Privacy-Preserving Language Model Inference with Instance Obfuscation

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Abstract

Language Models as a Service (LMaaS) offers convenient access for developers and researchers to perform inference using pre-trained language models. Nonetheless, the input data and the inference results containing private information are exposed as plaintext during the service call, leading to privacy issues. Recent studies have started tackling the privacy issue by transforming input data into privacy-preserving representation from the user-end with techniques such as noise addition and content perturbation, while the exploration of inference result protection, namely *decision privacy*, is still a blank page. In order to maintain the black-box manner of LMaaS, conducting data privacy protection, especially for the decision, is a challenging task because the process has to be seamless to the models and accompanied by limited communication and computation overhead. We thus propose Instance-Obfuscated Inference (IoI) method, which focuses on addressing the decision privacy issue of natural language understanding tasks in their complete life-cycle. Besides, we conduct comprehensive experiments to evaluate the performance as well as the privacy-protection strength of the proposed method on various benchmarking tasks.

1 Introduction

Language Models as a Service (LMaaS; Yao et al. 2024; Sun et al. 2022; Brown et al. 2020) empowers researchers and developers to access pre-trained language models (PLMs) through cloud services without worrying about the complexities of model training, deployment, and infrastructure management. To interact with LMaaS, users usually send API requests to the designated endpoints designed by the service providers and receive responses generated by the remote language models. Such a setup benefits both parties: on the one hand, users can jump-start on integrating the powerful PLMs into their data processing tasks; on the other hand, the underlying models and the processing pipelines, as the intellectual properties, are hidden from end users so that the service providers can protect them from leakage. However, given the lack of user control over the blackbox cloud service, the data in the requests can be illegally used by the service providers or potential attackers, thus causing privacy issues, including data leakage, unauthorized data access, profiling, and tracking (Sen, 2015; Tang et al., 2016).

Recent literature (Das et al., 2024) has started to address the privacy issues of user inputs in LMaaS, for which solutions are typically based on techniques privatizing the input representation into intermediate ones. Methods of such kind include noise injection (Plant et al., 2021), differential privacy (DP) (Hoory et al., 2021; Yue et al., 2021; Xu et al., 2020), and adversarial training (Li et al., 2018; Coavoux et al., 2018). Moreover, the intermediate representations are further fused or manipulated to prevent reverse engineering, while still remaining sufficient information for effective model inference (Zhou et al., 2022). Unfortunately, to the best of our knowledge, none of the existing methods takes decision privacy into consideration, that is, the inferencing results are not protected which could implicitly or explicitly reveal users' sensitive information based on the specific tasks applied (Shejwalkar et al., 2021; Kahla et al., 2022). For example, as shown in Figure 1, a PLM employed by the online disease diagnosis service can analyze and determine the type of diseases based on the symptom descriptions from the patients. Even though privacy-preserving representations as the input can somehow protect the patients' submitted content, sensitive information such as the distribution of diseases

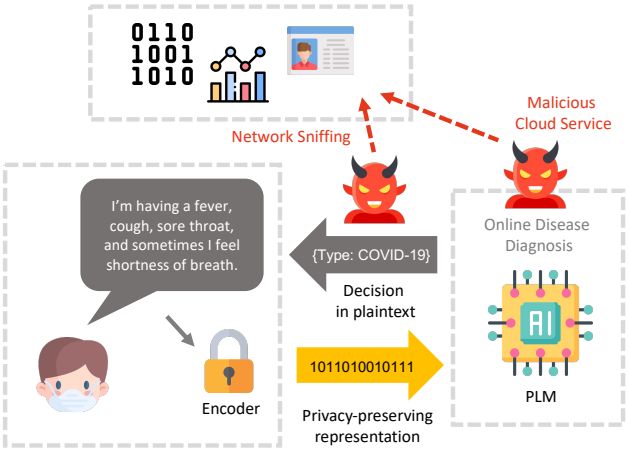

Figure 1: A privacy adversary example with state-of-the-art privacy protection in LMaaS. Despite encoding the end user's input into privacy-preserving representations, the raw output representations or decisions are still in plaintext, making them vulnerable to attacks from both network channels and servers.

(Mao et al., 2011) from the output aggregation still discloses to the malicious cloud service providers or the hackers via network sniffing.[1]

Considering the significance and necessity of decision privacy protection, we propose to investigate a method that ensures the protection of both raw input content and raw output representation. However, protection in the decision phase could be more challenging than its counterpart in the input phase due to several reasons. First, unlike user inputs, since the final decision is made by the PLM on the cloud, users will have no direct means to intervene in it. Second, due to the required anonymity, incurred communication costs inevitably increase. Third, from the perspective of intellectual property protection, it is not practical for LMaaS providers to disclose parameters and architectures of the models, including the last few layers that are close to the decisions, to users. These challenges call upon a solution that effectively protects the models' decisions before they come out, while does not violate the black-box nature of the LMaaS.

In this paper, we propose IoI (Instance-obfuscated Inference), which aims to protect the privacy of PLM decisions without losing the compatibility of utilizing the state-of-the-art input privacy protection approaches at inference phase. During inference, IoI intentionally obfuscates the instance, hiding the raw decision distribution from revealing any sensitive information. However, the user who applies the obfuscation retains the ability to recover the true decision distribution. Note as a pilot study, IoI focuses on text classification tasks.

Despite distinctiveness, to avoid the ambiguity of understanding different privacy techniques, in Figure 2, we summarize them according to the application scenarios. Specifically, SOTA methods utilize DP for training time data privacy. Other aforementioned noise addition or perturbation methods safeguard the raw input from being reverse-engineered. On the contrary, IoI ensures the confidentiality of decisions from the model inference.

The contributions of this work are three-folds. First, we explore the feasibility of protecting PLM *decisions* in *a black-box manner* for text classification tasks. Second, we define *decision privacy*, and comprehensively study the instance obfuscation strategies and privacy-preserving decision resolution in the context of it. Third, we define evaluation metrics for decision privacy, and empirically verify the performance and privacy strength of the proposed method.

2 Privacy-Preserving Inference

For a text classification task $M : \mathcal{X} \rightarrow \mathcal{Y}$, where $\mathcal{X}$ is the input text and $\mathcal{Y}$ is the label set. The *privacy-preserving inference* takes a step further avoiding the exposure of any private information about the inputs

[1]The security of the network channel is not the scope of this paper. You can assume it is already end-to-end encrypted.

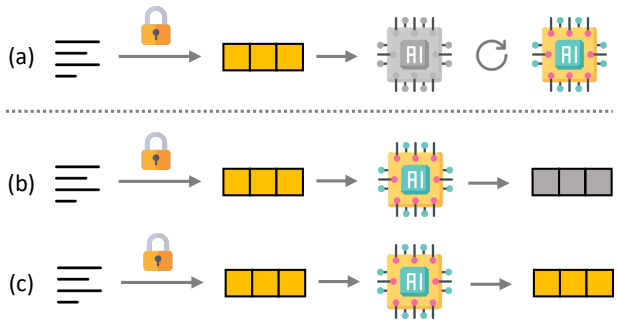

Figure 2: Privacy-preserving scenario comparison. **(a) Training Privacy** aims to protect the private training data. A typical privacy tool for this scenario is differential privacy. **Inference Privacy** includes **(b) Input Privacy** that prevents the raw input data from being revealed; and **(c) Decision Privacy** that protects the inference results. The vectors in orange are privacy-preserving, while the ones in gray are not.

and model decisions to the service provider. While the encoding methods[2] for protecting the privacy of $\mathcal{X}$ start emerging, the counterpart for $\mathcal{Y}$, which we call decision privacy, remains uncharted.

The intuition for achieving decision privacy is to make the model's raw decision as random as possible to all parties except the input instance owner, and the raw decision can only be recovered via a certain resolution method by the input instance owner. In the rest of this section, we formally define decision privacy in the context of text classification, as well as privacy-preserving inference.

2.1 Decision Privacy

For text classification, suppose $(\boldsymbol{x}, y)$ is an instance of $(\mathcal{X}, \mathcal{Y})$, and a finite label set $C = \{c_i | 1 \leq i \leq n, n \geq 2\}$ is the range of $\mathcal{Y}$. We say M's output has *perfect privacy* if

$$Pr[M(\boldsymbol{x}) = c_i] \approx \frac{1}{n}, \tag{1}$$

that is, the probability of an adversary acquiring the predicted label c_i from M for the given input $\boldsymbol{x}$ is almost *no better than a random guess*.

However, directly adhering to Equation (1) leads to compromised functionality of M, since M is essentially a random choice function and useless in practice. Instead, a certain encoding function $E(\cdot)$ can be performed on the input $\boldsymbol{x}$, so that the decision privacy of an arbitrary model M is ensured by $E(\cdot)$:

$$|Pr[M(E(\boldsymbol{x})) = c_i] - \frac{1}{n}| \leq \epsilon, \tag{2}$$

where $\epsilon \in [0, 1)$ is seen as a privacy budget. Adjusting ϵ balances the utility and privacy: the smaller the ϵ is, the better the decision privacy.

2.2 Problem Definition

The privacy-preserving inference is defined as:

$$M(E(\boldsymbol{x})) \rightarrow y', \tag{3}$$

where the encoding function $E(\cdot)$ has **two** functionalities: (1) It encodes the raw $\boldsymbol{x}$ into some privacy-preserving representation remaining interpretable by M, which is already studied by previous work (Qu

[2]The encoding mentioned in this paper is not by the PLM's encoder but as "encryption".

et al., 2021; Yue et al., 2021; Zhou et al., 2022) and is **not** the focus of this paper. (2) The inference result transitions from the actual prediction y to the privacy-preserving y', whose distribution satisfies decision privacy defined by Equation (2):

$$|Pr[y' = c_i] - \frac{1}{n}| \leq \epsilon. \tag{4}$$

The privacy property is ensured by $E(\cdot)$. It is mathematically hard or impossible to find its inverse function $E^{-1}(\cdot)$, so that the adversary can not either recover *the raw input* $\boldsymbol{x}$ from the privacy-preserving representation $E(\boldsymbol{x})$, or *the actual prediction* y from the privacy-preserving prediction y'. A decoding function $D(\cdot)$ is available to decode true y from y' with the knowledge of the raw input and encoding settings,

$$y \leftarrow D(y', E, \boldsymbol{x}). \tag{5}$$

Without loss of generality, rather than determining the true prediction y from a single y', Equation (5) can be extended to cases where the solution for y depends on multiple y' values, that is,

$$y \leftarrow D(y'_0, \cdots, y'_g, E, \boldsymbol{x}), \tag{6}$$

where $y'_0 \cdots y'_g$ are all necessary y's to decode y. Note that E and $\boldsymbol{x}$ serve to identify these y' values as a group and can be omitted if the user maintains the reference between y's and y.

Therefore, privacy-preserving inference allows the user to query LMaaS without exposing sensitive information to the service provider or the adversary, by sending $E(\boldsymbol{x})$ to the server and decoding y from y' with $D(\cdot)$ locally. Throughout the process, *the adversary learns nothing from the encoded input* $E(\boldsymbol{x})$ *or encoded decision* y'.

Distinctions to DP or input privacy. In general, DP adds proper noise to the given input instances so that the individual information of input instances will not be leaked, but the overall statistical features of them remain. Similarly, most input privacy methods perturb the raw input to prevent input reverse-engineering while keeping the necessary information for inference. Hence, an ideal DP or input privacy method should satisfy $M(E(\boldsymbol{x})) \approx M(\boldsymbol{x})$, where E is the corresponding DP or input privacy method, while protecting the privacy of $\boldsymbol{x}$. On the contrary, decision privacy tends to make $M(E(\boldsymbol{x}))$ as random as possible whereas $D(M(E(\boldsymbol{x}))) \approx M(\boldsymbol{x})$.

3 Method

This section begins with an overview of our privacy-preserving inference framework for text classification. It follows by detailing the core component $E(\cdot)$ for encoding in Section 3.1, and $D(\cdot)$ for decoding in Section 3.2.

The intuition behind IoI is to obfuscate the raw instance with obfuscators so that the PLM's inference distribution is intentionally steered. Thus, the adversaries cannot deduce the true decision unless they possess knowledge of the corresponding resolution method and parameters. The general workflow of IoI is shown in Figure 3, consisting of instance obfuscation as $E(\cdot)$ and decision resolution as $D(\cdot)$. Instead of sending the raw instance x to the PLM and acquiring the decision, IoI conceals x by concatenating it with an obfuscator b, which is also a text sequence (Section 3.1). The concatenated text $[b; x]$ along with the obfuscator b are sent to the privacy-preserving representation generation (PPRG) module, respectively, where the input is encoded by a compatible SOTA input privacy method. PPRG produces privacy-preserving representations, which are <u>irreversible</u> and remain <u>distinct</u> even for identical inputs, and are treated as inputs for the PLM. After PLM's inference on PPRG-encode b and $[b; x]$, the raw decision distribution of $[b; x]$ does not reflect the inference of x since it is steered by the elaborated obfuscator b. But as the data owner, the actual decision y can be resolved via decision resolution (Section 3.2) by utilizing the decision distributions of $[b; x]$ and corresponding b. We further show that the true y is hard to be recovered from y's in Section 4.

3.1 Instance Obfuscation

Sending the input instance x in plaintext to the PLM reveals the input completely. Hence, some previous studies (Zhou et al., 2022; Plant et al., 2021) employ a *privacy-preserving text representation* that transforms

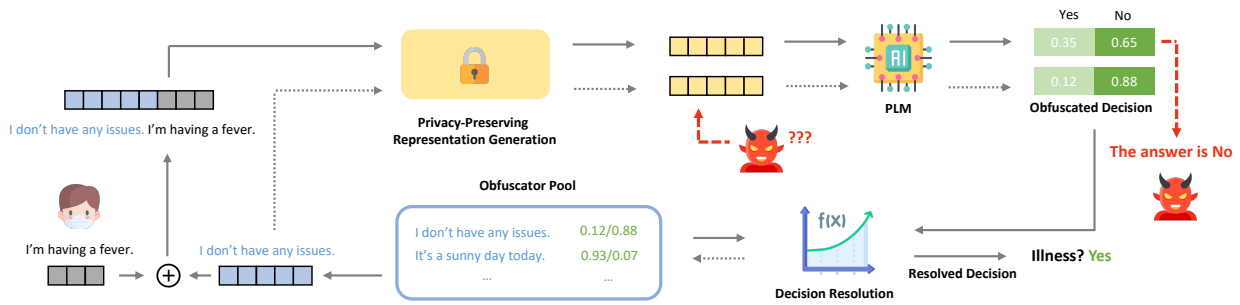

Figure 3: The demonstration of IoI workflow for decision privacy protection. If a user (bottom left) makes illness inquiries via a PLM-driven online diagnosis system, normally, the inference result will be returned in plain text. As a most basic example, in IoI, the raw text is concatenated with an obfuscator, which is also a text. Subsequently, the concatenated text and the obfuscator are encoded respectively by the privacy-preserving representation generation module, which ensures the produced embedding representation is privacy-preserving (irreversible and unique). Consequently, instead of receiving one "plaintext", the PLM receives two independent "ciphertext" and makes inferences on them without knowing their correlation, raw text, and true decision. However, only the user is able to recover the true decision by leveraging the distribution of these two inferences. In practice, each input text is obfuscated by a group of obfuscators, and the requests from multiple inputs are sent to the PLM in arbitrary order.

the input into "ciphertext" form by perturbing representations. In this way, although the raw input content is not exposed, the output of the PLM still carries meaningful information and may be exploited by the adversary. To tackle the flaw of limited protection of the decision by previous methods, IoI uses instance obfuscation, acting as $E(\cdot)$ in Section 2. It not only protects the input privacy by reusing the existing SOTA privacy-preserving text representation methods as PPRG but also "fools" the adversary with baffled output for decision privacy.

The instance obfuscation is motivated by mixup (Zhang et al., 2018), originally proposed for data augmentation. Zhang et al. (2018) theoretically shows that mixup can produce virtual feature-target pairs sampled from the same vicinal distribution as the original data. Specifically, it shows that, through a mapping (i.e., the LM in this context), the mixup of two raw inputs can be mapped to the mixup of their corresponding labels. Based on that, if $E(\cdot)$ conceals the real instance x by mixing it up with dummy instances, the PLM only makes an inference on the mixup instance without seeing x, and the proportion of dummy instances participated in the mixup steers the final decision. We call these dummy instances obfuscators; thus, $E(\cdot)$ obscures the true instance with selected obfuscators and let the PLM make decisions based on the elaborated input. The obfuscation process is the key for concealing information in a black-box LMaaS setting. This leads to the question of what is considered to be a high-quality obfuscator and how to obfuscate x with b properly, hence maximizing the performance as well as privacy protection.

Obfuscator Selection. Obfuscators are simply normal (unlabeled) sentences that could be with or without any relation to the real instances to be protected. To be used as an obfuscator, an instance requires to have a corresponding predicted label from PLM. Note that the predicted label does not need to be correct so there is no need for a gold label. Thus, an obfuscator b could be a sentence from any arbitrary corpus.

To steer the PLM's decision towards being affected by b instead of x, we prioritize b instances with higher confidence regarding the PLM decision. For example, in a binary classification task, if an instance x_1 scored 0.9 for label 1 and x_2 scored 0.7, then x_1 is picked over x_2 for x_1 is more deterministic to get label 1. Since the selected obfuscators can be paired with any real instances, an optimized way to re-use them is to have them pre-computed in an *obfuscator pool*.

Obfuscator Balancing. Based on the observation, a single b instance for obfuscating x results in the un-stableness in decision resolution (Section 3.2) due to the uneven distribution of the PLM's decision. For example, in a 3-class classification, assume b_1 has label c_1, b_2 has label c_2, and b_3 has label c_3. After a single

obfuscation with b_1, the label of $[b_1; x]$ predicted by M could remain c_1, or change to c_2 or c_3. Thus, the steering of decision distribution using a single obfuscator is not steady. Balancing, as a solution, is employed to mitigate this issue. Specifically, each real instance x is paired with *at least* one *unit group* of obfuscators. A unit group of obfuscators is defined as a set containing obfuscators with uniformly distributed labels from the label set C, that is,

$$g = \{b_j | M(b_j) = c_i, b_j \in B, \forall c_i \in C\}, \tag{7}$$

where B is the obfuscator pool, and $|g| = |C|$. Moreover, a group can consist of more than one unit group. Formally, a group contains n unit group is defined as

$$G_n = g_1 \cup g_2 \cup \cdots \cup g_n. \tag{8}$$

Therefore, the obfuscated instances of x are noted as $[b_i; x]$ where $b_i \in G_n$. Using balancing in the previous example, x concatenates with all three obfuscators and results in three obfuscated instances $[b_1; x]$, $[b_2; x]$ and $[b_3; x]$.

Privacy-Preserving Representation Generation. Even though the raw instance x is replaced with $[b; x]$ and x, the content remains in plaintext. To protect their privacy, IoI uses PPRG, which can be *any compatible SOTA input privacy methods* (Zhou et al., 2022; Plant et al., 2021), for transforming $[b; x]$ and b from text sequences to privacy-preserving representations. A qualified SOTA input privacy method has two requirements regarding privacy. First, the produced representation is not invertible so that the adversary can not reverse it back to plaintext. Second, the input privacy method is equipped with randomness so that the produced representation is distinct even for identical inputs. As long as the methods satisfy these two requirements and convert input text to embedding vectors, they are considered compatible. After applying PPRG, the representations from multiple xs should be sent to the PLM in arbitrary order. This prevents the adversary from pairing up the encoded $[b; x]$ and b. A more detailed discussion regarding privacy is in Section 4.

3.2 Privacy-Preserving Decision Resolution

While the obfuscated instance ceases the raw instance x from being accessible by the PLM, the true decision of x is concealed in the concatenated result y's as well. We outline a decision resolution method, as $D(\cdot)$ in Section 2 (Equation (6)), to resolve true y from multiple associated y's.

As the balancing described in Section 3.1, successfully executing $D(\cdot)$ to get the decision of x requires all the associated $[b; x]$ and b pairs. As to adversaries, correctly locating all associated instances from a tremendous amount of mixed instances, which are sufficiently obfuscated and randomized, is equivalent to finding a needle in a haystack. We have detailed analysis in Section 4.

Oppositely, as the data owner, running $D(\cdot)$ is as easy as pie. The strategy to separate x's result y from y's is based on the divergence between the decision distribution of $[b; x]$ and b. Specifically, if x's label is c_k, blending it with b shifts the confidence of $[b; x]$'s decision distribution towards c_k regardless of the b's label. Taking our example in Figure 3, $[b; x]$ has 0.35 for "yes" and 0.65 for "no," while b has 0.12 for "yes" and 0.88 for "no". The confidence of "yes" for $[b; x]$ increases because of the involvement x, thus x is highly like to be "yes."

Without loss of generality, we inductively evaluate such divergence over a unit group g, the decision label raises to be the label of x if the confidence difference between the obfuscated instance and obfuscator that increases the most,

$$\arg\max_{1 \le i \le |C|} (c_i^{b_j;x} - c_i^{b_j}), \tag{9}$$

where $b_j \in g$, $c_i \in C$, i denotes label id ($|C|$ is the number of labels) and j denotes the obfuscator id. If the obfuscator group is extended to G_n, Equation (9) can be generalized as

$$\arg\max_{1 \leq i \leq |C|} \frac{1}{n} \sum_{j=1}^{|G_n|} (c_i^{b_j;x} - c_i^{b_j}), \tag{10}$$

where $b_j \in G_n$ and the confidence difference on the decision distribution is averaged.[3]

4 Privacy Discussion

In this section, we formally define the threat model in Section 4.1, and analyze IoI's privacy from the perspective of possible attacks in Section 4.2. Moreover, we discuss the incurred cost of privacy in Section 4.3.

4.1 Threat Model

According to Equation (3), we consider a threat model where the adversary $\mathcal{A}$ collects data from the output of $E(\boldsymbol{x})$ and y', that is, the input representation and obfuscated decision. Additionally, as a malicious cloud service provider, $\mathcal{A}$ also has white-box access to M and maintains M's training data. $\mathcal{A}$ seeks to reverse the original input text $\boldsymbol{x}$ and/or recover the true output y.

4.2 Privacy Analyses

In IoI, $E(\boldsymbol{x})$ is the PPRG-encoded $[b; x]$ and b pair. In order to acquire x, $\mathcal{A}$ needs to recover the text representation of all $[b; x]$ and b, as well as pairing them up. As mentioned in Section 3.1, a qualified PPRG ensures the irreversibility of the input text sequence, meanwhile generating distinct representations even for identical input. Even though $\mathcal{A}$ has training data of M and white-box access to M, these do not help $\mathcal{A}$ reverse PPRG-encoded instances as long as PPRG has sufficient privacy strength for resisting known attacks (Song and Raghunathan, 2020). Thus, we conclude that (1) The obfuscator b or the obfuscated instance $[b; x]$ can not be reverse-engineered. (2) Every time the produced representation of b or $[b; x]$ is different, and it is not possible to identify the same b or $[b; x]$ from their PPRG-produced representation. (3) $\mathcal{A}$ is not able to differentiate $[b; x]$ from b. (4) No $\boldsymbol{x}$ could be extracted from $[b; x]$.

When it comes to resolving a y from y's, as is illustrated in Equation (6), $\mathcal{A}$ has to collect all the associated $[b; x]$ and b pairs in a group G_n. However, identifying a group of bs or $[b; x]$s is no better than exhausting all the possible PLM inference request combinations because of the hardness of reversing PPRG-encoded instances and the arbitrary request order of unique representations. For example, let $m = |g|$ be the unit group size and n be the number of unit groups that participated in one instance obfuscation, resolving a y involves $2mn$ independent PLM inference requests. Since $b \in G_n$ is uniformly distributed, the probability of $\mathcal{A}$ to find all these $2mn$ instances in r total requests to the PLM is $1/\binom{r}{2mn}$. Even in a toy setup, say 3-class classification ($m = 3$) with one group ($n = 1$) of obfuscators, merely 100 total requests would require more than a billion tries to identify all of them. Therefore, it is impossible for $\mathcal{A}$ to extract $\boldsymbol{x}$ from encoded b and $[b; x]$ with a qualified PPRG method and reversing y from y' is no better than exhausting all the possible combinations of requests.

4.3 Privacy Cost

Privacy comes with a cost. Here, we elaborate it from two aspects: communication and computation.

Communication cost. As a baseline, each instance x sends one request to the PLM. In IoI, as Equation (8), each x is concatenated with $|G_n| = n|C|$ instances. All these obfuscated instances, along with the same amount of obfuscators, form the total requests to the PLM, namely, $2n|C|$. In practice, when there are

[3]Note that this succinct but effective strategy can seamlessly be applied to various privacy-preserving inference tasks, for it is not restricted by the number of labels.

Dataset	Method	T_r	T_o	$\Phi_r \downarrow$	$\Phi_o \downarrow$	$\Phi \downarrow$
SST-2 (Acc.)	Fine-tuned	.924	.924	–	–	–
	Random Guess	.500	.500	–	–	–
	PP-BERT	.909	.909	.016	.818	.417
	SanText+	.830	.830	.102	.660	.381
	TextFusion	.904	.904	.022	.808	.415
	IoI	.913	.770	**.012**	**.540**	**.276**
MRPC (Acc./F1)	Fine-tuned	.860/.904	.860/.904	–	–	–
	Random Guess	.500/.500	.500/.500	–	–	–
	PP-BERT	.434/.294	.434/.294	.489/.675	**.132**/.412	.310/.543
	SanText+	.711/.750	.711/.750	.164/.170	.422/.500	.293/.335
	TextFusion	–/.882	–/.882	–/**.024**	–/.764	–/.394
	IoI	.745/.794	.570/.628	**.124**/.122	.166/**.256**	**.132**/**.189**
SST-5 (Acc.)	Fine-tuned	.500	.500	–	–	–
	Random Guess	.200	.200	–	–	–
	PP-BERT	.490	.490	**.020**	.362	.191
	SanText+	.426	.426	.148	.282	.215
	IoI	.467	.339	.066	**.174**	**.120**
QNLI (Acc.)	Fine-tuned	.915	.915	–	–	–
	Random Guess	.500	.500	–	–	–
	PP-BERT	.658	.658	.281	.316	.298
	SanText+	.725	.725	.208	.450	.329
	IoI	.849	.648	**.072**	**.296**	**.184**

Table 1: Performance of resolved and obfuscated decisions by IoI and baselines. T_r indicates the task raw performance after decision resolution by the data owner, while T_o indicates the performance that model owner or attacker retrieves. Φ_r and Φ_o measure how close T_r and T_o to the baseline and the random guess, respectively, and Φ is a balance between Φ_r and Φ_o. The smaller the three Φs, the better the task performance and decision privacy protection. The best result in each task is highlighted in **bold**. Only IoI has effects on decision privacy, while the other baselines are either non-privacy-preserving or only protect input privacy.

multiple xs, the obfuscators are pre-computed and reused from the obfuscator pool. Hence, for k x instances, the total number of requests ranges in $[(1 + kn)|C|, 2kn|C|]$.

Computation cost. On PLM's side, the number of requests to inference is indicated in the communication cost. On the data owner's side, resolving a y requires the execution of Equation (10), which only involves trivial matrix operations.

5 Experiments

We first introduce the datasets, baselines, and evaluation metrics in Section 5.1. The main results regarding task performance and decision privacy are illustrated in Section 5.2. We further study the functionalities of technical components in Section 5.3.

5.1 Experimental Setup

Datasets. Our experiments are conducted on four benchmark datasets that span across various text classification tasks. **SST-2** (Socher et al., 2013) requires to classify the sentiment of the given text into either positive or negative class. **SST-5**, as an extension of the SST-2, granularizes the binary label into five categories: very negative, negative, neutral, positive, and very positive. **MRPC** (Dolan and Brockett, 2005) is a paraphrase identification task to determine whether two sentences are paraphrases. **QNLI** (Wang et al., 2018), derived from SQuAD (Rajpurkar et al., 2016), is a natural language inference task seeking to identify if the context sentence contains the answer to the question.

	SST-2	MRPC	SST-5	QNLI
Max sequence len	128	512	128	256
Min confidence of b	> 0.99	> 0.90	> 0.90	> 0.99
Group size n	1	1	1	1

Table 2: IoI settings for main results

Baselines. Although no direct comparable methods regarding decision privacy are available, we select four reasonable and related baselines. **Fine-tuned** is task fine-tuned model without privacy protection. **Random Guess** denotes the random guess results. **PP-BERT** (Qu et al., 2021) is a privacy-preserving encoder that perturbs the token embeddings by adding random noise $N = rp$ where r is the distance from the origin and p is a unit hypersphere. r is sampled from the Gamma distribution $\Gamma(n, \frac{1}{\eta})$.[4] **SanText+** (Yue et al., 2021) replaces sensitive words with GloVe (Pennington et al., 2014) and utilizes differential privacy to ensure the privacy of the sanitized words.[5] **TextFusion** (Zhou et al., 2022) alters the input text sequence or intermediate representations by eliminating redundant or sensitive information. Note PP-BERT, SanText+, and TextFusion were all designed for input privacy.

Metrics. Generally, the performance is evaluated by task-specific metrics (Accuracy/F1) denoted as T. To measure the raw performance, we use the obfuscated (T_o) for the obfuscated version of the decision, and the resolved (T_r) for the true (original) performance from the decision resolution.

Besides, to quantify the effectiveness of the decision privacy protection and decision resolution, we additionally define $\Phi_r = \frac{T_{\texttt{baseline}} - T_r}{T_{\texttt{baseline}}}$ and $\Phi_o = \frac{|T_o - T_{\texttt{random}}|}{1 - T_{\texttt{random}}}$. They measure the relative performance difference from resolved T_r to non-privacy-preserving baseline, and from obfuscated T_o to random guess, respectively. Finally, a unified metric $\Phi = \frac{\Phi_o + \Phi_r}{2}$ measures the balance between the obfuscation strength and the task performance.[6]

5.2 Main Results

The backbone PLM used in each task is fine-tuned and consistent with all baselines because PP-BERT, SanText+, TextFusion, and IoI are applied in the inference phase. The parameter settings of IoI are in Table 2. PPRG is not enabled in this experiment and the effect of it is studied in Section 5.3. As the main results presented in Table 1, IoI performs almost the best among all tasks regarding the resolved (Φ_r) and obfuscated (Φ_o) results, and the balance between them (Φ), except few are lower but close to the best baselines. Note that only IoI can protect decision privacy, thus, its Φ_o is the best as compared to all others.

Specifically, on SST-2 and QNLI, the resolved results T_r by IoI have similar accuracy as the non-privacy fine-tuned baselines indicated by the smaller Φ_r while still deviating obfuscated result T_o to be as close to random as possible showing as the smaller Φ_o. For SST-5, as a harder version of SST-2, albeit it is not the best regarding task performance, IoI balances the trade-off, indicated by Φ, to still archive relatively better decision privacy. For MRPC, the evaluation metrics capture the abnormal performance of PP-BERT, whose resolved prediction performance T_r is worse than a random guess. In this case, while its Φ_o seems to be the best among all other methods, the high Φ_r and Φ precisely reflect its poor balance between task performance and decision privacy.

5.3 Analyses

We further study the influence of the technical components described in Section 3.

Obfuscator Selection. To verify the loose policy of obfuscator selection that any normal sentence can be a qualified obfuscator, we conduct the following contrastive experiment on SST-2 and SST-5. Specifically, we

[4] We set $\eta = 100$, a moderate value in the original paper, for balancing the noise strength and accuracy.
[5] Considering fairness, we set $\epsilon = 3$ in SanText+ and use sanitized text directly in inference.
[6] All three metrics are scaled to be in the range $[0, 1]$, and the smaller value indicates better performance.

Evaluation	Obfuscator	T_r	T_o
SST-2	SST-2	0.907	0.770
SST-2	QNLI	0.891	0.777
SST-5	SST-5	0.467	0.339
SST-5	QNLI	0.461	0.331

Table 3: The performance impact with obfuscators from the same and different datasets

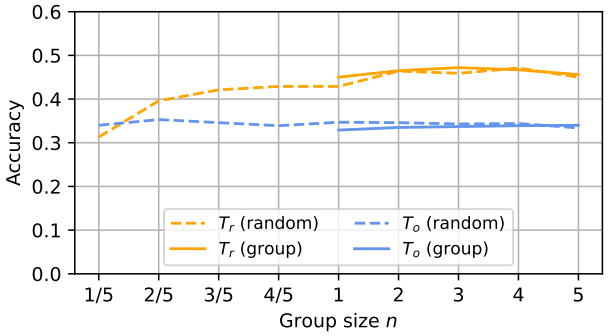

Figure 4: Balancing with different group size (SST-5)

test the real instances with the obfuscator from the same and different datasets. As shown in Table 3, using instances from a different dataset as obfuscators is indistinguishable from the ones from the same dataset.

Balancing. This technique is intended for mitigating the issue of unbalanced obfuscator distributions, thus increasing the accuracy for decision resolution. Here, we study the necessity of balancing. Because SST-5 can be identified as a 5-class classification problem, a unit group g (Equation (7)), in which the obfuscator's labels are uniformly distributed, contains five obfuscators with different labels. According to Equation (8), a group G_n consists of n gs. We set the n to be from 1 to 5, that is, 5 to 25 obfuscators. Additionally, as the baseline, we test the obfuscation without balancing by randomly sampling 1 to 25 obfuscators from the obfuscator pool regardless of the classes they belong to. In Figure 4, the performance of applying balancing is presented in a solid line, and the one for the randomly sampled obfuscators is in the dashed line. For the resolved version, without balancing, the accuracy T_r (random) improves by more than 15% from one randomly sampled obfuscator to five, and fluctuates relatively smooth after having more than a unit group of obfuscators (orange dashed line). With balancing G_n (T_r, orange solid line), where n ranges from 1 to 5, performs overall better and more steadily than the random samples. Unlike the resolved version, which receives the performance gains, for the obfuscated version, the performance remains stable with different n, and is outperformed by the resolved version for more than 10% when the group size is at least a unit (blue lines). As a consequence, balancing archives the best and most robust performance for the resolved version, meanwhile maintaining the maximum gap to the obfuscated version for better decision privacy protection.

Privacy-Preserving Representation Generation. PPRG utilizes the compatible input privacy method in a black-box fashion to transform obfuscated instances and obfuscators into representations that preserve privacy. Since the privacy strength and the ability to prevent attacks of the input privacy method are already comprehensively studied in its corresponding papers and follow-up works, we focus on the performance of plugging it with IoI.

Table 4 demonstrates the performance of IoI when employing PP-BERT as PPRG. We test PP-BERT with various η and compute its accuracy on SST-2. We then use it as PPRG and report T_r and T_o. From the observation, the difference between the resolved result T_r and PP-BERT is trivial (see %), which indicates the strong compatibility and recovering ability of IoI. Hence, we conclude that IoI's task performance is dominated by the selected PPRG method as well as input privacy, meanwhile keeping the decision privacy.

PP-BERT	Acc	T_r	T_o	%
$\eta = 200$	.914	.912	.768	.002
$\eta = 100$	.925	.908	.759	.018
$\eta = 50$	.851	.846	.698	.006
$\eta = 25$	.536	.528	.516	.015

Table 4: PPRG-enabled IoI performance (SST-2)

k	$M([b;x])$	$M(b)$	$M(\cdot)$
1	0.431/0.569	0.5/0.5	0.465/0.535
5	0.487/0.513	0.5/0.5	0.493/0.507
10	0.502/0.498	0.5/0.5	0.501/0.499

Table 5: Decision distribution (SST-2)

Decision Distribution. According to Equation (4), the decision distribution of $M(b)$ or $M([b;x])$ should be as close to random as possible, and the overall decision distribution of $M(\cdot)$ should also lean towards randomness. For validation purposes, we conduct an additional experiment in Table 5, which presents the decision distribution of $M(b)$, $M([b;x])$ and the overall $M(\cdot)$ on SST-2. Specifically, each cell denotes the distribution of negative/positive decisions. The parameter k controls the strength of the obfuscator, a higher k enhances privacy but reduces utility (details of k is in Appendix A.1).

At $k = 1$ (optimal utility), the distributions of $M(b)$, $M([b;x])$ and $M(\cdot)$ approach randomness. As k increases, the level of randomization intensifies. At $k = 10$, the distribution becomes equivalent to random. Moreover, we set $k = 1$, and report the decision distribution for the other three datasets in Table 6. Similarly, each cell denotes the distribution of decisions. The results show that our method achieves a promising decision distribution even with optimal utility.

Time Cost. We conducted an experiment regarding running time (in seconds) on SST-2 and SST-5 with 872 and 1101 instances, respectively. The result is reported in Table 7, where each number averaged from 5 runs. Two numbers in inference are the time cost in the best and worst cases.

The results indicate that the experimental outcomes align with the theoretical analysis in Section 4.3 and are even faster in practice, likely due to factors like memory caching. The time cost for decision resolution is also minimal since it involves only summation and averaging operations.

6 Related Work

Privacy Preservation in LMaaS. Recent studies are actively engaged in addressing the privacy concerns associated with LMaaS. Methods including noise injection (Plant et al., 2021), differential privacy (Hoory et al., 2021; Yue et al., 2021; Xu et al., 2020), and adversarial training (Li et al., 2018; Coavoux et al., 2018), and representation fusion (Zhou et al., 2022) tend to perturb the input text sequence or intermediate representations by reducing unnecessary or sensitive information for PLM's inference. There also exist approaches (Feng et al., 2020; Chen et al., 2022) that seek to protect data flow end-to-end, relying on homomorphic encryption, albeit the execution of such models is very time-consuming and computationally expensive, and needs to modify the model from the server side. On the other hand, to mitigate privacy issues in cloud PLM fine-tuning, offsite-tuning (Xiao et al., 2023) compresses the full PLM into a distilled version that allows users to tune plug-in adapters on their local, which protects the privacy of the user as well as the weights of PLM. Du et al. (2023) exploit local differential privacy to sanitize the embedding (and labels) for fine-tuning. However, none of the above work protects inference decision privacy of the LM under the black-box setting, which is exactly the focus of this work.

Data Obfuscation. Although mixup (Zhang et al., 2018) is designed to alleviate the undesirable drawbacks of large deep neural networks, the concept of data combination and its effect on inference with minimal computation overhead is valuable and worth learning. Guo et al. (2019) extend the mixup into the NLP

Dataset	$M([b;x])$	$M(b)$	$M(\cdot)$
SST-5	0.141/0.227/0.191 0.273/0.168	0.2/0.2/0.2 0.2/0.2	0.171/0.213/0.195 0.236/0.184
MRPC	0.528/0.472	0.5/0.5	0.514/0.486
QNLI	0.532/0.468	0.5/0.5	0.516/0.484

Table 6: Decision distribution ($k = 1$)

Dataset	Method	Pre-process	Inference	Resolution
SST-2	Plaintext	0.002	0.936	-
SST-2	IOI	0.005	1.652/3.327	0.060
SST-5	Plaintext	0.001	1.149	-
SST-5	IOI	0.003	5.223/10.421	0.145

Table 7: Time Cost

world, and Co-mixup (Kim et al., 2021) discovers the possibility of applying mixup on multiple instances. Besides representation mixup, recent studies also obfuscate authorship of text by neutralizing the stylistic features of text with techniques, such as back-translation or representation disentanglement (Mahmood et al., 2022; Altakrori et al., 2022; Bevendorff et al., 2019). Our instance obfuscated technique is inspired by representation mixup, while representing a pilot approach for LM decision protection.

7 Conclusion

In this work, we introduce decision privacy and propose IoI that prohibits information leakage of PLMs under the settings of black-box LMaaS. In contrast to prior works, we consider the end-to-end privacy protection of PLM's input and decision via instance obfuscation. Correspondingly, we define the evaluation metrics tailored for decision privacy and conduct comprehensive experiments regarding task performance and privacy protection. We anticipate our work conveys valuable insight and sheds some light on the trajectory of privacy in NLP.

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Limitations

We discuss two main limitations of this work. First, the extra instance inference cost. IoI hides the target instance behind obfuscators so that the target instance never exposes directly to the PLM. To guarantee the strength of privacy protection and stability of the task performance, the strategies, including balancing and randomization, emit additional requests which result in multiple inferences for one instance. However, such incurred cost is not as severe as the previous works, for some of them need significant effort to fine-tune the remote PLMs, and some others require partial/entire model sharing hence compromising the privacy of the model.

Second, IoI is deliberated for text classification tasks in a solely black-box fashion, thus it is not suitable for generative tasks. As for natural language generation, the adaption based on the current method requires addressing the problems such as mix-up tokens and variable lengths of generated text which are non-trivial. We leave this to be the future work.

Ethical Considerations

Technology innovations generally offer potential benefits, but they also possess the risk of intentional exploitation for nefarious purposes, and LMaaS is not immune to this reality. The presence of regulations and standards establishes a legal structure that ensures responsible utilization of data and grants individuals the right to request the deletion of their data. In the absence of such regulations, society depends on the ethical responsibility of technology practitioners to ensure the ethical usage of data.

Decision privacy, defined in this paper, provides a fundamental direction for protecting the data, as well as LMaaS, from being abusively used. The proposed method technically guarantees the privacy of the input and output data to and from the LMaaS being fully obfuscated. Adopting this method ensures the operations and data are intended for legitimate purposes rather than malicious. Besides, the method itself can seamlessly be integrated into compatible underlying technologies or running systems without any extra modification, which reduces the barriers associated with implementation for increasing accessibility for individuals or organizations.

All experimental datasets used in this work are openly available benchmarks. No demographic or identity characteristics are used in this paper.

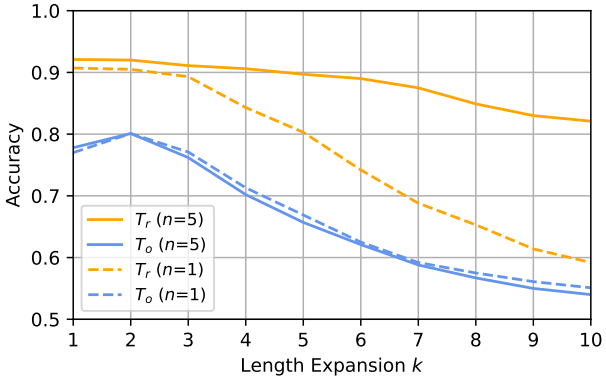

Figure 5: Length Expansion (SST-2)

A Experiments

We report additional information regarding experiments and analyses in this section.

A.1 Length Expansion

The privacy strength of a single obfuscated instance $[b; x]$ mainly comes from the domination of b. Kim et al. (2021) demonstrate that the model has the ability to map a mixed instance consisting of more than two raw instances to a mixed label. Inspired by that, We expand the length of b to amplify the impact of it on PLM's decision by duplicating it k times. [7] Correspondingly, the concatenation sequence length becomes $k|b| + |x|$. Here, we seek to verify the relation between the accuracy and the obfuscator's length over obfuscated and resolved prediction results.

We duplicate b by k times before encoding to realize the length increment, and the dataset we used here is SST-2. As the solid lines shown in Figure 5, k is tested from 1 to 10 consecutively, and it presents a negative correlation to accuracy. Specifically, when $k = 1$, the accuracy of resolved inference is more than 0.9 whereas the accuracy of obfuscated inference is less than 0.8. When k becomes larger, the accuracy of resolved inference T_r drops gradually until it reaches around 0.82 when k is 10. As a comparison, the trend of obfuscated T_o falls quickly almost throughout the k's process and when k is 10, it hits 0.55, which is close to the random guess. The maximum difference of the accuracy between two variants is more than 2.25 times to the minimum difference at the beginning (k=2). This experiment demonstrates the massive impact of length expansion on the performance, and a proper k could deviate the obfuscated distribution of PLM's decision far from the true one, thus intensifying the privacy protection. Note that we set another hyper-parameter n in G_n to be 1 and 5 in this experiment; regardless of n, the negative correlation holds.

[7] The duplication does not hurt the privacy of the generated representation because it is before semantic-neutral shuffling.