

# Fast top-k frequent itemset mining under Local Differential Privacy\*

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**Abstract**—This is the abstract.

**Index Terms**—This is the keywords

## I. INTRODUCTION

Differential privacy (DP) [7] is the state-of-the-art approach that is used to protect individual privacy in the process of data collection, which has been named one of the world's top 10 breakthrough technologies in 2020 by the MIT technology review. It is a means in cryptography that aims to provide a way to maximize the accuracy of data queries when querying from statistical databases while minimizing the chances of identifying their records. Meanwhile, as a mathematical technique, it can add noise to the data while quantifying the extent of the increase in privacy, thus making the process of adding “noise” more rigorous.

Due to its unique advantages, DP has been widely studied by the academia and industry. For example, Google, Microsoft, apple and other companies use this technology to protect users' privacy, and at the same time, mobile phones aggregate data, so as to improve service quality. And the U.S. government is to complete a census of 330 million U.S. residents by 2020, keeping their identities secret, in what would be the largest application of DP ever.

There are two types of differential privacy - Centralized differential privacy (CDP) and Local differential privacy (LDP). Compared with CDP, the LDP does not require the assumptions of a trusted third party and provides stronger privacy guarantees. **DP's research has involved many aspects, in recent years, the work in mining frequent itemsets has attracted the attention, which is one of the most important techniques because of its ability to locate the repeating relationships between different items in a data set and plays an essential role in mining association rules [9].** Formally, let  $I = \{x_1, x_2, \dots, x_d\}$  be a set of items and  $D = \langle T_1, T_2, \dots, T_n \rangle$  denote a transaction database, where  $T_i (i \in [1 \dots n])$  is a transaction that is a subset of  $I$ . A sample of transactional data is shown in Table I. The support of an itemset  $X$ , where  $X \subset I$  is a set of items, is the number of transactions containing  $X$  in  $D$ .

Given a minimum support threshold  $\delta$ , the problem of finding the complete set of frequent itemsets that supports no less than  $\delta$  is called the frequent itemset mining (FIM) problem.

TABLE I  
SAMPLE OF TRANSACTIONAL DATA.

TID	List of items
T01	$a, f, c, g, p$
T02	$a, b, c, f, l, o$
T03	$b, f, h, o$
T04	$b, c, p$
T05	$f, a, c, l, p, n$

A lot of work [3]–[6] has been done to solve DM problems in CDP. However, since the analyst holds the user's raw data in CDP setting, its main job is to add noise to the results to satisfy the DP definition.

In this paper, we consider the  $top - k$  FIM problem in transaction databases under LDP setting. However, there is no reliance on third party assumptions in LDP. The data analyst wants to find  $k$  itemsets with highest support while users are sensitive and unwilling to answer their real information. The main challenge is that the analyst does not hold the user's original sensitive information, which makes it quite difficult to mine useful information with sanitized data. Qin et al. [1] point out that if utilize directly existing FIM algorithm (e.g. Apriori [9], [10], FP-growth [8], Eclat [13]) would result in accumulation of dramatic noise because of multi-iteration between users and analyst.

Specifically for FIM in the local setting, Qin et al. [1] leave it as a future work but there is no clear solution. Wang et al. [2] solves the  $top - k$  frequent itemset mining (FIM) task for the first time with **padding-and-sampling-based frequency oracle** (PSFO). In [2], the Set-Value Item Mining (SVIM) protocol has been proposed to handles set values under the LDP setting, with the purpose of finding the  $k$  most frequent items and their frequencies. To mine frequent itemsets, a core technique is “**Guessing Frequency (GF)**”. That is, the analyst first calculated the frequency of a given itemset  $X$  for all

candidate itemsets by (1),

$$\varphi(X) = \prod_{x \in X} \mu(x), \mu(x) = \frac{0.9 \times \tilde{\theta}(x)}{\max_{x \in S'} \tilde{\theta}(x)} \quad (1)$$

where  $\varphi(X)$  represents the speculative frequency of itemset  $X$ ,  $S'$  and  $\tilde{\theta}(x)$  are denoted separately the  $top-k$  frequent items set and the frequency of a given item  $x$ . Then  $2k$  itemsets with highest guessing frequencies are selected to construct candidate set  $IS$ . Finally, reference [2] utilized SVIM protocol again with the domain  $IS$  to mine  $top-k$  itemsets. We observe that, the size of candidate set to construct  $IS$  increase significantly with  $k$ . As a result, it is computationally expensive when  $k$  is large (e.g.,  $k = 100$ ).

Inspiringly, we propose **minefp** protocol, which aims at finding  $top-k$  itemsets under the LDP setting and provides similar accuracy while providing lower overhead than existing SVSM protocol within the same privacy constraints. First, the SVIM protocol is used to estimate the  $k$  most frequent items and their frequencies. Second, users report the number of frequent items they have; the analyst estimates the distribution user reported and figure out the right  $M$  as the maximum iteration of the tree. Third, users interact with the analyst to build effectively the FP-tree [8]. Fourth, the analyst optimizes and mines the FP-tree. Fifth, the analyst publishes  $top-k$  itemsets. Experimental results show that **minefp outperforms SVSM in that it identifies quickly frequent itemsets as well as estimates the frequencies more accurately.**

To summarize, the main contributions of this paper are:

- We study the application of FP-growth algorithm and design the FP-tree-based-mine (minefp) protocol to find frequent itemsets as well as their frequencies in the LDP setting. Experimental results on real-world datasets show the significant improvement over previous techniques.
- We investigate GF to construct candidate set and point out that it is beneficial to build hierarchically FP-tree.

**Roadmap.**

## II. BACKGROUND

### A. Local Differential Privacy (LDP)

In the local setting, there is no trusted third party and an aggregator wants to gather information from users, where each user possesses an input  $v$ . The privacy of the data contributor is protected by perturbing her/his original data at the data contributor's side; thus, the aggregator cannot access the original data, but is still able to obtain population statistics.

Formally, let  $D$  denote the whole transaction databases.  $\epsilon$ -local differential privacy (or  $\epsilon$ -LDP) is defined on an algorithm  $\mathcal{A}$  and a privacy budget  $\epsilon \geq 0$  as follows.

**Definition 1:** ( $\epsilon$ -LDP). A randomized algorithm  $\mathcal{A}$  satisfies  $\epsilon$ -local differential privacy ( $\epsilon$ -LDP), if and only if for (1) all pairs of input  $v_i, v_j \in D$ , and (2) any possible output  $\mathcal{O}$  of  $\mathcal{A}$ , we have:

$$\frac{\Pr[\mathcal{A}(v_i) = \mathcal{O}]}{\Pr[\mathcal{A}(v_j) = \mathcal{O}]} \leq e^\epsilon$$

*Sequential composability* [12] and *post-processing* [14] are vitally important properties of differential privacy. The former allows each user to divide privacy budget into multiple portions and use each portion to execute independent LDP protocols on the same input while the sequential executions provide  $\sum \epsilon_i$ -LDP; the latter guarantees that any processing of the noisy data do not disclose the privacy.

**Theorem 2.1:** (*sequential composability*). Given  $m$  randomized algorithms  $\mathcal{A}_i (1 \leq i \leq m)$ , each of which satisfies  $\epsilon_i$ -local differential privacy. Then the sequence of  $\mathcal{A}_i$  collectively provides  $(\sum_{i=1}^m \epsilon_i)$ -local differential privacy.

**Theorem 2.2:** (*post-processing*). For any method  $\phi$  which works on the output of a  $\epsilon$ -LDP algorithm  $\mathcal{A}$  without accessing the raw data, the procedure  $\phi(\mathcal{A}(\cdot))$  remains  $\epsilon$ -LDP.

### B. LDP Protocols

A frequency oracle (FO) protocol enables the estimation of the frequency of any given value  $v \in D$  under LDP. Randomized response (RR) [15] is a traditional technique for estimating unbiasedly a population proportion, which is the building block of many LDP protocols, such as RAPPOR [16], GRR and OLH [11]. Suppose the respondents were asked to answer a sensitive Boolean question (e.g. have you ever cheated on your partner?) in a survey and provisions made for each person to be interviewed. That is, each respondent gives the raw answer with probability  $p$  and gives the opposite answer with probability  $q = 1 - p$ . Specially, to satisfy  $\epsilon$ -LDP, the probability  $p$  is set to  $\frac{e^\epsilon}{1+e^\epsilon}$ .

Then, the aggregator calculates the estimated percentage of “Yes” (denote as  $\tilde{\theta}$ ) as example from all sanitized answers, which is unbiased, as follows:

$$\tilde{\theta}(Yes) = \frac{\mathcal{C}(\text{answer} = Yes) - nq}{p - q}$$

where  $n$  is the total number of respondents and  $\mathcal{C}(\text{answer} = Yes)$  denotes the number of occurrences respondents answered “Yes”. Accordingly, the variance of it is

$$\text{Var}[\tilde{\theta}(Yes)] =$$

However, the RR protocol only applies to binary Boolean problems, which greatly limits its application. Therefore, in [11], two effective protocols, Generalized Random Response (GRR) and Optimized Local Hash (OLH), are proposed for the purpose of solving problems with large domain size  $\mathcal{D}$ . Specially, GRR extends the RR protocol by setting probability  $p = \frac{e^\epsilon}{e^\epsilon + \mathcal{D} - 1}$  to give the raw answer  $y = v$  and probability  $q = \frac{1-p}{\mathcal{D}-1}$  (i.e.  $q = \frac{1}{e^\epsilon + \mathcal{D} - 1}$ ) to give the perturbed answer  $y \neq v$ . It is shown that RR is the special case while  $\mathcal{D} = 2$ .

In [11], it turns out that when  $\mathcal{D}$  is large, the OLH protocol provides the best accuracy while maintaining a low communication cost. In this paper, we use the OLH protocol as a primitive and describe it below.

*Optimized Local Hashing (OLH)*

In [11], the two best performing FO protocols are Generalized Random Response (GRR) and Optimized Local Hash

(OLH). The former extends the randomized response (RR) technique [15], which is an old technique developed for the interviewees in a survey to give random answer to a sensitive boolean question so that they can achieve plausible deniability; the latter deals with a large domain size  $|I|$  by hashing a large domain size  $|I|$  to a smaller size  $g$  and applying RR to the hashed value. It was found that GRR offers the best accuracy than OLH when  $|I| < 3e^\epsilon + 2$ , where  $|I|$  is the size of the domain of items under consideration. Therefore, in [2], an adaptive FO protocol can be proposed from the known  $I$  as well as  $\epsilon$ .

### Generalized Random Response (GRR)

#### C. FP-growth algorithm

Frequent pattern growth (FP-growth) [8] is an algorithm that mines the complete set of frequent patterns without a costly candidate generation process, which based on the frequent pattern tree (FP-tree) structure that is an extended prefix-tree structure for storing compressed, crucial information about frequent patterns. The FP-Tree is further divided into a set of Conditional FP-Trees for each frequent item so that they can be mined separately. An example of the FP-Tree that represents the frequent items is shown in Fig. 1, where the minimum support threshold is set to 3.

The FP-growth algorithm solves the problem of identifying long frequent itemsets by searching through smaller conditional FP-tree repeatedly. The conditional pattern base is a “sub-database” which consists of every prefix path in the FP-Tree that co-occurs with every frequent length-1 item. It is used to construct the conditional FP-tree and generate all the frequent patterns related to every frequent length-1 item. In this way, the cost of searching for the frequent patterns is substantially reduced.

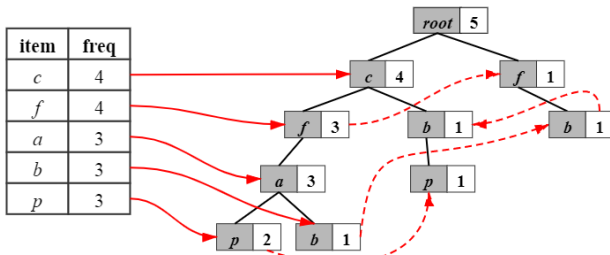


Fig. 1. Frequent pattern tree (FP-tree).

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#### ACKNOWLEDGMENT

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#### REFERENCES

- [1] Qin, Zhan, et al. “Heavy Hitter Estimation over Set-Valued Data with Local Differential Privacy.” *computer and communications security* (2016): 192-203.
- [2] Wang, Tianhao, Ninghui Li, and Somesh Jha. “Locally Differentially Private Frequent Itemset Mining.” *ieee symposium on security and privacy* (2018): 127-143.
- [3] Bhaskar, Raghav, et al. “Discovering frequent patterns in sensitive data.” *knowledge discovery and data mining* (2010): 503-512.
- [4] Li, Ninghui, et al. “PrivBasis: frequent itemset mining with differential privacy.” *very large data bases* (2012): 1340-1351.

- [5] Lee, Jaewoo, and Chris Clifton. “Top-k frequent itemsets via differentially private FP-trees.” *knowledge discovery and data mining* (2014): 931-940.
- [6] Zeng, Chen, Jeffrey F. Naughton, and Jinyi Cai. “On differentially private frequent itemset mining.” *very large data bases* (2012): 25-36.
- [7] C. Dwork. Differential privacy. In *ICALP*, pages 1–12, 2006.
- [8] Han J, Pei J, Yin Y, et al. Mining frequent patterns without candidate generation[C]. *international conference on management of data*, 2000, 29(2): 1-12.
- [9] Agrawal R, Imielinski T, Swami A N, et al. Mining association rules between sets of items in large databases[C]. *international conference on management of data*, 1993, 22(2): 207-216.
- [10] Agrawal R, Srikant R. Fast Algorithms for Mining Association Rules in Large Databases[C]. *very large data bases*, 1994: 487-499.
- [11] Wang T, Blocki J, Li N, et al. Locally Differentially Private Protocols for Frequency Estimation[C]. *usenix security symposium*, 2017: 729-745.
- [12] F. D. McSherry. Privacy integrated queries: an extensible platform for privacy-preserving data analysis. In *SIGMOD*, pages 19–30, 2009.
- [13] Zaki M J. Scalable algorithms for association mining[J]. *IEEE Transactions on Knowledge and Data Engineering*, 2000, 12(3): 372-390.
- [14] C. Dwork, F. McSherry, K. Nissim, and A. Smith, “Calibrating noise to sensitivity in private data analysis,” in *Theory of Cryptography Conference*. Springer, 2006, pp. 265–284.
- [15] S. L. Warner. Randomized response: A survey technique for eliminating evasive answer bias. *Journal of the American Statistical Association*, 60(309):63–69, 1965.
- [16] U. Erlingsson, V. Pihur, and A. Korolova. Rappor: Randomized aggregatable privacy-preserving ordinal response. In *CCS*, pages 1054–1067. ACM, 2014.
- [17] G. Eason, B. Noble, and I. N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” *Phil. Trans. Roy. Soc. London*, vol. A247, pp. 529–551, April 1955.
- [18] J. Clerk Maxwell, *A Treatise on Electricity and Magnetism*, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.
- [19] I. S. Jacobs and C. P. Bean, “Fine particles, thin films and exchange anisotropy,” in *Magnetism*, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.
- [20] K. Elissa, “Title of paper if known,” unpublished.
- [21] R. Nicole, “Title of paper with only first word capitalized,” *J. Name Stand. Abbrev.*, in press.
- [22] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, “Electron spectroscopy studies on magneto-optical media and plastic substrate interface,” *IEEE Transl. J. Magn. Japan*, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].
- [23] M. Young, *The Technical Writer’s Handbook*. Mill Valley, CA: University Science, 1989.

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