

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. 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 census 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 data mining (DM) has attracted the attention. 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.

The LDP setting, by contrast, has no reliance on third party assumptions. The main challenge with a DM task is that the data analyst does not hold the user's original sensitive information, so it is quite difficult to mine useful information with noise data. Qin et al. [1] proposed LDPMine protocol

for heavy hitter estimation over set-valued data and left data mining as an open problem. Wang et al. [2] solved 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 had 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.

In [2], the SVSM protocol first selected *2k* itemsets with highest guessing frequencies to construct candidate set *IS*, then utilized SVIM protocol again with the constructed 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).

TABLE I
SAMPLE OF TRANSACTIONAL DATA.

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

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 in value domain I . 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.

Definition 1 (Local Differential Privacy) A randomized algorithm \mathcal{A} satisfies ϵ -LDP, if and only if for (1) all pairs of input $v_i, v_j \in I$, and (2) any possible output \mathcal{O} of \mathcal{A} , we have:

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

where $\epsilon \leq 0$ is the privacy budget (the larger ϵ is, the stronger the privacy guarantee).

An important property of differential privacy is *sequential composability* [10], which also applies to the local setting:

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

B. LDP Protocols

A frequency oracle (FO) protocol enables the estimation of the frequency of any given value v

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 count 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.

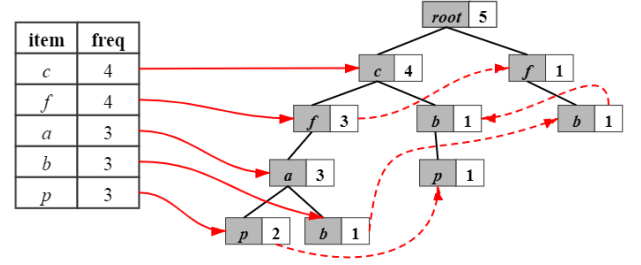


Fig. 1. Frequent pattern tree (FP-tree).

III. EASE OF USE

A. Maintaining the Integrity of the Specifications

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Before you begin to format your paper, first write and save the content as a separate text file. Complete all content and organizational editing before formatting. Please note sections IV-A–IV-E below for more information on proofreading, spelling and grammar.

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Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, ac, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

B. Units

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Number equations consecutively. To make your equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use a long dash rather than a hyphen for a minus sign. Punctuate equations with commas or periods when they are part of a sentence, as in:

$$a + b = \gamma \quad (2)$$

Be sure that the symbols in your equation have been defined before or immediately following the equation. Use “(2)”, not “Eq. (2)” or “equation (2)”, except at the beginning of a sentence: “Equation (2) is . . .”

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Please use “soft” (e.g., `\eqref{Eq}`) cross references instead of “hard” references (e.g., (1)). That will make it possible to combine sections, add equations, or change the order of figures or citations without having to go through the file line by line.

Please don’t use the `{eqnarray}` equation environment. Use `{align}` or `{IEEEeqnarray}` instead. The `{eqnarray}` environment leaves unsightly spaces around relation symbols.

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E. Some Common Mistakes

- The word “data” is plural, not singular.
- The subscript for the permeability of vacuum μ_0 , and other common scientific constants, is zero with subscript formatting, not a lowercase letter “o”.
- In American English, commas, semicolons, periods, question and exclamation marks are located within quotation marks only when a complete thought or name is cited, such as a title or full quotation. When quotation marks are used, instead of a bold or italic typeface, to highlight a word or phrase, punctuation should appear outside of the quotation marks. A parenthetical phrase or statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.)
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- The prefix “non” is not a word; it should be joined to the word it modifies, usually without a hyphen.
- There is no period after the “et” in the Latin abbreviation “et al.”.
- The abbreviation “i.e.” means “that is”, and the abbreviation “e.g.” means “for example”.

An excellent style manual for science writers is [17].

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a) *Positioning Figures and Tables:* Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation “Fig. 2”, even at the beginning of a sentence.

TABLE II
TABLE TYPE STYLES

Table Head	Table Column Head		
	Table column subhead	Subhead	Subhead
copy	More table copy ^a		

^aSample of a Table footnote.



Fig. 2. Example of a figure caption.

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an

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ACKNOWLEDGMENT

The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g”. Avoid the stilted expression “one of us (R. B. G.) thanks ...”. Instead, try “R. B. G. thanks...”. Put sponsor acknowledgments in the unnumbered footnote on the first page.

REFERENCES

Please number citations consecutively within brackets [11]. The sentence punctuation follows the bracket [12]. Refer simply to the reference number, as in [13]—do not use “Ref. [13]” or “reference [13]” except at the beginning of a sentence: “Reference [13] was the first ...”

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Unless there are six authors or more give all authors’ names; do not use “et al.”. Papers that have not been published, even if they have been submitted for publication, should be cited as “unpublished” [14]. Papers that have been accepted for publication should be cited as “in press” [15]. Capitalize only the first word in a paper title, except for proper nouns and element symbols.

For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [16].

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