{1}{2}$. This is the probability that x_i is chosen, and times the probability that it is set to be 1.

   $\mathrm{E}_0(f(X_t)|Y_t) = \sum_i \mathrm{E}_0(X_{ti}|Y_t) = \frac{Y_t}{2}$.

   $\mathrm{E}_0(f(X_t)) = \sum_y \mathrm{E}_0(f(X_t)|Y_t = y)P(Y_t = y) = \sum_y \frac{y}{2}P(Y_t = y) = \frac{\mathrm{E}(Y_t)}{2}$.

4. $\mathrm{Var}_0(f(X_t)|Y_t) = Y_t\frac{1}{2}(1-\frac{1}{2}) = \frac{1}{4}Y_t$, as $f(X_t)$ given Y_t is a Binomial distribution. $\mathrm{E}_0\mathrm{Var}_0(f(X_t)|Y_t) = \frac{1}{4}\mathrm{E}_0(Y_t)$.

   $\mathrm{E}_0(f(X_t)|Y_t) = \frac{Y_t}{2}$. $\mathrm{Var}_0\mathrm{E}_0(f(X_t)|Y_t) = \mathrm{Var}_0\frac{Y_t}{2} = \frac{1}{4}\mathrm{Var}_0(Y_t)$.

   $\mathrm{Var}_0(f(X_t)) = \mathrm{E}_0\mathrm{Var}_0(f(X_t)|Y_t) + \mathrm{Var}_0(\mathrm{E}_0(f(X_t)|Y_t)) = \frac{1}{4}(\mathrm{E}(Y_t) + \mathrm{Var}(Y_t))$.

   By substituting the results we have, $\mathrm{E}(Y_t) + \mathrm{Var}(Y_t) = n - n(1-\frac{1}{n})^t + (n^2 - n)cov + n(1-\frac{1}{n})^t(1-(1-\frac{1}{n})^t) = n + (n^2-n)cov - n(1-\frac{1}{n})^t < n$, where cov is $\mathrm{Cov}(I_i(t), I_j(t))$ for $i \neq j$, which we have shown to be negative.

   So $\mathrm{Var}_0(f(X_t)) < \frac{1}{4}n$.

5.