Reproducibility study of "LICO: Explainable Models with Language-Image Consistency"

Abstract

The growing reproducibility crisis in machine learning has brought forward a need for careful examination of research findings. This paper investigates the claims made by Lei et al. (2023) regarding their proposed method, LICO, for enhancing post-hoc interpretability techniques and improving image classification performance. LICO leverages natural language supervision from a vision-language model to enrich feature representations and guide the learning process. We conduct a comprehensive reproducibility study, employing (Wide) ResNets and established interpretability methods like Grad-CAM, GroupCAM and RISE. We were mostly unable to reproduce the authors' results. In particular, we did not find that LICO consistently led to improved classification performance or improvements in quantitative and qualitative measures of interpretability. Thus, our findings highlight the importance of rigorous evaluation and transparent reporting in interpretability research.

1 Introduction

Machine learning is facing a reproducibility crisis Kapoor & Narayanan (2022), necessitating the replication and validation of research findings. Consequently, our focus in this paper is on reproducing the research conducted by Lei et al. (2023) (LICO), as well as on investigating their claims and results.

LICO aims to improve *model interpretability*: an active area of research because of its applicability to explain important decisions models make in industries such as healthcare and defence. Model interpretability approaches can be subdivided into two categories: model-based and *post-hoc*. Model-based interpretability refers to *intrinsically* interpretable methods (e.g. linear regression), whereas post-hoc interpretability methods aim to explain model decisions *after the fact*. We can subdivide post-hoc interpretability methods further into two main approaches — gradient-backpropagation-based, where explainable noisy gradients are generated, and class activation mapping-based, which yield saliency maps. Within this categorisation, LICO is a method to improve post-hoc class activation maps (CAMs).

Ordinarily, CAMs are generated by using one-hot class labels to determine which pixels in the input image are important for the classification. Yet, using one-hot encoded labels leads to biased and poor-quality latent representations (Vyas et al., 2020), because one-hot labels carry minimal semantic information. The insight provided by the LICO paper is that training a network for classification while using natural language supervision from a vision-language model such as CLIP to regularise the feature maps may lead to more interpretable feature maps as well as better classification performance Radford et al. (2021). LICO aims to achieve this by shaping the latent feature space to approximate a semantically rich text encoder space via learnable prompts.

To investigate these claims, we make quantitative and qualitative comparisons between ResNets and Wide ResNets with and without the LICO losses (He et al., 2015; Zagoruyko & Komodakis, 2017) for a subset of the original interpretability methods (Selvaraju et al., 2019; Zhang et al., 2021; Chattopadhay et al., 2018). Moreover, we measure classification accuracy for a subset of the datasets in the original setup to investigate the improved classification performance claim.

In the remainder of our work, we will first provide an outline of the claims made by the authors, as well as a discussion of which claims we will be investigating (Section 2). Next, we will explain how we investigated these claims (Section 3). In Section 4, we provide the results of these experiments. Finally, in Section 5, we

discuss the claims of the paper in the context of these results, and we discuss how reproducible the authors' results were.

2 Scope of reproducibility

The LICO method proposed by (Lei et al., 2023) is claimed to be a qualitative and quantitative enhancement of existing interpretability methods in deep learning. From their experiments and conclusions, we identified the following main claims of the paper:

1. *Training an image classifier with LICO consistently improves quantitative and qualitative model interpretability.*
2. *Training an image classifier with LICO consistently improves classification accuracy.*
3. *Tasks with more classification categories benefit more from LICO because the prompt guidance comes from a manifold consisting of more classes.*

Ultimately, this report aims to investigate the reproducibility of the LICO paper (Lei et al., 2023) by attempting to fully or partially reproduce its main experiments and determining how strongly they back the aforementioned claims. In Section 3 we provide more detail on how the original authors set up their experiments and we compare their results directly with ours in Section 4.

3 Methodology

The training objectives added by LICO are twofold: firstly, the image manifold is encouraged to have a similar shape as the text prompt manifold by the manifold matching (MM) loss, and secondly, prompt tokens are mapped to specific feature maps and vice versa by the optimal transport (OT) loss. The MM loss coarsely aligns the manifold structure, whereas the OT loss establishes fine-grained relations between individual tokens and feature maps.

As a starting point for our implementation, we used the publicly available code by the authors (Lei et al., 2023). As their codebase was incomplete, we implemented the training loop, the manifold loss and the Insertion/Deletion metrics (Section 3.4) ourselves. Additionally, we made use of existing implementations of CAM-based interpretation methods (Gildenblat & contributors, 2021) and RISE (Ishikawa, 2019).

3.1 Model descriptions

LICO consists of a vision-language model with an image encoder, whose embedding space is structured by a pre-trained text encoder that has learned a good semantic space. This "structuring" is achieved via adding the MM loss and the OT loss terms to the main cross-entropy loss objective.

The output of the image encoder $\boldsymbol{F} \in \mathbb{R}^{N \times d'}$ are N feature map embeddings of dimension d' (Figure 1a). The inputs to the text encoder $\boldsymbol{t}_i = [X_1, X_2, \ldots, X_{M-1}, t_i]$ are learnable prompt context tokens X_m concatenated with t_i, where t_i is the text from the class label (Figure 1b). Each class has its own prompt input $\boldsymbol{t}_i$ with $i \in \{1, ..., K\}$, where K is the number of classes. The output of the text encoder for a given $\boldsymbol{t}_i$ is $\boldsymbol{G}_i \in \mathbb{R}^{M \times d}$. Since the dimensions of the image feature maps and the text features d' and d are of different size, the authors use an extra mapping multi-layer perceptron $h_\psi[d, d']$ to map the text features to the dimension of the image features, as seen in Figure 1b.

The MM loss aims to match the manifolds in embedding space of image features and text features in a training batch via a similarity metric. It uses their corresponding adjacent matrices $\boldsymbol{A}^G_{B \times B}$ and $\boldsymbol{A}^F_{B \times B}$ defined as

$$\boldsymbol{A}^F_{i,j} = \frac{\exp\left(-D\left(\boldsymbol{F}_i, \boldsymbol{F}_j\right)/\tau\right)}{\sum_{s=1}^{B} \exp\left(-D\left(\boldsymbol{F}_i, \boldsymbol{F}_s\right)/\tau\right)}, \quad \boldsymbol{A}^G_{i,j} = \frac{\exp\left(-D\left(\boldsymbol{G}_i, \boldsymbol{G}_j\right)/\tau\right)}{\sum_{s=1}^{B} \exp\left(-D\left(\boldsymbol{G}_i, \boldsymbol{G}_s\right)/\tau\right)}, \tag{1}$$

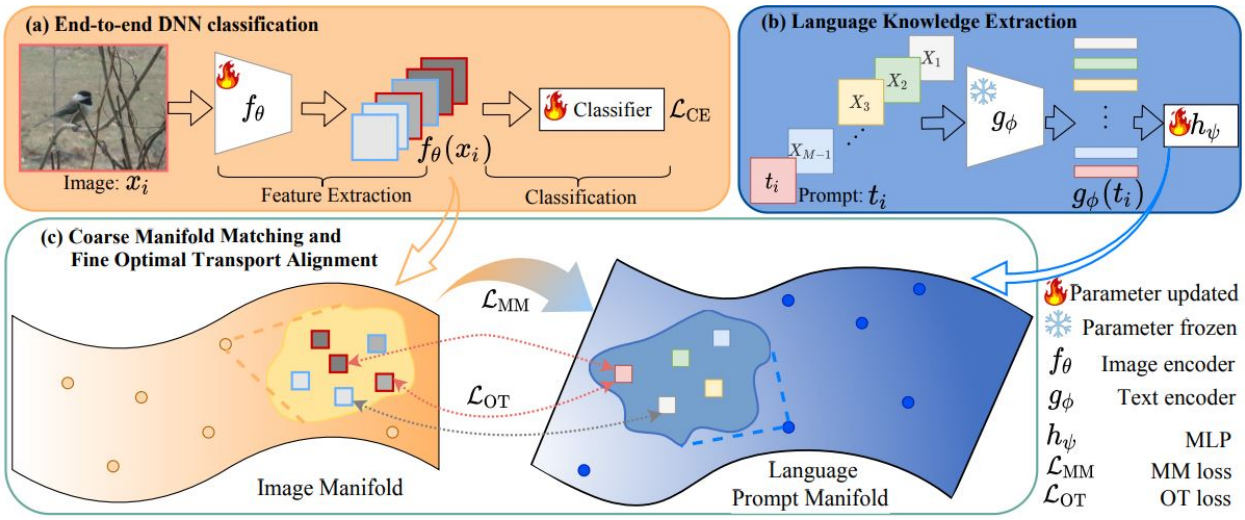

Figure 1: The evaluated LICO pipeline. (a) A regular image classification neural network pipeline. (b) Extraction of language features from learnable prompts and a frozen pre-trained text encoder. (c) A visualisation of the two objectives proposed in LICO: manifold matching and Feature alignment by optimal transport.

where $D(.,.)$ is a distance metric like Euclidean distance and i, j index specific feature map embeddings within a training batch of size B. Here, Lei et al. (2023) state that τ is a learnable parameter. We will cover the implications of this design choice in Section 3.3.

While the MM loss provides a coarse alignment of the structure of the feature maps and encoded prompts, the OT loss aims to match individual feature maps in $\boldsymbol{F}_i$ to individual tokens in $\boldsymbol{G}_i$ by solving the optimal transport problem (Monge, 1781) via the Sinkhorn algorithm (Cuturi, 2013), thus providing a fine-grained mapping between the two sets of embeddings. The MM loss is coarse because it aggregates the set of embeddings of each input sample, be it image or text, to a single vector representation, transforms it to a distribution and then uses this per-sample representation to calculate a KL divergence with other sample representations. The optimal transport objective is argued to be fine-grained because it does not aggregate the feature maps of a sample to a single representation vector but keeps the sets of feature embeddings $\boldsymbol{F}_i$ and $\boldsymbol{G}_i$, transforms each set of embeddings into a single multimodal discretized distribution and finds the minimum distance between the two distributions by means of optimal transport. For mathematical details on how optimal transport is applied here, we refer readers to Lei et al. (2023).

The total loss of LICO is then $\mathcal{L} = \mathcal{L}_{\text{CE}} + \alpha\mathcal{L}_{\text{MM}} + \beta\mathcal{L}_{\text{OT}}$.

3.2 Datasets

We evaluate LICO's classification performance and measure Insertion/Deletion scores, as defined in Section 3.4, on CIFAR-10, CIFAR-100 (Krizhevsky et al., 2009) and Imagenette (Howard, 2019) datasets. The CIFAR family of datasets are well established datasets in literature, while Imagenette is a subset of 10 classes of the ubiquitous Imagenet dataset Deng et al. (2009) with 160×160 pixel images. We turn to this alternative because the images in it are larger, like in Imagenet, and running on Imagenette instead of Imagenet keeps the amount of compute necessary for training runs manageable. Testing on this dataset we theorize might be important because larger image sizes might benefit more in the interpretability evaluation, possibly due to more detailed saliency maps.

Even though the authors use CIFAR-10/100 only to measure classification performance, we perform further investigation and additionally evaluate Insertion/Deletion scores. For both datasets we split the dataset into 47,500 training, 2,500 validation and 10,000 test samples. On CIFAR-100, we also create a subset consisting

of only 2,500 examples to compare the performance of a baseline model vs. a model trained with LICO when trained with limited data.

For Imagenette, we assess both classification accuracy and Insertion/Deletion scores (Section 3.4). The dataset is divided into 9000 training samples, 475 validation samples, and 3925 test samples.

During training, we use two augmentations: random horizontal flip and random crop of size $H \times W$ with a reflect padding of 4, where H and W are the image height and width, respectively. For both training and test sets, we also perform normalization with per-channel mean/std statistics.

We also evaluate the LICO model on the PartImageNet dataset (He et al., 2022). This dataset has segmentation masks so that we can evaluate the Intersection over Union (IoU) of the generated saliency maps with the segmentation masks. This provides us with another metric of saliency map quality, as a high score means that the network is consistently looking at exclusively the salient parts of images. Since these are ImageNet images, we use the standard ImageNet augmentations: random horizontal flip, resize the short side to 224, random crop, and normalize with per-channel mean/std statistics. In the evaluation phase, we skip the horizontal flip, and exchange the random crop for a center crop.

3.3 Hyperparameters

In our reproduction we mainly aim to adhere to the implementation details of the LICO paper. For more details, readers are referred to Section A in the Appendix. The Wide ResNet we use for training on CIFAR-10 has depth factor 28 and widening factor of 2, as this was also used by Zhang et al. (2022); Sohn et al. (2020), and the authors of LICO used many of the experimental settings from those papers. On CIFAR-100 we use a depth of 28 and a widening factor of 8 for the same reason, and on Imagenette we use the same settings as on CIFAR-100. The number of context tokens in a prompt is set to 12, as the ablation study in the LICO paper shows that the LICO losses give the best results with 12 context tokens.

We also take a closer look into the authors' design choice of τ (Equation 1) being a learnable parameter. It should be noted that as τ increases to arbitrarily large values, both $\mathbf{A}^F_{i,j}$ and $\mathbf{A}^G_{i,j}$ approach a constant value:

$$\lim_{\tau \to \infty} \frac{\exp(-D(a,b)/\tau)}{\sum_{s=1}^{B} \exp(-D(a,b)/\tau)} = \frac{\exp(0)}{\sum_{s=1}^{B} \exp(0)} = \frac{1}{B}.$$

Thus, in the limit, both $\mathbf{A}^F$ and $\mathbf{A}^G$ will be matrices with all entries equal to $\frac{1}{B}$. This, in turn, means that

$$\mathcal{L}_{\text{MM}} = \frac{1}{B} \sum_{i=1}^{B} \text{KL}[\mathbf{A}^G_{i,:} || \mathbf{A}^F_{i,:}] = 0.$$

Thus, it seems likely that τ should either not be learnable, or if it is learnable, it ought to be clipped to a maximum value. We perform experiments with it being either a learnable parameter or a constant $\tau = 1$ to determine whether this matters.

3.4 Experimental setup and code

In this study, we ran experiments aiming to reproduce the main parts of the LICO paper and its results. Our code and hyperparameters follow exactly the methodology and values described in the paper, but we run two experiments beyond the original paper: one with the aim to investigate the generalisability of the authors' claims about model interpretability by evaluating the IoU between ground-truth segmentation masks and saliency maps. With the other auxiliary experiment, we aimed to investigate whether the τ parameter should be a learnable parameter or a constant.

As image encoders we use Wide ResNet for the CIFAR-10, CIFAR-100, and Imagenette datasets, and we use a ResNet18 for the PartImageNet dataset. (Zagoruyko & Komodakis, 2017; He et al., 2015).

Three metrics were used to measure the performance of LICO against a non-LICO trained model — classification accuracy, Insertion/Deletion scores (Petsiuk et al., 2018), and the IoU between generated saliency

maps and ground-truth segmentation masks. The Insertion score is determined by starting from a blurred input image, and gradually unblurring pixels, where the order in which pixels are unblurred is determined by the saliency map. Then, if the saliency map has correctly assessed which pixels are important for the network to make its prediction on the partially-blurred image, the class probability should quickly rise as a function of unblurred pixels. The Insertion score is the AUC of this curve, so a good Insertion score is close to 1. The Deletion score is measured analogously, by starting with the base image, and gradually removing pixels; a good Deletion score is close to 0. We measure Insertion/Deletion in conjunction with interpretation methods — Grad-CAM, Grad-CAM++ and RISE. This follows the same set-up as the original experiment conducted by Lei et al. (2023). We also show an Overall score (Lei et al., 2023) in conjunction with the Insertion/Deletion like the authors of LICO.

As for the IoU scores, they serve to evaluate whether the model accurately focuses on relevant areas within the image. A high IoU indicates consistent attention to the object of interest rather than the background. To incorporate IoU into our analysis, we must interpret it within the context of non-binary saliency maps and binary ground truth labels as regions for comparison. We utilize the original IoU formula, which is sensible because we can view the saliency map region as a soft assignment of a region for segmentation. This approach offers an alternative metric for assessing saliency map quality, leveraging segmentation masks as a potentially stronger signal than class probabilities in insertion/deletion scores. Furthermore, we hypothesize that since segmentation maps directly highlight the object of classification, they serve as an effective proxy for evaluating saliency map quality.

Lastly, our code is available on GitHub[1].

4 Results

We have performed extensive experimentation with the aim to test the claims of the authors. It includes testing the interpretability claims and the classification accuracy improvement claims of the authors. We further show our results on an ablation study on the different loss terms introduced and on our extensions of the paper's experiments — comparing segmentation labels with our saliency maps and the effects of a learnable τ parameter.

Overall, our results do not support the central claims of the paper. Saliency map interpretability did not increase either quantitatively or qualitatively for models trained using LICO. In addition, the use of LICO decreased classification performance across the board. The results of our extension are also in lin with these findings.

In the following subsections we will analyze the results of each experiment in detail and provide evidence for our discussion in the following section.

4.1 Claim 1: Improvement in interpretability

As shown in the results in Table 1, we did not replicate the authors' findings that LICO improves the interpretability of saliency maps. With the exception of CIFAR-10 using Grad-CAM/RISE, LICO reduced our quantitative measure of interpretability (Insertion/Deletion scores) for every saliency map method and dataset tested.

[1] `https://anonymous.4open.science/r/lico-fact-C643/`

Dataset	Method	Grad-CAM++	Grad-CAM	RISE
CIFAR-10	Insertion	**53.8**/48.7	63.0/**63.6**	**73.3**/72.4
	Deletion	**43.8**/46.9	37.3/**35.4**	**31.8**/30.0
	Overall	**9.9**/1.7	25.8/**28.2**	41.5/**42.4**
CIFAR-100	Insertion	**34.1**/33.8	**44.0**/43.4	**54.3**/54.2
	Deletion	**27.6**/28.6	**19.2**/19.8	**13.4**/14.3
	Overall	**6.5**/4.2	**26.2**/23.6	**40.9**/39.9
Imagenette	Insertion	**60.2**/59.2	**77.1**/74.5	**70.9**/70.3
	Deletion	**36.9**/38.3	**23.0**/25.5	36.2/**35.8**
	Overall	**23.3**/21.0	**54.1**/49.0	**34.7**/34.5

Table 1: Baseline/LICO Insertion, Deletion, and Overall (Insertion - Deletion) scores for CIFAR-10, CIFAR-100 and Imagenette. Numbers in bold are the highest for a specific interpretability method.

Figure 2 also demonstrates that the generated saliency maps do not show any obvious qualitative improvement when training with LICO, in contradiction with the authors' claims. Furthermore, we would argue that in both ours and the authors' saliency maps figures one can not clearly observe that either baseline or LICO produces more explainable attention maps. Our interpretation is that this qualitative measure is rather obsolete for comparison purposes between baseline and LICO. Rather, it serves as a sanity check if the models focus on the right parts of the image.

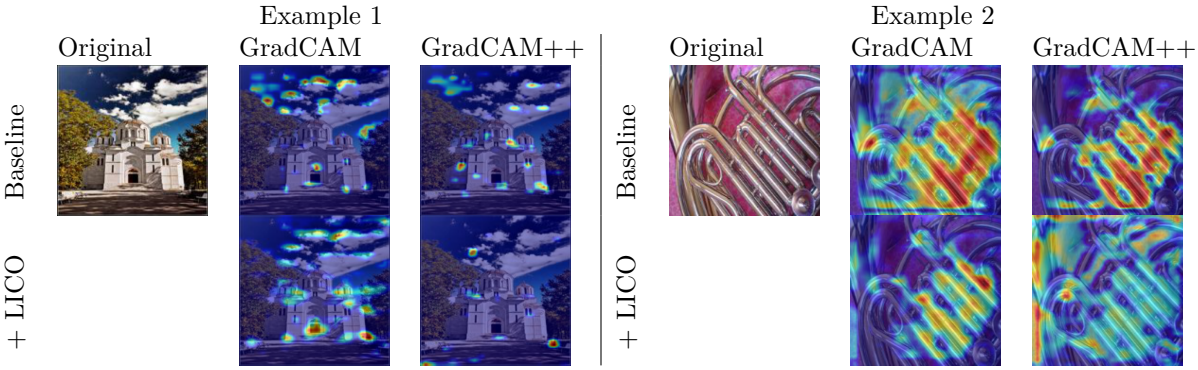

Figure 2: Examples of saliency maps for a model trained with and without LICO

4.2 Claims 2 and 3: Improvement in classification accuracy

We find that LICO slightly decreases test accuracy on all three datasets (Table 2), as well as on the smaller subset of CIFAR-100. These results also contradict the authors' claim that a greater number of classification categories leads to a greater increase in classification performance when using LICO: we find that LICO does not perform any better in the CIFAR-100 case with 100 classes than in the CIFAR-10 and Imagenette cases with 10 classes.

Similarly, our results also contradict the authors' assertion that LICO is particularly beneficial in circumstances with limited data. We instead find that in the limited data case, the degradation in performance due to LICO is significantly worse than in the full data case. It should be noted that, in general, our results are much worse than the authors' results in this case. This leads us to believe that the authors did something that was not described in the paper to improve results on limited data. This missing part might also explain why, in our case, LICO was much worse with limited data, whereas in their case, LICO was better.

	Imagenette	CIFAR-10	CIFAR-100	CIFAR-100 (2500 examples)
Wide ResNet-18	**87.3** $\pm$ 0.74	**93.9** $\pm$ 0.13	**78.1** $\pm$0.66	**28.5** $\pm$ 0.39
+LICO	86.8 $\pm$ 1.58	93.6 $\pm$ 0.29	77.3 $\pm$ 0.90	18.6 $\pm$ 1.64

Table 2: Test accuracy of baseline Wide ResNet-18 against LICO on CIFAR10/100 and Imagenette over 3 runs. A limited case with 2500 exapmles for CIFAR-100 is also evaluated.

4.3 Loss ablation study

As a further investigation into why most of our results differ from the authors, we performed an ablation study on the individual loss components. Specifically, we trained models on CIFAR-10, CIFAR-100 using only cross entropy loss and one of the OT/MM losses.

4.3.1 Classification performance

In the original paper, the authors perform one ablation study on the individual losses only for the Imagenet dataset. It shows that using only the OT loss leads to a degradation in test accuracy versus baseline and using only the manifold loss leads to an improvement in test accuracy versus baseline. We find that training with the OT loss alone leads to a small drop or no change in test accuracy, while training with the manifold loss alone leads to a small increase or no change in test accuracy, approximately replicating the authors' results (3).

The one exception to our findings is in the case of limited data, where the baseline model remains significantly better than all other models. Even here, however, the model trained using only the manifold loss performs the best of the three non-baseline models.

The authors also find that using both losses leads to a greater improvement in test accuracy than using the manifold loss alone. We do not see this in our results, instead we find that using both losses is always worse than using the manifold loss alone.

	Imagenette	CIFAR-10	CIFAR-100	CIFAR-100 (2500 examples)
Baseline	87.3 $\pm$ 0.74	93.9 $\pm$ 0.13	77.7 $\pm$ 0.08	**28.5** $\pm$ 0.39
OT only	83.8 $\pm$ 1.58	93.6 $\pm$ 0.35	78.0 $\pm$ 0.38	23.6 $\pm$ 1.96
MM only	**88.0** $\pm$ 0.26	**93.9** $\pm$ 0.11	**78.6** $\pm$ 0.33	26.1 $\pm$ 1.10
LICO (OT + MM)	86.8 $\pm$ 1.58	93.6 $\pm$ 0.29	77.0 $\pm$ 1.08	18.6 $\pm$ 1.64

Table 3: Test accuracy of LICO with ablated losses (over three runs) on CIFAR-10/100, Imagenette and CIFAR-100 in the limited data setting.

4.3.2 Interpretability

In the authors' ablation study, both OT loss only and manifold loss only improve interpretability of saliency maps as measured by insertion-deletion scores. They find that the best performance on this metric is achieved with the use of both losses. Our results do not bear this out, with the baseline models more often than not performing the best (Table 4). We also do not see a clear pattern of one loss providing more improvement than another, with all of the non-baseline models performing approximately as well across datasets.

Dataset	Method	Gradcam			GradCAM++			RISE		
		Ins	Del	Ovr	Ins	Del	Ovr	Ins	Del	Ovr
CIFAR10	Baseline	63.0	37.3	25.4	**53.8**	**43.8**	**9.9**	73.3	31.8	41.5
	MM only	59.3	39.5	19.8	51.5	46.4	2.6	72.8	30.9	41.9
	OT only	63.0	36.8	26.2	53.5	44.4	9.1	**73.9**	30.4	**43.5**
	LICO (OT + MM)	**63.6**	**35.4**	**28.2**	48.7	46.9	1.7	72.4	**30.0**	42.4
CIFAR100	Baseline	**44.0**	**19.2**	**26.2**	**34.1**	27.6	**6.5**	54.3	13.4	40.9
	MM only	41.0	21.2	19.8	31.8	29.2	2.6	55.0	**13.3**	41.7
	OT only	41.3	20.8	20.5	32.9	**27.5**	5.4	**55.1**	**13.3**	**41.8**
	LICO (OT + MM)	43.4	19.8	23.6	32.8	28.6	4.2	54.2	14.3	39.9
Imagenette	Baseline	**77.1**	**23.0**	**54.1**	60.2	**36.9**	**23.3**	**70.9**	36.2	**34.7**
	MM only	75.9	27.0	48.9	**60.4**	39.0	21.4	69.1	38.0	31.1
	OT only	71.7	27.3	44.4	57.3	38.3	19.0	64.7	37.8	26.9
	LICO (OT + MM)	74.5	25.5	49.0	59.2	38.3	21.0	70.3	**35.8**	34.5

Table 4: Ablation study results of LICO with MM/OT losses evaluated for interpretability: Insertion, Deletion and Overall scores. The results are on CIFAR10/100 and Imagenette datasets.

4.4 Results beyond original paper

4.4.1 Saliency maps and segmentation ground truths comparison

We perform a further investigation of the model's interpretability by evaluating the IoU between ground truth segmentation masks and saliency maps generated with Grad-CAM (5). Over three runs, we get a mean IoU of 0.185 for the baseline model against 0.141 for LICO, which is 23.7% lower. This is a significant difference, which shows that LICO produces worse-quality saliency maps, because it focuses less on the segmented object of classification and is possibly more spread out. To back this, from Figure 2, Example 2 we can see that sometimes the saliency magnitude is low, even though it is focused on the correct object, and contrarily, with another interpretability method, it becomes more spread out outside the segmented object. Both variants are causes for low IoU score.

Method	Intersection over Union
Baseline	0.185 ± 0.005
LICO	0.141 ± 0.008

Table 5: Intersection over Union scores, evaluated on PartImageNet

4.4.2 The effect of a learnable versus constant τ

To investigate the effect of using a fixed or learned temperature, we performed an experiment on CIFAR-10 where we compare 3 models: one without LICO losses, one with LICO losses but with fixed temperature, and one with LICO losses and with learned temperature.

In Table 6 we see that keeping τ fixed does not seem to have any beneficial effect. The test accuracy is not significantly different from the test accuracy with a learnable τ, and the Insertion/Deletion scores are generally worse than with a learnable τ. We attempt to justify that substantial differences in results are not observed between setups of τ because in all of our other experiments, using the LICO losses has also not improved results. Our hypothesis with this experiment was that keeping τ fixed would prevent the manifold loss from vanishing during training, therefore positively influencing the training process, however, it does not have a significant effect accross datasets. Therefore, the design choice of τ being learnable is unlikely to matter for the results obtained from LICO.

Method	Accuracy	GradCAM			GradCAM++			RISE		
		Ins	Del	Ovr	Ins	Del	Ovr	Ins	Del	Ovr
Baseline	$\mathbf{93.6 \pm 0.09}$	63.9	38.0	25.8	**56.0**	**44.1**	**11.8**	**69.7**	**34.0**	**35.7**
LICO (τ learnable)	93.5 ± 0.08	**66.8**	36.6	**30.1**	50.1	47.9	2.2	68.5	34.5	34.0
LICO (τ fixed)	93.4 ± 0.08	65.2	**36.5**	28.7	49.2	49.2	0.0	67.7	36.2	31.4

Table 6: Test accuracy, Insertion/Deletion and Overall scores for the experiment with τ for LICO. The setups are LICO with learnable τ against fixed τ with a baseline no LICO training.

5 Discussion

In general, our results did not support the claims of the paper. We extensively tested the methodology of the paper across CIFAR-10 and CIFAR-100 datasets, because these datasets were manageable in size while also having results in the paper we could compare to. We did many iterations and variations of experiments in an effort to replicate the reported results. However, However, in almost all our experiments, we did not observe consistent improvements in accuracy, nor did we detect qualitative or quantitative enhancements in interpretability.

We did replicate some of the findings of the authors regarding ablation on losses. Specifically, we found that using the manifold-matching loss alone leads to consistently better classification performance than using the OT loss alone. However, we did not replicate the finding that using both losses performs best. This implies that much of the difficulty in replicating the authors' findings is due to issues with the OT loss. It is possible that our implementation of the OT loss differs substantially from that of the authors, however, we are unable to confirm this due to incomplete code provided by them and a lack of response to our inquiries seeking clarification.

A limitation of our study is that our implementation may differ substantially from the implementation the authors used to generate their results (see Section 5.2). It is likely that we missed several setup details and optimizations that the authors used to get the networks to train slightly better, resulting in a slightly better accuracy. Thus, all we can conclude is that the paper is not reproducible as it is now, given the existing resources - the paper itself and the code provided.

5.1 What was easy

The paper gives both an intuitive as well as a formal description of the losses, and pseudocode for the training algorithm, which is very helpful in understanding how the method works and why. Thus, the core contributions of the paper are well explained.

In addition, the paper provides extensive experimentation and results with discussions to solidify the scope of the proposed methods and to evaluate them from different aspects. We found this very helpful for understanding why and to what extent LICO performs well.

5.2 What was difficult

Attempting to reproduce the LICO paper was, in general, quite difficult. This was caused by three main factors: firstly, the code [2] provided by the authors was incomplete. The MM loss function and the training loop were missing, as well as the implementations for a ResNet50 and PARN with prompts. We attempt to alleviate this problem by providing our own codebase, where many parts of the methodology are implemented exactly as described in the paper.

Secondly, in several cases, the provided code did not match the methodology as described in the paper. Most notably, the paper proposed "to align G_i (...) and F_i (...) for achieving consistency between feature maps and specific prompt token". However, the implementation in the code provided reduces the output of the

[2] `https://github.com/ymLeiFDU/LICO/tree/main`

text encoder into a single feature vector per class instead. This does not correspond to the description in the paper and based on our observations, the discrepancy renders the OT loss meaningless. This reduction to single vector in the authors' implementation, is realized via an "." (EOT) token contained in the corresponding prompt G_i for every class, which is being used like a [CLS] token in ViT (Dosovitskiy et al., 2021). Additionally, in the paper, the learned context is shared between the prompts for every class: in $\mathbf{G}_i$, the only part that depends on the sample index is $\mathbf{g}_{t_i}$. In the code, there is a separate learned context for every class prompt.

Finally, details of the experimental setup were ambiguous, which exacerbated the difficulty of reproduction. The paper did not describe the depth and width of the WideResNet used to generate their results on CIFAR-10, CIFAR-100, and SVHN. Instead, they referred to another paper's setup without pointing out what part of the experimental setup was used. The paper also missed a justification for a key design choice: in Equation 1, τ is defined to be a learnable parameter, which leads to issues in $\mathcal{L}_{\text{MM}}$ (see Section 3.3 for a discussion of the implications). This prompted our investigation in Section 4.4.2.

5.3 Communication with original authors

We attempted to establish communication with the authors persistently over a span of more than four weeks. Regrettably, we received no response to any emails, nor an open issue on their GitHub repository. This substantially hindered the efforts to reproduce the original experiments, as the code provided was incomplete and inconsistent with the paper itself on multiple occasions (see Section 5.2 for more detail). We were only provided the code in this state after emailing the authors about the lack of code in the paper's repository. This was the only time we received any response to our queries, although the emails themselves never received an explicit reply.

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A Hyperparameters

All hyperparameters are shown in Table 7.

We keep $\alpha = 10$ and $\beta = 1$ for all experiments. The batch size is kept at 64, and the learning rate at 0.03. We use SGD as optimizer with momentum 0.9 and weight decay 0.0001.

We apply the cosine learning rate scheduler $\eta = \eta_0 \cos\left(\frac{7\pi k}{16K}\right)$ from the paper (Lei et al., 2023), and we train on CIFAR-10/100 for 200 epochs and on Imagenette for 90 epochs.

Hyperparameter	**Value**
α	10
β	1
Batch size	64
Learning rate	0.03
Optimizer	SGD
Momentum	0.9
Weight decay	0.0001
Learning rate scheduler	Cosine
Learning rate scheduler parameters	$\eta = \eta_0 \cos\left(\frac{7\pi k}{16K}\right)$
Training epochs (CIFAR-10/100)	200
Training epochs (Imagenette)	90

Table 7: Hyperparameters for experiments

B Computational requirements and environmental impact

For our runs we used NVIDIA A100 GPUs on a cluster. Completing a single training run on CIFAR-10 with and without LICO took around 2.5 hours, on CIFAR-100 around 4 hours, on Imagenette approximately 1.5 hours, and on PartImageNet around 2 hours.

To calculate the environmental impact of our reproducibility study, we use the following formula:

$$\mathrm{CO_2}e = \mathrm{CI} \cdot \mathrm{PUE} \cdot \mathrm{E},$$

where CI is Carbon Intensity (g $\mathrm{CO_2}e$/kWh), PUE is the Power Usage Effectiveness (no unit), and E is the energy used (kWh). For the CI, we use the most recent value provided by the European Environment Agency: in the Netherlands in 2022, generating one kWh of electricity emitted an amount of greenhouse gases equivalent to 321 grams of $\mathrm{CO_2}$ [3]. As for the PUE, we do not know the value of Snellius specifically, but the European Commission has stated that the average value in the EU is 1.6 [4], so that is the value we will use. In our efforts to reproduce the paper, we used an estimated 205 kWh (calculated using the "eacct" command of the "Energy Aware Runtime (EAR) SLURM plug-in"). Putting this all together, we arrive at a total of

$$321\text{g } \mathrm{CO_2}e/\text{kWh} \cdot 1.6 \cdot 205\text{kWh} \approx 105 \text{ kg } \mathrm{CO_2}e.$$

If we compare this to the greenhouse gas emissions per capita, which was 9600 kg $\mathrm{CO_2}e$ per year in the Netherlands in 2021 [5], we find that running the experiments for our paper used approx. 11% of what a Dutch citizen uses per year. Alternatively, comparing to the EU $\mathrm{CO_2}$ emission target for passenger cars, which is 95 g $\mathrm{CO_2}$/km, our study used the same amount of $\mathrm{CO_2}e$ as driving a passenger car for approx. 1105 km.

[3] https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emission-intensity-of-1

[4] https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/eu-code-conduct-data-centres-towards-more-innovative-sustai
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[5] https://climate.ec.europa.eu/eu-action/transport/road-transport-reducing-co2-emissions-vehicles/
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