CS 281 Homework 3

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1 ε-DP mean estimation

Assume we are given a database of medical records $X \in \{0,1\}^{n\times d}$ where each record X_i is a vector $(x_{i1}, ..., x_{id})$, where $x_{ij} \in \{0,1\}$ is a boolean denoting whether a person i has a medical condition j (diabetes, hypertension, chronic kidney disease etc.) or not.

We are interested in identifying an ε-DP mechanism for calculating the prevalence of each of the d medical conditions in the dataset. In other words, we're interested in a mechanism $M(X)$ which approximates $f(X) = \mathbb{E}[X] = \frac{1}{n}\sum_{i=1}^{n} X_i$, such that, for any two datasets X, X' which differ in exactly one entry, and all possible prevalence vectors $T \in \mathbb{R}^d$,

$$\frac{P(M(X) \in T)}{P(M(X') \in T)} \leq \exp(\varepsilon)$$

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1.1 Intuition [2 points]

Explain, in plain language, what the ε-DP mechanism would guarantee in our case. (1-2 sentences).

1.2 Univariate case [11 points]

Consider a simplified, univariate version of this problem, where you're trying to estimate the prevalence of diabetes ($j = 0$), using the Laplace mechanism

$$M(X) = f(X) + W$$

where

$$W \sim \text{Laplace}\Big(\frac{\Delta f}{\varepsilon}\Big)$$

(a). Sensitivity and noise [2 points]. Calculate Δf and state the distribution of $W \sim$ Laplace(), using variables n, d, ε.

(b). Implementation. [6 points] For the simulated dataset in the starter code, implement the Laplace mechanism for calculating prevalence of diabetes for three different ε values: 0.01, 0.1 and 1. For each ε, calculate the mean 1000 times, and plot the resulting distributions of mean estimates (using a histogram with 30 bins). Hint: use the np.random.laplace function with appropriate parameters.

(c). Interpretation. [1 point] How do the plots change across the values of ε?

1.3 Multivariate case [10 points]

Consider a full version of this problem, where the Laplace mechanism

$$M(X) = f(X) + (W_1, ..., W_d)$$

where W_j are independent Laplace random variables $W_j \sim \text{Laplace}\left(\frac{\Delta f}{\varepsilon}\right)$

(a). Sensitivity and noise [2 points]. Calculate Δf and state the distribution of $W_j \sim \text{Laplace}()$, using variables n, d, ε.

(c). Implementation. [6 points] For the simulated dataset in the starter code, implement the Laplace mechanism for calculating prevalence of all 10 diseases for three different ε values: 0.01, 0.1 and 1. For each ε, calculate the mean 1000 times, and plot the resulting distributions of mean estimates (using a histogram with 30 bins).

(d). Interpretation. [2 points] How do the plots change across the values of ε? Compare your plots to those generated in part 1.2. How do the plots for the first disease (diabetes) differ in the multivariate case from the univariate case?

2 (ε, δ)-DP mean estimation

Recall the Gaussian mechanism satisfies approximate DP.
Given $f : \mathcal{X}^n \to \mathbb{R}^k$, the Gaussian mechanism outputs

$$M(X) = f(X) + (Y_1, \ldots, Y_d)$$

where $Y_i \sim \mathcal{N}(0, \sigma^2)$, $\sigma^2 = \frac{2\ln(1.25/\delta)\cdot(\Delta_2 f)^2}{\epsilon^2}$, and $\Delta_2 f$ is the ℓ_2 sensitivity of the function. The Gaussian mechanism is (ϵ, δ)-DP.

2.1 The Gaussian mechanism [12 points]

(a). Sensitivity and noise [4 points]. Calculate $\Delta_2 f$ and state the distribution of $W \sim \mathcal{N}()$, using variables $n, d, \varepsilon, \delta$.

(b). Implementation. [6 points] For the simulated dataset in the starter code, implement the Gaussian mechanism for calculating prevalence of all 10 diseases for three different ε values: 0.01, 0.1 and 1, and $\delta = 0.1$. For each ε, calculate the mean 1000 times, and plot the resulting distributions of mean estimates. Hint: use the np.random.normal function with appropriate parameters.

(d). Interpretation. [2 points] How do they change across the values of ε? How is it different from the Laplace mechanism?