LABEL-FOCUSED INDUCTIVE BIAS OVER LATENT OBJECT FEATURES IN VISUAL CLASSIFICATION

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ABSTRACT

Most neural networks for classification primarily learn features differentiated by input-domain related information such as visual similarity of objects in an image. This input-domain focused inductive bias, while natural, can unintentionally conflict with unexpressed yet implicitly utilized relations over latent objects in human labeling, referred to *Undescribed world knowledge (UWK)*. Such conflicts can limit generalization of models by potential dominance of the input-domain focused bias in inference. To overcome this limitation without external resources, we introduce *Label-focused Latent-object Biasing (LLB)* training method that constructs label-focused inductive bias over latent objects determined by only labels as UWK. It has four steps: 1) it learns intermediate latent object features in an unsupervised manner; 2) it decouples their visual dependencies by assigning new independent embedding parameters; 3) it captures structured features optimized for the original classification task; and 4) it integrates the structured features with the original visual features for the final prediction. We implement the LLB on a vision transformer architecture, and achieved significant improvements on image classification benchmarks. This paper offers a straightforward and effective method to obtain and utilize undescribed world knowledge in classification tasks. The codes are available at https://github.com/IlminKang/LLB

1 INTRODUCTION

In many classification tasks, a neural network has a role of learning latent features from an input to determine its accurate output labels. In case of image classification, the model learns the features based on visual similarity and differentiation depending on their classes. This preference for the input-domain to handle the similarity of features is a common property in most well-known models such as convolutional neural network (Krizhevsky et al., 2017; He et al., 2016) and vision transformer (ViT) (Dosovitskiy et al., 2020) as their high sensitivity to input specific information (Park & Kim).

Figure 1: Visually similar but semantically different images when we see the relations of all objects that are not explicitly described in data

This behavior is naturally expected for neural networks, but the relations on the latent objects may be different in human labeling based on world knowledge. Figure 1 shows the clear example of the conflict in image classification. The figures on the left are visually very similar to the figures on the right, but the semantics of the labels are different in the real world. These samples may be regarded as just ambiguous and difficult samples for visual classification, but in fact we can correctly differentiate the cases by using unobserved relations in the data such as the stick part of Mop or the ice ground for the Hockey puck.

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This conflict between input-domain and potential knowledge on labels has been already discussed in many practical tasks such as visual question answering, cross-modal learning, and domain adaptation (Hendricks et al., 2018; Rohrbach et al., 2018; Zhou et al., 2019; Zhang et al., 2021; Cadene et al., 2019; Lemesle et al., 2022; Min et al., 2020; Radford et al., 2021) in various perspectives. However, these works have primarily focused on the inconsistency of rich information in observed data of two explicitly different domains (i.e. linguistic and visual relations of observed entities in each domain), while the conflict between input-domain information and undescribed relations over internal objects for determining output labels referred to *Undescribed World Knowledge (UWK)* in a single classification has been less investigated.

Such conflict in a single classification can limit generalization, because training and test data collected in the same labeling environment share the same UWK. If a model fails to learn such UWK, inference on test data can be dominated by input-domain focused inductive bias and lead to incorrect prediction. This limit of generalization by the conflict has not been discussed as an important issue to control so far. In fact, in visual classification, for example, the training data already contain a part of UWK, because labeling can inform the category of internal objects of an image that are sufficiently abstract for the use as basic elements of the knowledge.

To this end, we propose *Label-focused Latent-object Biasing (LLB)* method for learning *label-focused inductive bias* over latent object features determined solely by categorization of labels, regarded as UWK. It has four sequential steps: 1) it learns intermediate latent object features in an unsupervised manner; 2) it decouples their visual dependencies by assigning new independent embedding parameters; 3) it captures structured features optimized for the original classification task; and 4) it integrates the structured features with the original visual features for final prediction. We empirically investigate the conflict and impact of LLB on latent feature distributions, implement it on ViT architecture. In experiments on image classification task, the approach improves performance in quantitative and qualitative analysis, and shows the benefit of regularizing the model without any help of external resources.

Our contribution points are:

- We first raise the dominance of input-domain focused inductive bias of neural networks on inference that conflicts with undescribed world knowledge over latent objects by human labeling.
- We propose a training strategy, *Label-focused Latent-object Biasing (LLB)*, to obtain and utilize to obtain UWK and utilize it as label-focused inductive bias, and implement it on vision transformer for visual classification.
- We verify the proposed method in various image classification benchmarks with quantitative and qualitative analysis.

2 Related works

Conflict of Input Domain Focused Inductive Bias The conflict of input-domain and potential knowledge on labels has been discussed in various tasks, but most works focuses on the inconsistency of two different domain resources rather than the conflict of input-domain to an undescribed world knowledge over latent objects in human labeling. In image captioning, (Hendricks et al., 2018) addresses the conflict of bias on visual contextual cues with gender-specific texts. (Rohrbach et al., 2018) raises over-reliance issue on language prior, leading to hallucination problem. (Zhou et al., 2019; Zhang et al., 2021) also observes that semantic inconsistency in the visual-text domain leads to hallucination, highlighting the issue of scarce aligned visual-text pairs. In visual question answering, (Cadene et al., 2019) introduces the impact of reducing dependencies on single-domain based statistical regularities when using both text and image input information. In cross-modality representation learning, vision networks leverage broader supervision of texts and adopts language bias in visual representation (Radford et al., 2021). However, cross-modal representations suffer inconsistency of language and visual domains (Pan et al., 2022; Lemesle et al., 2022). (Chen et al., 2019; Alberts et al., 2020; Li et al., 2020; Tan & Bansal, 2019) aim to make semantic aligned object representation using image-text paired dataset. To adapt CLIP (Radford et al., 2021) in a different domain, (Ma et al., 2022) made semantic alignments with large collection of semantic entities

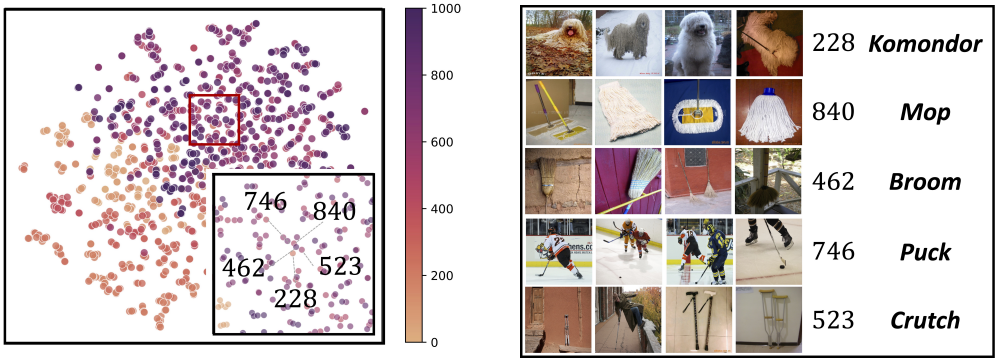
paired with images. (Pan et al., 2022) suggests semantic connection between different modalities for semantic perceiving and addressed the limitation with external knowledge-graph based networks.

Conflict Reduction via Knowledge Graph A traditional and direct solution of reducing the input-domain focused bias is to use external resources defined on labels as knowledge graphs. In visual understanding, (Marino et al., 2017) learns structured semantic representation over objects (Ren et al., 2015) with structured prior knowledge graph (Krishna et al., 2017; Miller, 1995). (Wang et al., 2018; Kampffmeyer et al., 2019) tried to inject knowledge graph and biases of language in the vision classifier to make zero-shot predictions. For open-world detection, (Yao et al., 2022) proposed large-scale unified concept dictionary with large-scaled image-text paired dataset to provide prior knowledge on detection. (Zhu et al., 2021) also learns dynamic knowledge graph over object class label from language domain bias to overcome the limitation of data scarcity in few-shot object detection. However, all these works focus on the effective use of external knowledge while UWK of the target training data has not been utilized and even recognized.

Disconnecting Latent Objects from Inputs In visual understanding, (Marino et al., 2017) learns graph structures on internal objects regarded as nodes and integrates the features with external prior knowledge. Each Node feature is initialized by object class label, which disconnects the visual dependency in the separate phase for graph neural networks. (Zhu et al., 2021) also learns dynamic semantic knowledge graph on object class label, which disconnects the visual dependency. However, visual disconnection in (Marino et al., 2017) are based on graph extraction and analysis. And (Zhu et al., 2021) may have learn separate embedding to input-domain, by aims to represent language based semantic embedding over object class label rather than label-focused inductive bias. (Min et al., 2020) highlights the need for managing input-domain focused bias in regularizing representation for zero-shot classification, using decoupling effects by contrastive learning. Differently, our method focus on the conflict in standard classification, and direct extraction of UWK to induce not only decoupling but also re-positioning bias insensitive to input-domain features.

3 METHOD

3.1 PRELIMINARIES

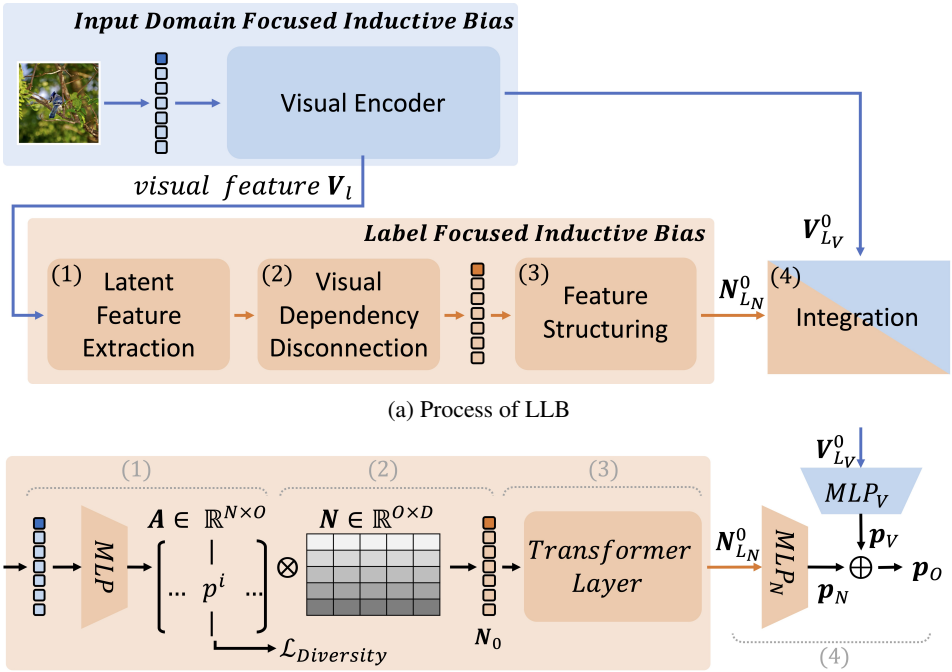


(a) Centroids of Class-wise Features (1000 classes)

(b) Image Samples for Adjacent Classes

Figure 2: Input-domain focused inductive bias on features at the final layer, and its conflict with semantic difference on labels.

Problem Confirmation in Class Distribution The problem to be addressed in this paper is the dominance of the input-domain focused bias on latent object features that conflicts with UWK. In Figure 2, the problem is clearly shown. The dots in the leftside figure are centroids of all features in each class of ImageNet, extracted from a MAE He et al. (2022) trained on the data. We zoomed in an area where the centroids are closed located, and selected almost adjacent five classes. However, in the rightside figure, their class labels are semantically unrelated. Although their visual similarity is sufficiently high, human can recognize the label correctly. For example, the pole in a mop image may be confused with a tightened harnes of a komondor, but their shape and angles associated with the other hairy features are distinguished in the two classes. This observation shows an evidence



(a) Process of LLB

(b) LLB Module on Visual transformer

Figure 3: Overview of Label-focused Latent-object Biasing in image classification. (blue: visually determined, red: non-visually determined)

for the dominance of the visual input-domain focused bias over the UWK. See Appendix C for additional problem confirmation using CNN and comparison with LLB.

Motivation for Method: Label-based Grouping of Latent Objects Determines Their Similarity in UWK Our motivation is that categorizing latent object features provides their similarity on the UWK without the help of external resources. A simple method to use this *label-focused bias* is to learn a classification model that receives the latent features as inputs. But, input-domain focused inductive bias can dominate over the label-focused bias in determining the feature positions. For this reason, we propose to learn a separate plug-in classification model to capture the label-focused bias, and to disconnect the direct forward path from an input to latent object features that are fed into the model as new inputs.

Notations for ViT We start with brief recap of ViT (Dosovitskiy et al., 2020). ViT reshape input image $\mathbf{x} \in \mathbb{R}^{C\times H\times W}$ to patches $\mathbf{x}_p \in \mathbb{R}^{N\times(P^2\cdot C)}$, where (H, W) is original image's resolution with channel size C. Patches have size of (P, P), and the derived total number N of patches per images is HW/P^2. Patches are then projected into hidden dimension of size D with additional positional embedding. Function $f(x)$, encodes patch representations with additional CLS token $\boldsymbol{c}_v$ by stacks of L_V transformer (MHSA+FFNN) layers. We denote visual features as $\boldsymbol{V}_l = [\boldsymbol{v}_l^i]_{i=0}^N$, where $\mathbf{v}_l^i \in \mathbb{R}^D$ is hidden vector of ith-patch of lth-layer.

3.2 Method Description

Overview of Architecture on Vision Transformer We propose *Label-focused Latent-object Biasing (LLB)* method for visual classification problems as shown in Figure 3. The network is based on a typical pre-trained ViT Dosovitskiy et al. (2020) using split image-patches as an input sequence, and implemented by four sequential steps: 1) latent object extraction, 2) visual dependency disconnection, 3) object feature structuring, and 4) integration of non-visual and visual features for the final prediction. In the first step, the generated features from an intermediate l-th layer of the ViT (*visual features* $\boldsymbol{V}_l$) generates probability to select a latent object index among O objects. In the next step for the disconnection, the most probable object index is mapped to separate learnable embedding *non-visual features* $\boldsymbol{N} = [\boldsymbol{n}^i]_{i=0}^O \in \mathbb{R}^{O\times D}$ where D is the equal dimension to visual features and i

indicates the object index. In the third step, the following transformer stacks (LLB layers) learn the structures of the non-visual embedding. At the end, the visual and non-visual features are integrated as an ensemble for the final decision.

Latent Object Extraction from Visual Features The first step in visual object extraction is to quantize visual features into a set of latent objects. This process is essential to limit the number of non-visual features that could be related to UWK, ensuring computational cost constraints are met. To implement the quantization, we pass a visual feature of each image patch into an `MLP`. This is then followed by a `Softmax` operation at a temperature of $T(= 0.1)$. The resulting vector, $\boldsymbol{p}^i$, determines the probability of selecting the latent object of index i. The following process is applied to all patches generated from an image.

$$\boldsymbol{p}^i \quad = \quad \texttt{Softmax}(\texttt{MLP}(\boldsymbol{v}_l^i)) \quad , \quad \boldsymbol{p}^i \in \mathbb{R}^O \tag{1}$$

The number of objects influences the clarity of the objects; hence, we treat it as a hyper-parameter. The effective range for this parameter is detailed in Table 7a.

To effectively represent groups of visual features using limited latent objects, we incorporated a loss function that promotes diversity of the probability, as described in (Van Gansbeke et al., 2020; Mustafa et al., 2022).

$$\mathcal{L}_{Diversity} \quad = \quad -\mathcal{H}(\tilde{p}), \quad \text{where } \tilde{p} = \frac{1}{N}\sum_{i=0}^{N} \boldsymbol{p}^i \quad \text{and} \quad \mathcal{H}(p) = -\sum_{i=1}^{O} p^i \log(p^i) \tag{2}$$

where $\mathcal{L}_{Diversity}$ makes the averaged probability vectors of all objects uniform, encoursing even assignment across all objects. $\mathcal{L}_{Diversity}$ is combined with downstream task loss (e.g., cross-entropy loss) using the balancing parameter λ(=0.5).

Visual Dependency Disconnection The core idea of visual disconnection is to assign separate embedding parameters to visually determined latent objects. This step interrupts the gradient flow of the embedding parameters stemming from input-based differentiation, ensuring that subsequent training on the embedding is not overly influenced by this differentiation. To achieve this, we employ a straightforward *Disconnect* network, as illustrated in Figure 3b.

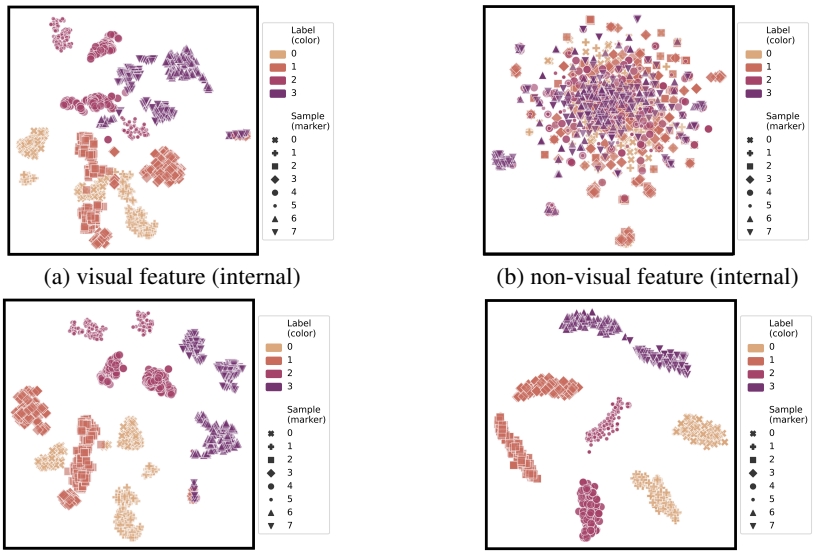
$$\begin{aligned} \boldsymbol{N}_0 \quad &= \quad \texttt{Disconnect}(\boldsymbol{A}, \boldsymbol{N}) = \boldsymbol{A} \times \boldsymbol{N} \\ \boldsymbol{A} \quad &: \quad \text{A matrix of patch-wise probability vectors to select latent objects} \\ \boldsymbol{N} \quad &: \quad \text{A matrix of non-visual features in disconnected parameters from input} \end{aligned} \tag{3}$$

The `Disconnect` network straightforwardly assigns disconnected embedding parameters to latent objects and subsequently produces patch-wise non-visual features, denoted as $\boldsymbol{N}_0 = [\boldsymbol{n}_0^i]_{i=0}^N$, used as inputs of LLB module. It operates matrix multiplication of assign matrix $\boldsymbol{A} = [\boldsymbol{p}^i]_{i=0}^N \in \mathbb{R}^{N \times O}$, composed of the generated probability vectors ($\boldsymbol{p}^i$s in Equation(1)) to select latent objects, and the separate trainable non-visual feature $\boldsymbol{N}$. Rather than using the `argmax` function, matrix multiplication with the assign matrix is employed. This makes it differentiable while interrupting the input-based differentiation. It is worth noting that we utilize a separate CLS token, denoted as $\boldsymbol{n}_0^0$, for downstream tasks.

Non-visual Feature Structuring Structuring non-visual features is the core step to re-define similarity of features built over latent objects via solely the categorization of labels. The structuring method, referred to $g(\boldsymbol{X}, \boldsymbol{W})$, processes non-visual features $\boldsymbol{N}_0$ using weights $\boldsymbol{W}$ from structuring module to produce *structured non-visual features* $\boldsymbol{N}_{L_N}$. We implemented the function g by a stacking L_N layers of transformer (Vaswani et al., 2017) layer. We use transformer to extensively discern semantic relations within sequential input, as evidenced by works like (Devlin et al., 2018; Radford et al., 2018; Park & Kim), owing to their flexible and scalable architecture. Adhering to the original method, we attached a CLS token to the head of non-visual feature sequence, denoted as $\boldsymbol{c}_n$, from the structured non-visual features for the final decision.

$$\boldsymbol{N}_{L_N} \quad = \quad g([\boldsymbol{c}_n || \boldsymbol{N}_0], \boldsymbol{W}) \tag{4}$$

where $\boldsymbol{N}_{L_N} = [\boldsymbol{n}_{L_N}^i]_{i=0}^N$. Compared to the original transformer layer, we exclude the positional embedding due to the weak dependence of clusters to specific positions in a sequence.



(a) visual feature (internal)

(b) non-visual feature (internal)

(c) visual feature (final)

(d) non-visual feature (final)

Figure 4: Comparison of object (image patch) feature distribution of each sample for four example classes at the end of training (Impact of visual disconnection: (a) and (b), Impact of structuring: (b) and (d), Impact of label-focused bias: (c) and (d)).

Integration of Non-visual and Visual Feature The primary objective of learning structured non-visual features is to achieve better generalization, as opposed to merely accurate prediction on observed data, which is effectively achieved by the original visual features. To harness the strengths of both visual and non-visual features, LLB consolidates the output probabilities from both domains as described below.

$$\boldsymbol{p}_V = \texttt{SoftMax}(\texttt{MLP}_V(\boldsymbol{c}_v)) \tag{5}$$

$$\boldsymbol{p}_N = \texttt{SoftMax}(\texttt{MLP}_N(\boldsymbol{c}_n)) \tag{6}$$

$$\boldsymbol{p}_O = \alpha \times \boldsymbol{p}_V + (1-\alpha) \times \boldsymbol{p}_N \tag{7}$$

To safely preserve the pre-trained probability for the visual features, we employ a separate classifier for predictions from non-visual features. Subsequently, we aggregate the output probability vectors, $\boldsymbol{p}_V$ and $\boldsymbol{p}_N$, from each classifier. A balancing parameter, α, is introduced to modulate their respective contributions, as elaborated in Equation (7). The integrated probability $\boldsymbol{p}_O$ determines the final cross-entropy.

3.3 Empirical Analysis on Feature Distribution

Simple Settings In this section, we provide empirical analysis of visual disconnection and structuring on feature representations. We extract them from a trained vanilla ViT (Dosovitskiy et al., 2020) described at Section 4. In Figure 4, each dot represents a feature corresponding to an image patch assigned to an object index, and the four figures illustrated via t-SNE (Van der Maaten & Hinton, 2008) show visual or non-visual feature distribution for internal or final layer. Check Appendix Section B.1 for closer look at the figure.

Impact of Visual Dependency Disconnection Comparing Figure 4a with 4b, we observe that visual features for objects tend to cluster by both sample and class. In contrast, non-visual features exhibit a distribution closer to randomness. This disparity indicates the existence of the dominance of visual input-domain focused inductive bias.

Impact of Non-Visual Feature Structuring Figure 4b and 4d and show the change of final features caused by the structuring non-visual features. The non-visual features are largely overlapped across samples and classes, showing their ambiguity for classification. However, the final features are more concentrated and separate by their class and sample. This implies that sufficient structuring is required for learning label-focused inductive bias useful in practical classification.

Impact of Label-focused Bias In comparison of Figure 4c with 4d, we can observe the difference of input-domain focused bias and label-focused bias. For most samples, the visual features are split into two clusters, with exceptions of sample 2 and 6. Notably, samples of different classes overlap in the cases of samples 2, 3, 4, 6, and 7. Furthermore, the sample area of two classes (0 and 1) are overlapped. In contrast, the label-focused inductive bias does not show any of the negative phenomena. This suggests that leveraging the feature concentration from the label-focused bias can further enhance generalization that was not achieved by input-domain focused inductive bias.

4 Experiment Setting

Our LLB can be applied to any networks base on Transformer architectures. We evaluate the effectiveness of our non-visual feature by comparing it to vanilla networks in standard benchmarks. With pre-trained transformer networks, we first train our LLB in supervised manner, and measure its performance via an integration method (Section 3.2) that does not require any additional training. We also provide series of analyses of the impact of each components.

Training Details. Our LLB is built upon pre-trained classical visual feature backbones. We extract hidden vectors from backbone while keeping the backbone parameter freezed. For backbone, we use ViT (Dosovitskiy et al., 2020) networks. We use l_V-th layer and consider them as visual features $\boldsymbol{V}_{l_V} = [\boldsymbol{v}^0_{l_V}; \boldsymbol{v}^1_{l_V}; \cdots; \boldsymbol{v}^i_{l_V}]$. We found that, extraction from $l_V = L_V - 1$ layer showed best performance (Figure 7a in Appendix). LLB takes $\boldsymbol{V}_{l_V}$ and cluster them into O latent objects. Based on our experiments (Figure 7b in Appendix), we use O=2048. We report the results of different α in Figure 7d in Appendix, and selected best one among them. Additional model settings are summarized in Table 3. We train our model with CrossEntropy loss with additional object diversity regularization term in Equation (2). Look at Table 4 in Appendix for detailed hyper-parameters we used. Our experiments are on 8×A100 with additional 4×A6000 GPUs for both reproduce baselines and training LLB.

Image Classification. We perform evaluation on image classification task. We show the effectiveness of the non-visual feature through the performance gained by adding our LLB to baselines. We use standard ImageNet (IN1K)(Deng et al., 2009), which consist of 1.28M training images with 1000 classes. We also use additional benchmarks including IN reassessed labels ImageNet-Real (IN-Real) (Beyer et al., 2020), scene recognition dataset Places356-Standard (Places) (López-Cifuentes et al., 2020), fine-grained and long-tailed iNaturalist2018 (iNat18) (Van Horn et al., 2018) dataset. For baselines, we first followed (Dosovitskiy et al., 2020; Steiner et al., 2021) to get vanilla ViT pre-trained using ImageNet21K (IN21K) (Ridnik et al., 2021). Also, to evaluate robustness of our method, we evaluate our method with diverse pre-training schemes. SWAG (Singh et al., 2022) is weakly-supervised ViT pre-trained via weakly supervision with hashtag labels (IG3.6B). . Additionally, we use self-supervised method MAE (He et al., 2022) trained on IN1K. MAE is trained to reconstruct masked portion of an image. For some models, we used parameter weights from open source[1][2][3]. For others, we followed the training details described on (Singh et al., 2022; He et al., 2022; Singh et al., 2023) with 5 runs. All reproduced and official performance are reported in Table 1.

5 Result and Discussion

5.1 Quantitative Analysis

Performance In Table 1, the performance before and after applying LLB is shown. Overall performance is significantly improved compared to the pre-trained models. Additionally, LLB remains effective even when applied to larger base models.

We also examine the robustness to different pre-training schemes. In this experiments, we replace supervised pre-trained ViT with weakly (SWAG) and self (MAE) supervised ViT. The results in Table 1 shows that the different pre-training schemes benefits from label-focused inductive bias on

[1]ViT: https://github.com/huggingface/pytorch-image-models
[2]MAE: https://github.com/facebookresearch/mae
[3]SWAG: https://github.com/facebookresearch/SWAG

Model	Pre.	Resolution		Image Classification (Top1 acc.)			
		Pre.	Fine.	IN1K	IN-Real	Places365	iNat18
ViT B/16*	IN1K	224	224	$79.00_{0.00}$ (77.91)	$83.76_{0.00}$ (83.57)	-	-
+ LLB (Ours)	-	224	-	$79.43_{0.03}$	$84.25_{0.02}$	-	-
ViT B/16*	IN21K	224	224	$84.40_{0.00}$ (83.97)	$88.55_{0.00}$ (88.35)	-	-
+ LLB (Ours)	-	224	-	$84.80_{0.01}$	$88.90_{0.02}$	-	-
ViT L/16*	IN21K	224	224	$85.68_{0.00}$ (85.15)	$89.05_{0.00}$ (88.40)	-	-
+ LLB (Ours)	-	224	-	$85.92_{0.02}$	$89.26_{0.01}$	-	-
MAE B/16†	IN1K	224	224	$83.63_{0.00}$ (83.60)	$88.29_{0.00}$ (-)	$57.84_{0.07}$(57.90)	$74.20_{0.05}$ (75.40)
+ LLB (Ours)	-	224	-	$83.78_{0.02}$	$88.40_{0.02}$	$57.90_{0.06}$	$74.32_{0.06}$
MAE L/16†	IN1K	224	224	$86.08_{0.00}$ (85.90)	$89.63_{0.00}$ (-)	$59.60_{0.06}$ (59.40)	$80.06_{0.06}$ (80.10)
+ LLB (Ours)	-	224	-	$86.12_{0.01}$	$89.65_{0.02}$	$59.70_{0.05}$	$80.00_{0.06}$
SWAG B/16‡	IB3.6B	224	384	$85.28_{0.00}$ (85.30)	$89.00_{0.00}$ (89.10)	$58.90_{0.13}$ (59.10)	79.78 ($79.90_{0.06}$)
+ LLB (Ours)	-	224	-	$85.35_{0.04}$	$89.10_{0.09}$	$59.17_{0.02}$	$79.86_{0.03}$

Table 1: Top-1 accuracy(Acc_{std}%) on four image classification benchmarks (red: positive, blue: negative). We report the results from the paper in parentheses(*: the result of (Steiner et al., 2021), †: the result of (He et al., 2022), ‡: the result of (Singh et al., 2022)). The baseline results for IN1K and IN-Real are reproduced from the fixed open-source fine-trained models. For models that reproduced our-self, we state standard deviation as well. For both reproduce and proposal, We report the results of 5 runs.

most of the evaluation benchmarks. Note that LLB does not use additional pre-training with large data and regularization such as (Zhang et al., 2017; Yun et al., 2019; Szegedy et al., 2016).

Ablation Study Table 2 reports ablation study results. We configure LLB with ViT B/16 trained on IN1K as the main model, and assess performance by excluding each attribute. First, we study the impact of the visual dependency disconnection (Visual Disc.). We do not use the disconnection method while remaining structuring method. Results shows that disconnecting visual dependency significantly improves performance than maintaining it. Structuring visual features shows worse results than the baseline, indicating that LLB does not benefit from simply adding additional parameters. Then, we evaluate the impact of implementation component. We ablate the diversity loss for latent object extraction (Diversity), and we also set the transformer not to use positional encoding (w/o Pos.). The results show each configuration is required to obtain the best performance. Lastly, the performance without our integration module with visual features (Integration) shows the worst performance.

Model	Visual Disc.	Diversity	w/o Pos.	Integration	IN1K (Top1-Acc_{std}%)
LLB (Ours)	✓	✓	✓	✓	$\mathbf{84.80_{0.01}}$
		✓	✓	✓	$84.25_{0.04}$
	✓		✓	✓	$84.74_{0.01}$
	✓	✓		✓	$84.77_{0.02}$
	✓	✓	✓		$82.58_{0.12}$
Baseline					$84.40_{0.00}$

Table 2: Ablation study results of 5 runs with random seeds. We study the impact of visual dependency disconnection (Visual Disc.), diversity loss (Diversity), not using positional encoding (w/o Pos.), and integration module with visual features (Integration).

5.2 Qualitative Analysis

In this section, we provide an in-depth qualitative analysis on visual examples where LLB successfully predicts.

Final Feature Distribution Figure 5 visualizes the final feature distribution generated from visual features (left) and non-visual features (right). In the left figure, we can find some visually similar features to be classified to semantically different labels. We trace the location of the sample (e.g. the screwdriver, quill, dough images with circle marker) in the right figure, but those samples are adjacent to the sample in the correct class. This outcome demonstrates that the label-focused inductive bias can effectively refine features towards their correct classes, and rectify incorrect decisions made on visually ambiguous samples.

Object Map on All Patches Figure 6 shows the examples of latent object indices mapped to each patch of an image via visual-feature based latent object extraction. We selected the samples

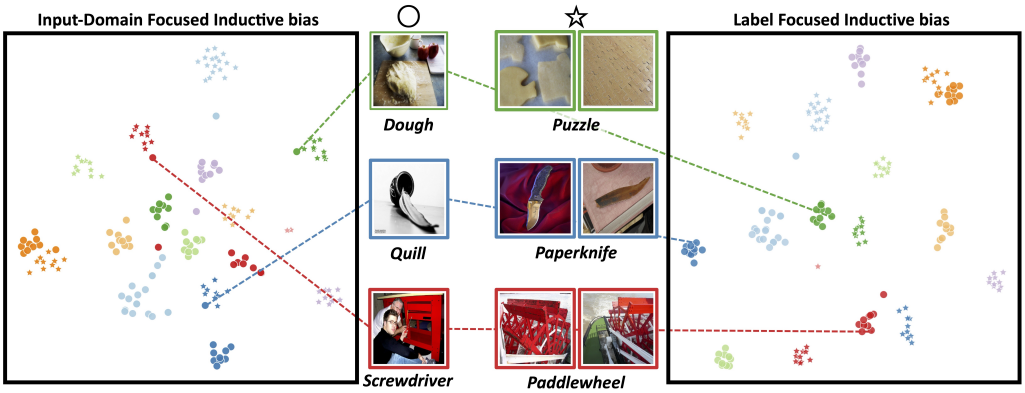
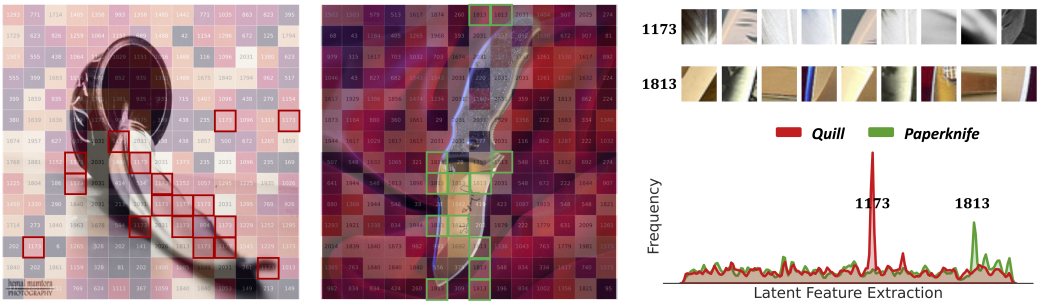


Figure 5: Final visual (*left*) and non-visual (*right*) feature for each sample. (color: a pair of two confused classes in visual feature based prediction, marker: one of the classes). Note that the circle sample is confused in visual feature map, but not in non-visual feature map.



(a) Latent object map extracted from its overlapping image (b) latent object frequency for each class

Figure 6: An example of extracted latent object distribution in a sample and over samples in each class. In (a), each tile shows an assigned latent object index of O(=2048) to an image patch. Red and green patches are dominating latent objects (1173 and 1813) in each image. (b) shows patch samples for the dominating objects and the frequency of the objects over all samples in each class.

that visual-feature based models are confused. In Figure 6a, we observe the object 1173 over the feather and some background in the quill image, while the image patches on the paper knife are assigned to the different object 1813. The two objects are distinct in the comparison of the other assigned image patches as shown in Figure 6b, and they are also identified as the most frequently used objects across all samples of the classes, serving as clear markers to distinguish between the classes. This finding suggests that latent objects derived from visual features inherently possess the capacity to differentiate their respective classes. However, the input-domain focused inductive bias locates patches of the objects closely, which confuses the prediction. In contrast, LLB disconnects the bias, and can leave the two objects as effective identifiers for correct classification. Additional object map results are in Figure 9 in Appendix.

6 Conclusion and Future Work

Conclusion In this paper, we highlighted the conflict of input-domain focused inductive bias and undescribed world knowledge over latent objects in human labeling. To advance regularization on this issue, we introduced *Label-focused Latent-object Biasing (LLB)* method that simply learns a separate classification model from intermediate object features disconnected from an input, and then integrates it with the original visual feature based classification model. Implementing the method on Vision transformer architecture, we can confirm its positive impact to model generalization through qualitative and quantitative analysis of its results in image classification tasks.

Future Work Beyond using the plug-in model, effectively harmonizing the undescribed world knowledge with input-domain focused bias on a simple network still remains an open question. Also, we hope that our approach will evoke further research on diverse visual domains.

7 REPRODUCIBILITY STATEMENT

We demonstrate the reproducibility statement for this paper as follows.

- For reproducibility of our *Label-focused Latent-object Biasing (LLB)*, we first demonstrate our method in Section 3. Also we provide details of our implementation in Section 4 and Appendix A.1.
- To reproduce our implementation, we provide codes for training our LLB using various backbone models. Implemented codes are included in the supplementary material. We also provide README.md file for detailed description in the supplementary material.

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A APPENDIX

A.1 IMPLEMENTATION DETAILS

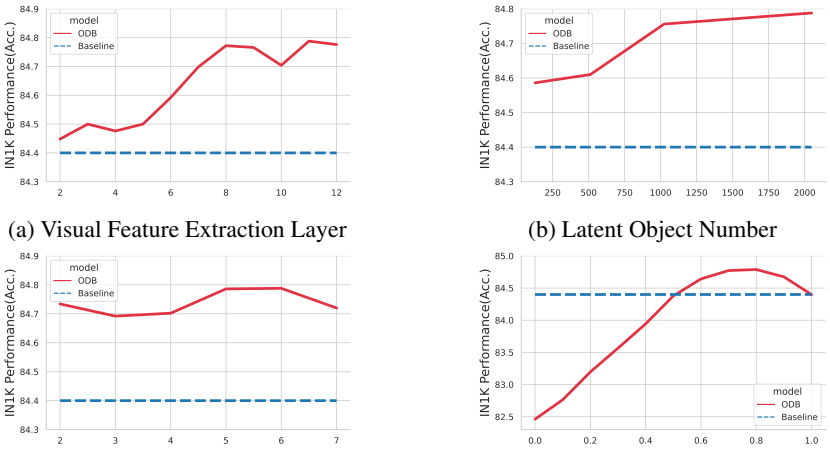
ViT architecture Our LLB is built upon pre-trained ViT backbones. We use ViT-Base and it's scaled version ViT-Large for LLB. Table 3 demonstrates detailed information about model variants. We follow the settings from (Dosovitskiy et al., 2020) for ViT parameters.

LLB stacks L_N layers of transformer layers to structure non-visual features. We report the impact of the number of layers on the LLB in Figure 7c, and selected values for L_N based on the results. Our LLB adds additional `MLP` layers for latent feature extraction and stacks transformer layers for non-visual feature structuring.For latent feature extraction, we use 2 layers of `MLP` with `ReLU` activation function.

	ViT				LLB					
Size	L_V	D	FF	H	L_N	D	FF	H	l_V	O
ViT-Base	12	768	3072	12	6	768	3072	12	11	2048
ViT-Large	24	1024	4096	16	6	1024	4096	16	23	2048

Table 3: Details of model variants

Hyper-parameter selection Depending on the input-domain and UWK in a task, the conflict may be cause by different numbers of objects in different layers. So we set the layer to extract the objects and their number as hyper-parameters for tuning by tasks. We also set the number of layers to structure non-visual and the value of α for integration as a hyper-parameter, and measured their influence on the IN1K classification task. The effective range of the hyper-parameters are shown in Figure 7a.



(a) Visual Feature Extraction Layer

(b) Latent Object Number

(c) Number of Structure Layer

(d) Integration Alpha

Figure 7: Impact of each hyper-parameter on IN1K image classification.

Training details We report our default training settings for IN1K image classification task in Table 4. For other evaluation benchmarks, only normalization values are changed. Table 5 reports the image classification performance on IN1K.

B ADDITIONAL QUALITATIVE ANALYSIS RESULTS

Object Clusters Figure 8 show successful examples of our latent object extraction. Each grid represents individual object cluster. We randomly sample clusters and clustered patches, and map them to the original image. For example, the second image in the first row has patterns like animal prints, and the second image in the second row has parts of fruit.

Setting	Value
Epochs	70
Batch size	1024
Optimizer	Adam (Kingma & Ba, 2014)
Optimizer Momentum	$\beta_1 = 0.9, \beta_2 = 0.999$
Learning rate:	
Schedule	Cosine
Peak	1e-4
Weight decay	5e-4
Loss	CrossEntropy
Augmentations:	
Size	224px or 384px
RandAugment (Cubuk et al., 2020)	
Magnitude	9
Normalize	
mean	[0.485, 0.456, 0.406]
std	[0.229, 0.224, 0.225]

Table 4: LLB training setting

Model	Pre.	Params (M)	Resolution Pre.	Resolution Fine.	Top1 (acc.) IN1K
ViT B/16	IN1K	86.57	224	224	79.00 (77.91)
+ LLB (Ours)	-	+46.45	224	-	79.43±.03
ViT B/16	IN21K	86.57	224	224	84.40 (83.97)
+ LLB (Ours)	-	+46.45	224	-	84.78±.01
ViT L/16	IN21K	304.33	224	224	85.68 (85.15)
+ LLB (Ours)	-	+80.80	224	-	85.92±.02
MAE B/16	IN1K	86.37	224	224	83.63 (83.60)
+ LLB (Ours)	-	+45.92	224	-	83.78±.02
MAE L/16	IN1K	304.33	224	224	86.08 (85.90)
+ LLB (Ours)	-	+80.80	224	-	86.12±.01
SWAG B/16	IB3.6B	86.37	224	384	85.28 (85.30)
+ LLB (Ours)	-	+45.92	224	-	85.35±.04

Table 5: Detailed top-1 accuracy on IN1K (accuracy in parenthesis: reference performance, red: positive, blue: negative).

Object Map on All Patches with Other Images Figure 9 show additional examples of object indices mapped to each patch of an image. In the mapped image in the *top* row, we found that patches of screwdriver are mapped to object 391 and the metal body patches are mapped to object 1736. From the frequency results in the right side, We can see that both feature are distinctive features for each class.

B.1 Empirical Analysis Results

We provide larger version of the visualization in Section 3.3.

C Additional Problem Confirmation and Comparison with LLB

Figure 11a from clearly shows the problem of the dominance of the visual-domain focused bias over the undescribed world knowledge over latent object in human labeling. The dots in the leftside figure represent the centroids of all features in each class of ImageNet, extracted from the ViT network trained on the data. When we zoomed in an area with closed centroids, we found five adjacent but semantically unrelated class labels, shown in the rightside.

We also confirm this problem with the Convolutional Neural Network (CNN). We follow the same procedure that is described in Section 3.1, but replace ViT with the well-known CNN network ResNet50 (Krizhevsky et al., 2017). We used two versions of ResNet50 pre-trained with ImageNet training data. First, we used the pre-trained ResNet50 (Krizhevsky et al., 2017) in a supervised manner. For supervised pre-trained ResNet50, we followed the details of (Krizhevsky et al., 2017)

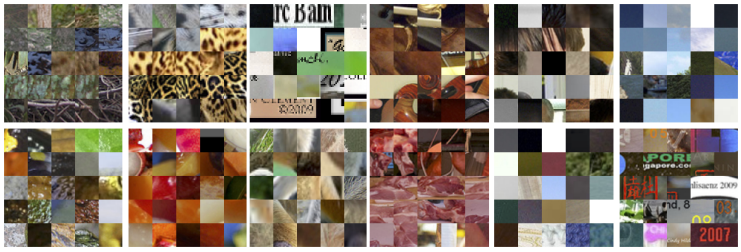


Figure 8: Positive examples of object latent clusters.

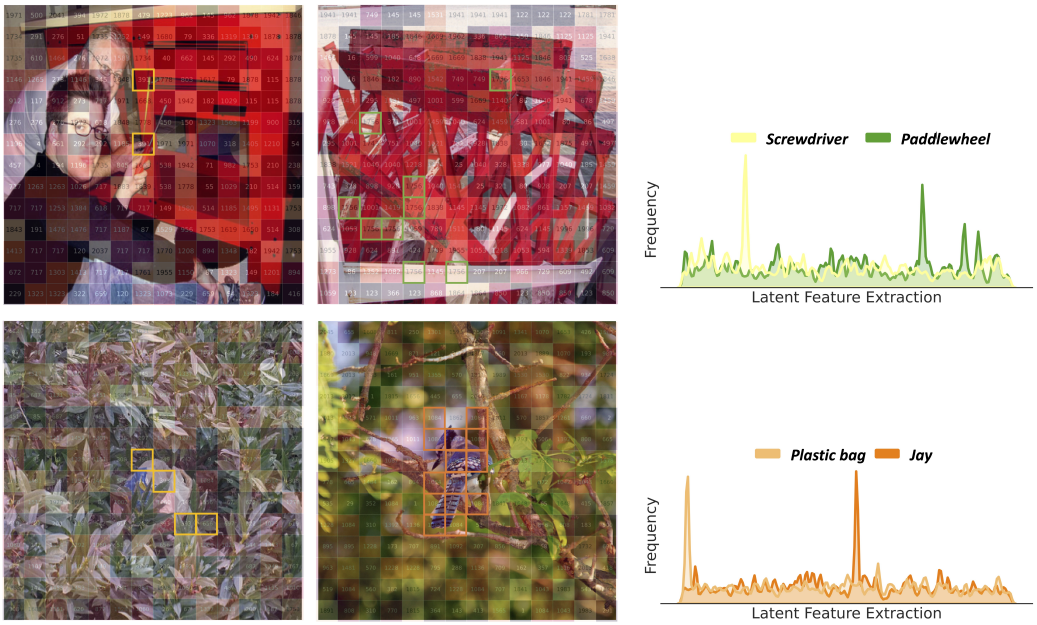


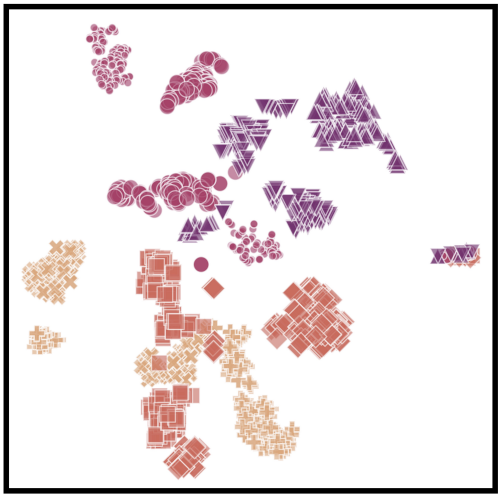
Figure 9: Additional example of object map on patches. In *left*, each tile shows an assigned object index to an image patch. *right* shows patch samples for the dominating objects and the frequency of the objects over all samples in each class.

and used parameters from open source[4] to reproduce a top-1 accuracy of 75.86% for IN1K (the reported performance from the open source is 76.13%). We also use ResNet50 pre-trained with self-supervised contrastive learning framework (Hadsell et al., 2006; Oord et al., 2018). Momentum Contrast (MoCo) (He et al., 2020) interpreted contrastive learning as dictionary look-up and built dynamic dictionaries with momentum-based moving average updates. MoCo v2 (Chen et al., 2020b) improved MoCo with the successes in (Chen et al., 2020a). We collected pre-trained ResNet50 weights using MoCo v2 from open source[5]. We then fine-tuned it using IN1K with the details described in (Chen et al., 2020b), and reproduced 77.01% top-1 accuracy in IN1K

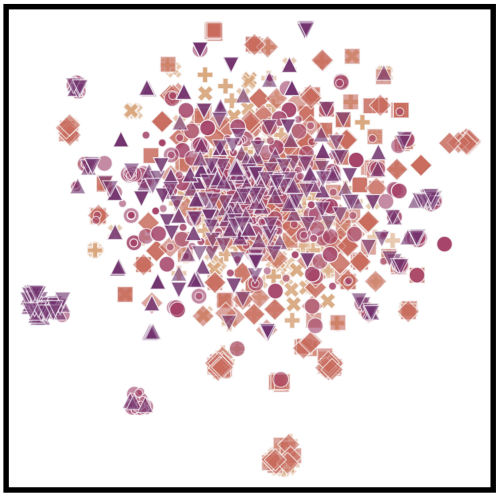
C.1 Input-Domain focused Bias in CNN

Figure 11c shows the results of CNN in the classification benchmarks. In comparison with the bias in ViT 11a, semantically distinct classes ('840: Mop', '462: Broom', '764: Puck', and '523: Crutch') are still closely located, which is the shared input-focused inductive bias of the dataset. This observation is an evidence for the conflict of the input-domain focused bias even in CNN.

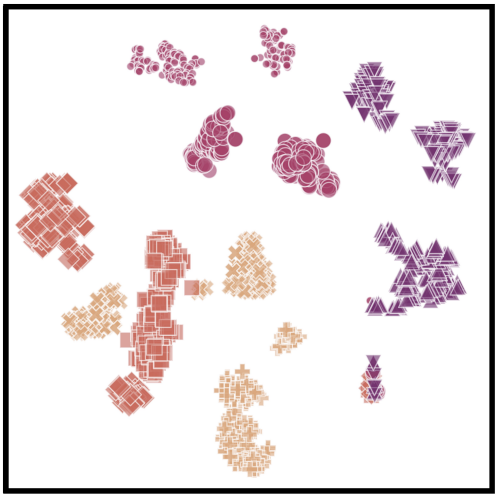
[4]ResNet50: https://pytorch.org/vision/main/models/generated/torchvision.models.resnet50.html
[5]MoCo v2: https://github.com/facebookresearch/moco/tree/main



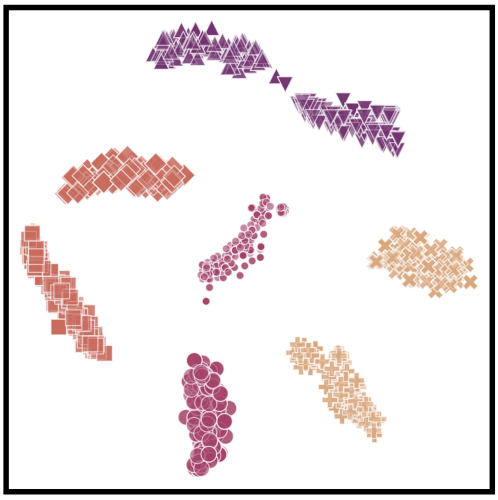
(a) Visual feature (Internal)



(b) Non-visual feature (Internal)



(c) Visual feature (Final)



(d) Non-visual feature (Final)

Figure 10: Feature distribution results.

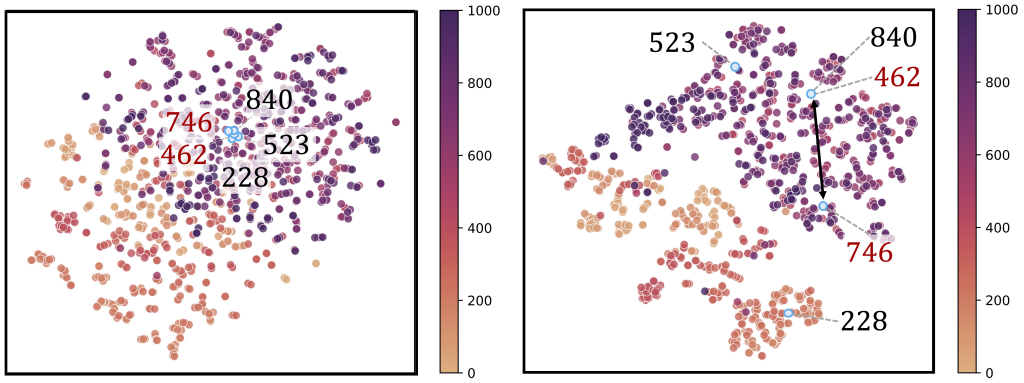
C.2 Input-Domain focused Bias in CNN with Contrastive Learning

Figure 11d shows the results of the CNN trained with contrastive learning. Using contrastive learning, the centroids of some classes (e.g. '523:Crutch' against '840: Mop', '462: Broom', '764: Puck') are slightly decoupled compared to supervised learning. However, this approach still fails to widen the gap between '462: Broom' and '746: Puck', where two class labels are visually similar in stick parts, but semantically distinguished by other objects. This observation shows that the input-domain focused bias still strongly used in determining the features.

C.3 Comparison with Label-focused Latent-object Biasing

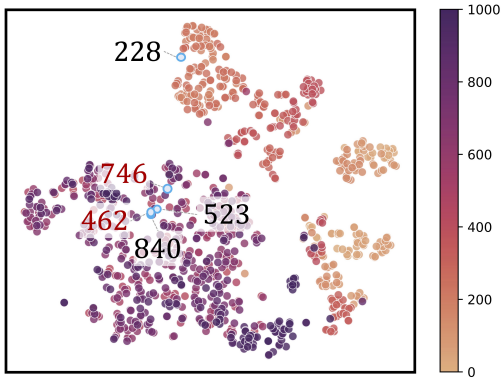
Figure 11b shows the results of LLB using the same classes in Figure 11e. Compared to ViT (Figure 11a), where the centroids of all features of five classes are closed located, LLB shows distant gaps between classes. Also, while other networks fail to widen the gap between '462: Broom' and '746: Puck', LLB placed them in a distant location.

Additionally, we can see that '840: Mop' and '462: Broom' are closed located in LLB. We hypothesise that, the way of structuring over components of mop and broom are similar, making LLB to generate their features in a close location. In contrast, the other methods placed '840: Mop' and '462: Broom' in relatively more distant locations. This observation implies that LLB can diminish the dominance of the visual input-domain focused bias, and introduce a distinct bias, regarded as the label-focused inductive bias.

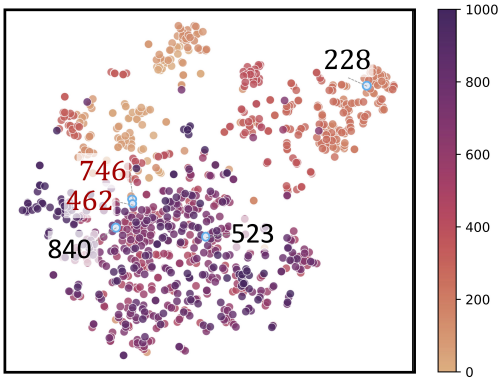


(a) ViT

(b) LLB (Ours)



(c) CNN with supervised pre-training



(d) CNN with contrastive learning

(e) Image Samples for Adjacent Classes

Figure 11: Comparison of the distribution of centroids of all features in each class of ImageNet. Centroids of all output features from ViT: (a), LLB (Ours): (b), CNN with supervised pre-training: (c), CNN with contrastive learning: (d). We highlighted the dots of five classes in (e) with sky-blue color.