

PART OF SPEECH MASKING EFFECT ON VISION-LANGUAGE REPRESENTATION LEARNING

by

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AUTHOR'S DECLARATION

I, Pasit Tiwawongrut, declare that the research work carried out for this thesis was in accordance with the regulations of the Asian Institute of Technology. The work presented in it are my own and has been generated by me as the result of my own original research, and if external sources were used, such sources have been cited. It is original and has not been submitted to any other institution to obtain another degree or qualification. This is a true copy of the thesis, including final revisions.

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ACKNOWLEDGMENTS

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ABSTRACT

Vision language (VL) models have shown promising performance across multiple tasks in both zero-shot and fine-tuning setups. Most studies use masked language modeling as a pre-training task, applying random masking to image caption tokens. However, random token masking is not an optimal strategy for training VL models, and effective masking strategies in VL remain underexplored. In this work, we investigate the effects of part of speech (POS) masking, as each POS category contributes differently to sentence meaning. By pre-training models with different POS masking strategies, we evaluate each model on image-text retrieval and visual question answering tasks, categorizing each question type following the VALSE. Our findings contribute to a deeper understanding of how POS masking influences model performance, providing insights that can lead to more effective pre-training strategies for future VL models.

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CHAPTER 1

INTRODUCTION

1.1 Background

Human beings describe and interpret the world through language, where each part of speech serves a distinct purpose: nouns ground entities, verbs express actions, and adjectives refine attributes. For example, we can easily imagine the scene described by the sentence “a dog chases a ball” because its words are organized into a structured form that maps directly onto real-world concepts. Motivated by this ability, researchers have developed Vision language (VL) models that aim to capture similar grounding by learning from large collections of paired images and text. These models attempt to bridge words and vision in the way humans naturally do.

One important training method in many VL models is masked language modeling (MLM), in which a random set of tokens is masked and the model must predict the masked tokens using both visual and textual information. Prior work has shown that effectiveness increases when the masked tokens are chosen to be semantically informative. For example, masking object words yields clear gains over random masking (Bitton, Stanovsky, Elhadad, & Schwartz, 2021); selectively masking infrequent words improves out-of-domain generalization during continued pre-training (Wilf et al., 2023); and curriculum-based masking reduces shallow reliance on local cues and promotes more consistent cross-modal interactions (Tou & Sun, 2024). These findings emphasize the importance of strategic token selection in MLM to enhance VL model performance and efficiency.

Despite the widespread adoption of MLM in VL training, the effects of masking tokens based on sentence structure remain underexplored. In this work, we aim to address the gap in understanding how masking each part of speech (POS) im-

pacts VL models. By selectively masking different parts of speech, we can better understand how each POS category affects the alignment between visual and linguistic information. This also allows us to probe what information the model can infer beyond the masked word itself, similar to how humans infer a missing word from surrounding context while simultaneously forcing human to understand the surrounding context. To further explore the effect of each POS, training without the MLM task and with different POS masking probabilities are compared.

The experiment is designed to answer the following questions:

1. How does masking each POS affect the performance and training loss of VL models during pre-training, and how does it influence downstream performance on visual question answering (VQA)?
2. What underlying representations do VL models acquire through MLM training, and does this process enable them to learn more than the masked word itself?
3. What is the difference between training without the MLM task compared to training with it, and when masking each POS with a 100 percent masking ratio?

1.2 Contributions

The main contributions of this thesis are summarized as follows:

1. We present a systematic study of POS masking strategies in VL pre-training, providing new insights into how each POS contribute to cross-modal alignment.
2. We benchmark the effects of different POS masking strategies across retrieval and visual question answering tasks, highlighting when and where specific linguistic categories are most influential.
3. We compare models trained with no MLM, standard random masking,

and 100% POS-specific masking, offering a deeper understanding of the effect of MLM in both retrieval task and VQA task.

4. The results provide valuable insights for designing more efficient and linguistically informed masking strategies in future VL systems.

1.3 Scope

The scope of this thesis is defined as follows:

1. The training and testing datasets are web-scale image–text pairs.
2. The scope is limited to cross-attention vision–language models trained with MLM, ITM, and ITC tasks, which are widely adopted objectives in modern VL pre-training.
3. This study concentrates on structured masking guided by parts of speech, specifically focusing on nouns, verbs, adjectives, adverbs, proper nouns, determiners, auxiliaries, pronouns, and adpositions.

CHAPTER 2

LITERATURE REVIEW

This section of the literature review is organized around two key topics relevant to our study. The first topic addresses VL models, providing an overview of the model architectures recently used in VL models and discussing the choice of the base architecture for the VL model used in this research. The second topic is MLM, an important pre-training approach that has improved VL model performance. Together, these sections provide a comprehensive overview of the methodological foundations of this study.

2.1 Vision-Language Representation Learning

VL learning aims to align visual and linguistic information for multimodal tasks that require reasoning across both modalities, such as image captioning, visual question answering, and multimodal retrieval. The training objective can be divided roughly into three main categories: contrastive, generative, and alignment. Firstly, the contrastive learning objective trains VL representations by maximizing the alignment score between paired images and text while minimizing the score between unpaired images and text (Radford et al., 2021; Jia et al., 2021; J. Yang et al., 2022). Secondly, the generative learning objective focuses on reconstructing masked tokens in either the image or text modality, or both, to learn VL representations (Singh et al., 2022; J. Li et al., 2021; Alayrac et al., 2022). This objective requires the model to utilize both modalities to reconstruct missing tokens, which enhances alignment. Lastly, the alignment objective involves learning VL representations by predicting whether an image and text pair match (Bao et al., 2022). The combined use of these three training objectives has proven effective and is commonly applied across various pre-trained VL models.

Recent advancements in VL fusion methods can be roughly categorized into three main approaches. The first approach is a separate unimodal encoder for each modality, as seen in models like CLIP (Radford et al., 2021) and ALIGN (Jia et al., 2021). This method is trained with the objective of aligning the intermediate outputs of each modality’s encoding. The second method uses a cross-attention layer to fuse multimodal inputs, e.g., Flamingo (Alayrac et al., 2022), LXMERT (Tan & Bansal, 2019), and ALBEF (J. Li et al., 2021). The cross-attention layer enables the model to fuse each modality more deeply. Finally, the third approach uses a single large attention model with concatenated image and text tokens as input, as in BEIT-3 (Wang et al., 2023), OSCAR (X. Li et al., 2020), UNITER (Chen et al., 2020), FLAVA (Singh et al., 2022), and mPLUG (C. Li et al., 2022). This approach allows for early-stage fusion of each modality, though it requires the highest amount of computational resources. In this work, we adopt the cross-attention method as the base model due to its effectiveness in fusing multimodal inputs. Additionally, this approach allows the model to be trained using the MLM task. We also use all three training objectives with a modified MLM for this experiment.

2.2 Masked Language Modelling

MLM is a widely used pre-training method in language model (LM) training (Devlin, Chang, Lee, & Toutanova, 2018; Lan, 2019; Yu et al., 2022; Zhang et al., 2022; Guu, Lee, Tung, Pasupat, & Chang, 2020) as a self-supervised task. BERT (Devlin et al., 2018) proposed MLM as a pre-training task, which has been proven effective for pre-training language models. The MLM task involves replacing some input tokens with a special [MASK] token, and the model must predict the masked tokens based on the given unmasked tokens. In the field of VL models, many VL models have also adopted MLM as a training task to train the model to predict masked text based on visual information (J. Li et al., 2021; C. Li

et al., 2022; Chen et al., 2020; Wang et al., 2023).

In the field of selective masking strategies in natural language processing, several works have further refined MLM to enhance training efficiency. ERNIE (Sun et al., 2019), SpanBERT (Joshi et al., 2020), and n -gram Masking (Levine et al., 2021) propose span masking instead of single-token masking, which forces the model to rely more on long-range dependencies rather than adjacent tokens, resulting in better performance compared to BERT (Devlin et al., 2018). Considering linguistic features, D. Yang, Zhang, and Zhao (2023) conducted a training analysis based on POS masking focused on LM training. The results showed that focusing the masking of non-function words, including ADJ, ADV, NOUN, PROPN, and VERB in the later stages of training can encourage the LM model to develop a better contextual understanding.

For selective masking in VL training, Bitton et al. (2021) introduced an object token masking strategy, selectively masking object tokens in image captions and pre-training the model. This approach achieved superior performance compared to random masking. Another study by Wilf et al. (2023) showed that selectively masking infrequent words from the pre-training dataset during continued training enhances model performance on out-of-domain datasets. Additionally, (Tou & Sun, 2024) proposed a curriculum-based masking strategy in which a reinforcement learning agent dynamically selects masking spans based on cross-modal interactions. This method improved the model’s multimodalities understanding while reducing the dataset size needed for effective training. In this work, we conduct experiments to analyze the impact of each POS on results within a VL setting.

CHAPTER 3

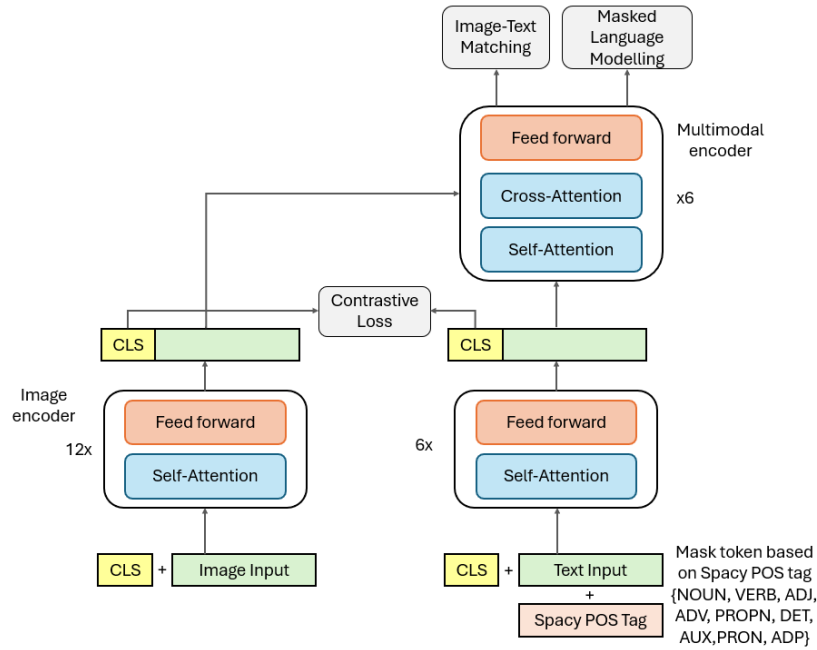
METHODOLOGY

In this chapter, the methodology is detailed as follows. First, we describe the architecture of the model. Second, we explain all pre-training loss functions used in this experiment. Third, the details of POS tagging are provided. Fourth, we outline the datasets used in this experiment. Lastly, we provide details on the visual question answering setup.

Figure 3.1

Overall methodology

Pre-training the model with a MLM task by masking tokens based on the POS in the image captions.



3.1 Model architecture

As shown in Figure 3.1, our model includes three main components: an image encoder, a text encoder, and a multimodal encoder. The first component is the image encoder, for which we use ViT (Dosovitskiy et al., 2021), modified following (Radford et al., 2021), as the image encoder in this experiment. The second component is the text encoder, which employs a transformer architecture as BERT (Devlin et al., 2018) to encode image captions with BERT tokenizer for tokenization. The final component is the multimodal encoder, where VL interactions occur.

Given a training dataset D consisting of image-text pairs $(I_i, T_i) \in D$, where I_i is the image and T_i is the image caption of the i -th image, each image is first encoded as a sequence of tokens $\{v_{cls}, v_1, \dots, v_n\}$ using ViT (Dosovitskiy et al., 2021). Here, v_{cls} represents the embedding of the [CLS] token prepended to the image patch sequence. In this experiment, the image encoder was initialized with ViT-B-32 pre-trained on ImageNet-21K (Deng et al., 2009). Next, we use a 6-layer transformer, randomly initialized, to encode the image caption T_i into text embeddings $\{w_{cls}, w_1, \dots, w_n\}$, where w_{cls} is the embedding of the [CLS] token. Finally, both text and image encodings are passed through the multimodal encoder to fuse both inputs, producing multimodal encodings. For the multimodal encoder, a cross-attention layer is used, where both keys and values are the image encodings, and the text encoding serves as the query in the cross-attention layer.

3.2 Pre-training Objectives

In this work, we pre-train our model with three objectives: masked language modeling (MLM), image-text contrastive learning (ITC) and image-text matching (ITM).

3.2.1 Mask Language Modelling

Typically, a percentage of tokens $\{w_1, \dots, w_T\}$ are replaced with a special [MASK] token to create a masked caption T^{mask} . However, in this work, the masked tokens were selected based on POS type instead of randomly masking. The model trained to predict the original tokens at the masked positions, conditioned on both the unmasked tokens in T^{mask} and the visual features of I as $p^{\text{mask}}(I, T^{\text{mask}})$. Let y^{mask} be a one-hot vector representing the ground-truth vocabulary for the masked token, where the masked token has a probability of 1. The model’s objective is to minimize the cross-entropy \mathbf{H} , given by:

$$\mathcal{L}_{\text{MLM}} = \mathbf{H}(y^{\text{mask}}, p^{\text{mask}}(I, T^{\text{mask}}))$$

For the masking ratio, each POS token is masked with either a 70 percent or 100 percent probability. In this work, random token masking was also tested with a masking ratio of 15 percent.

3.2.2 Image-Text Contrastive Learning

To improve each unimodal encoder’s representation, we used image-text contrastive learning to improve alignment of each modality. ITC aims to improve alignment by maximizing the similarity score of image and text from the same pair with the score function $s(I, T) = v_{cls}^\top w_{cls}$, and minimizing the similarity score of image and text not from its pair. We then calculate the softmax-normalized similarity score for each image to any text and each text to any image, identified as image-to-text $p^{i2t} \in \mathbb{R}^M$ and text-to-image $p^{t2i} \in \mathbb{R}^M$ scores as:

$$p_i^{i2t}(I) = \frac{\exp(s(I, T_i))/\tau}{\sum_{m=1}^M \exp(s(I, T_m)/\tau)}, \quad p_i^{t2i}(T) = \frac{\exp(s(T, I_i))/\tau}{\sum_{m=1}^M \exp(s(T, I_m)/\tau)}$$

where τ is a learnable temperature parameter. Let $y^{i2t}(I) \in \{0, 1\}^M$ and $y^{t2i}(T) \in \{0, 1\}^M$ be a ground truth with probability of 1 at a position of the same pair, and probability of 0 on the other hand. The ITC loss is calculated as cross-entropy \mathbf{H}

between p and y :

$$\mathcal{L}_{\text{ITC}} = \frac{1}{2}(\mathbf{H}(y^{i2t}, p^{i2t}) + \mathbf{H}(y^{t2i}, p^{t2i}))$$

3.2.3 Image-Text Matching

To further improve multimodal alignment in the VL model, image-text matching was employed to enhance alignment. The model is trained to predict whether an image and caption are from the same pair. A fully connected layer, followed by a softmax function, is added over the model. This layer takes the [CLS] embedding from the multimodal encoding as input to predict whether the pair is positive (matched) or negative (unmatched).

The loss function for ITM, using cross-entropy loss, is defined as:

$$\mathcal{L}_{\text{ITM}} = \mathbf{H}(y^{\text{itm}}, p^{\text{itm}}(I, T)),$$

where y^{itm} is a one-hot ground-truth label, and $p^{\text{itm}}(I, T)$ is the predicted class probability.

The full pre-training objective of our work can be written as:

$$\mathcal{L} = \mathcal{L}_{\text{MLM}} + \mathcal{L}_{\text{ITC}} + \mathcal{L}_{\text{ITM}}$$

3.3 Part Of Speech Masking

For each image caption, each token was classified into POS categories for masking. We used POS-tagging tools SpaCy¹ to classify each word into POS classes based on the Universal POS tag set². In this work, we modified the BERT tokenizer to integrate with SpaCy by using the Tokenizations³ tool to align BERT token IDs with SpaCy tokens IDs.

¹POS-tagging tool SpaCy: <https://spacy.io/>

²Universal POS tag set: <https://universaldependencies.org/u/pos/>

³Tokenizations alignment library tool: <https://github.com/explosion/tokenizations>

In this experiment, we explored the effect of each POS on VL learning in terms of performance, and training loss. For the main experiment, each token was assigned to one of nine POS categories: NOUN (nouns), VERB (verbs), ADJ (adjectives), ADV (adverbs), PROPN (proper nouns), DET (determiners), AUX (auxiliaries), PRON (pronouns), and ADP (adpositions), and masked with a 70% probability. For evaluation, these POS were further classified as functional (determiners, auxiliaries, pronouns, adpositions) or non-functional (nouns, verbs, adjectives, adverbs, proper nouns). For the 100 percent masking setting, where all tokens corresponding to a specific POS are masked, we conducted experiments on non-functional parts of speech.

3.4 Pre-Training Dataset

We pre-trained the model on the Conceptual Captions dataset (Sharma, Ding, Goodman, & Soricut, 2018) and the MSCOCO dataset, totaling 2.4 million image-text pairs. In Conceptual Captions dataset, an automated process was used to select, filter, and refine these image-caption pairs to ensure they are clear, informative, and suitable for effective model training.

3.5 Evaluation

In this work, we evaluated each model trained with different types of POS masking through image-text retrieval, image-text matching, and visual question answering tasks. Details of the evaluation methods and datasets used in these tasks are provided in this section.

3.5.1 Image-Text Retrieval

For the image-text retrieval, the model was tested by performing zero-shot evaluations on the Flickr30K (Plummer et al., 2015) dataset for both image retrieval (IR) and text retrieval (TR). The Flickr30K dataset is used to assess the model’s

overall performance in retrieval tasks. This setup allowed us to analyze how different POS masking strategies affect the model’s retrieval performance and the alignment between visual and textual representations.

3.5.2 Image-Text Matching

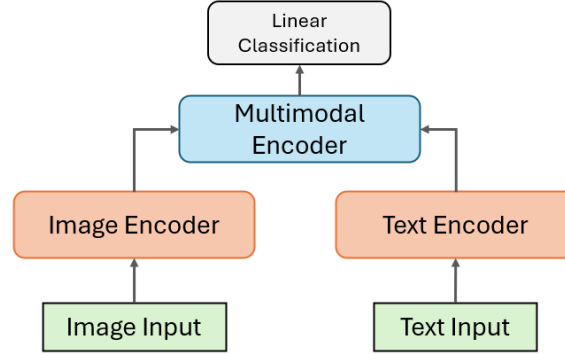
As demonstrated by Tou and Sun (2024), the results suggest that masking strategies impact a model’s ability to understand attributes, relationships, and word order. In this work, we benchmarked each pre-trained model with specific POS masking against VALSE benchmark (Parcalabescu et al., 2022). For the VALSE dataset, this benchmark categorizes each image-text sample into different linguistic phenomena as showed in Table 3.1, including six distinct types: existence, plurality, counting, relation, action, and coreference. Each image caption in the VALSE dataset also includes a ”Foil” version, where words related to each caption category are modified. This task is a classification task, where the model has to predict the correct caption for each image. We evaluated the model in a zero-shot manner by reusing the ITM head as a classifier. Evaluating models against this benchmark provides valuable insights into their semantic and contextual understanding of vision and language modality.

3.5.3 Visual Question Answering

In this work, the visual question answering (VQA) task was treated as a classification task. A classification head was appended to generate the answer, as shown in Figure 3.2. The benchmark dataset for the VQA task is the VQA2.0 dataset (Goyal, Khot, Summers-Stay, Batra, & Parikh, 2017), which is constructed using images from COCO (Lin et al., 2014). This dataset includes 83,000 images for training, 41,000 for validation, and 81,000 for testing. We further train our model using the VQA2.0 training set.

Figure 3.2

Visual question answering model architecture



3.6 Training

The model was pre-trained on a machine equipped with four NVIDIA A100 GPUs. The pre-training of the model was conducted using a batch size of 64 with 10 epochs. We used the AdamW optimizer with an initial learning rate of 1×10^{-4} and a weight decay of 0.02 to help regularize the training process. A cosine learning rate scheduler was applied, with the learning rate gradually increasing from a warm-up value of 1×10^{-5} during the first 5 epochs, before decaying towards a minimum learning rate of 1×10^{-5} by the end of training.

For the VQA task, the model was trained with a batch size of 32 on the same machine as pre-training. We used the AdamW optimizer with a learning rate of 2×10^{-5} and a weight decay of 0.02. A cosine learning rate scheduler was applied over 8 epochs, with a warm-up phase of 1 epoch starting at a learning rate of 1×10^{-5} , and decaying to a minimum of 1×10^{-6} .

VALSE Task	Test	Example
Existence Quantifier	Detect object presence or absence	“A cat on bed” vs. “A dog on bed”
Plurality Number	Singular vs. plural	“One flower” vs. “Some flowers”
Counting Balanced	Count with equal samples per class	3 apples vs. 5 apples
Counting Adversarial	Test for small-number bias	counts ≥ 4 vs counts 0–3
Counting Small Numbers	Count small numbers only	counts < 4
Spatial Relation	Understand positions	“Book on table” vs. “Book under table”
Action Replacement	Correct action	“Holding ball” vs. “Throwing ball”
Actant Swap	Correct roles	“Boy chases dog” vs. “Dog chases boy”
Coreference Standard	Pronoun–Entity Relation Understanding (from test set)	“Woman talks to girl. She smiles.”
Coreference Hard	Coreference Standard (from val set)	“Boy hugs dog. He is happy.”
Foil-COCO	Spot small caption error	Correct vs. nearly identical with one mistake

Table 3.1

VALSE dataset task explanations.

CHAPTER 4

Results

This chapter presents all the experiment results for each experiment and evaluation, aimed at addressing the research questions. The results are divided into four sections, including pre-training, image-text matching, visual question answering, and the evaluation result of varying the POS masking percentage.

4.1 Pre-training

To address the question of how masking each POS affects the performance and training loss of vision-language (VL) pre-training models, we present all relevant results in this section. All losses, including MLM, ITC, and ITM, along with the Flickr30K evaluation results, are provided. The loss values are plotted on a logarithmic scale to visualize improvements over time across different POS masking strategies. The results from training the ALBEF model using the same dataset are also included for consistent comparison. We also provided the histogram of each part-of-speech tag in the pre-training dataset as shown in Figure 4.4.

4.1.1 Flickr30K

The Flickr30K evaluation results are shown in Table 4.1, which presents the top-1, top-5, and top-10 retrieval scores for both image-to-text (i2t) and text-to-image (t2i) tasks across different training methodologies. By comparing r@1 performance for both TR, and IR, the model with determiner masking achieves the highest overall performance. Among the non-functional group, masking NOUN yields the best performance. By masking ADV and PROPN causes the most significant degradation compared to the random masking baseline.

From the training loss curves, it is evident that different POS categories affect

Masking Method		Flickr30K					
		TR			IR		
		r@1	r@5	r@10	r@1	r@5	r@10
ALBEF		70.40	89.50	94.00	54.66	82.02	88.70
Random Masking		67.00	88.00	93.75	52.61	80.14	87.76
Non-function	NOUN	67.15	88.60	94.65	52.73	80.45	87.79
	VERB	54.85	82.85	90.05	43.82	73.84	82.82
	ADJ	62.30	87.30	92.40	47.39	75.47	84.06
	ADV	46.85	76.25	85.75	36.40	66.38	76.78
	PROPN	44.85	74.40	84.10	34.91	64.09	75.01
	DET	71.05	92.00	95.30	56.01	81.93	88.59
Function	AUX	52.10	79.60	88.20	41.13	70.92	80.68
	PRON	51.45	78.80	87.10	39.97	69.58	79.32
	ADP	65.05	88.25	93.40	51.19	78.83	85.15

Table 4.1

Flickr30K benchmark image retrieval result.

the convergence behavior in difference ways. The loss for MLM, ITC, and ITM are displayed in the Figure 4.1, Figure 4.2, and Figure 4.3 respectively For both ITM and ITC, the loss curves are similar in behavior and follow a consistent order relative to each other. In the MLM loss graph, we can see that POS masking in the functional group result in lower loss, while those in the non-functional group show higher loss, and the random masking show the highest loss by the end of training.

Taken together, the results show that masking each POS impacts both the training loss trajectory and final model performance in distinct ways. By observing the MLM loss graph, we find that non-functional POS are more difficult for the model to learn through the MLM task, whereas functional POS are learned more quickly. The ranking of the performance for each POS masking method aligns with the ITM and ITC loss curves, where a lower loss corresponds to higher retrieval accuracy.

Figure 4.1

MLM loss curves for different POS masking strategies (log scale).

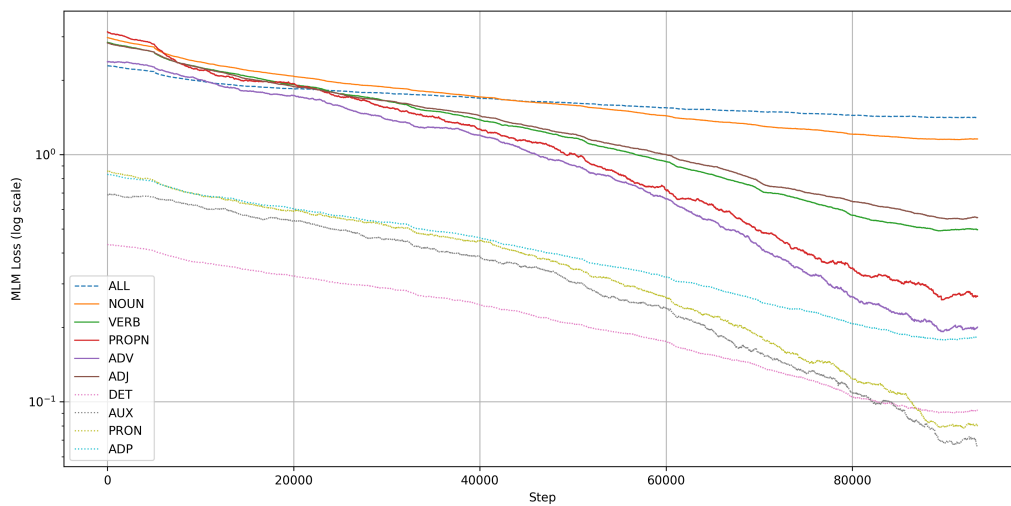


Figure 4.2

ITC loss curves for different POS masking strategies (log scale).

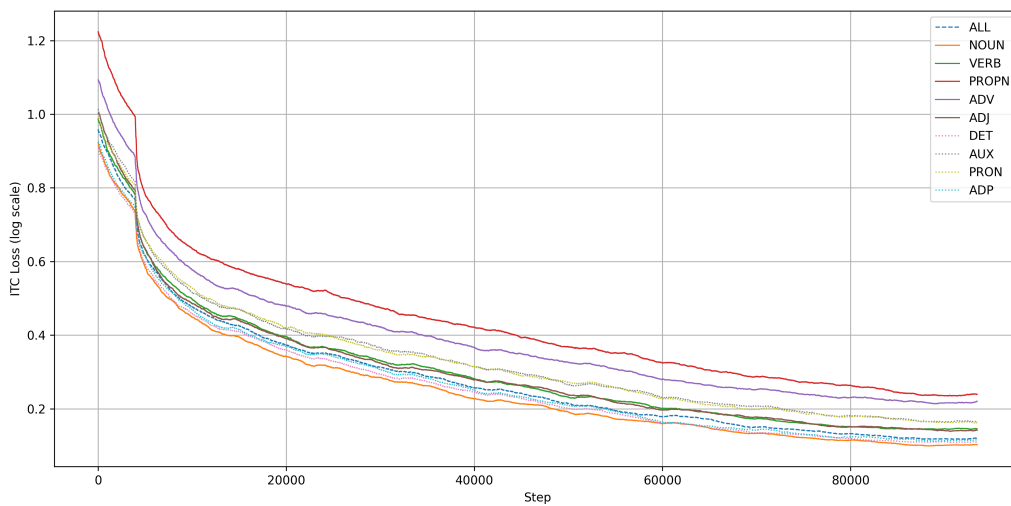
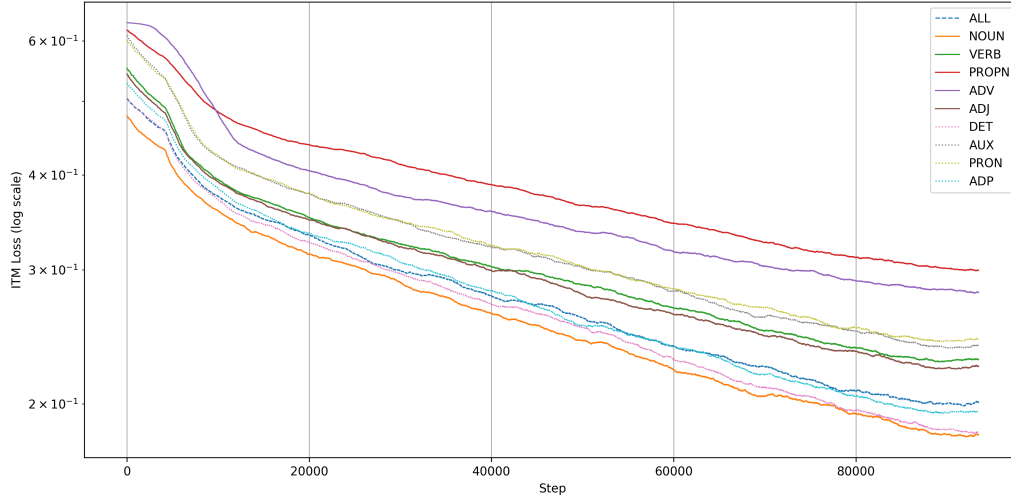


Figure 4.3

ITM loss curves for different POS masking strategies (log scale).

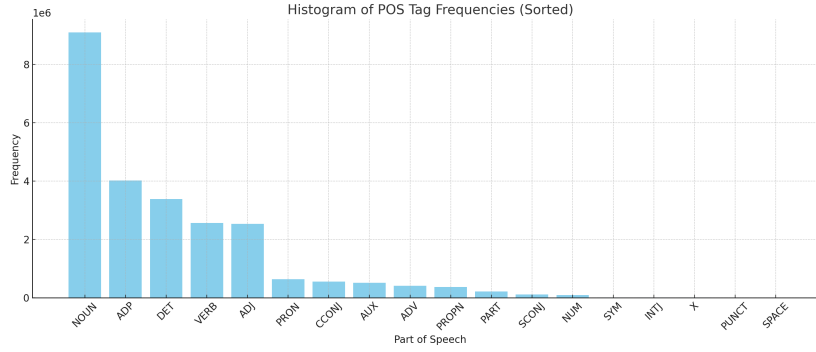


4.1.2 Histogram of POS tag

This section provides a visualization of tokens categorized by their POS from the training dataset, as shown in Figure 4.4. The histogram illustrates the frequency distribution of POS tags, sorted from the most to least common. NOUN tokens dominate the dataset, followed by ADP, DET, VERB, and ADJ, while categories such as SYM, INTJ, X, PUNCT, and SPACE appear rarely in the training dataset.

Figure 4.4

Histogram of POS tag frequencies in the training dataset (sorted by frequency).



4.2 Image-Text Matching

In this section, we evaluate the impact of POS masking on image-text matching by reporting zero-shot classification accuracy on the VALSE benchmark with a random masking method as a baseline. This experiment is designed to investigate whether the model acquires knowledge not only of the masked word itself but also of surrounding word elements, such as adjacent nouns, adjectives, and contextual relations.

4.2.1 VALSE

Table 4.2 summarizes zero-shot classification accuracy on the VALSE benchmark for each POS masking strategy. For completeness, we include the results of training without any masking, which serves as a reference point. Random masking is treated as the baseline, and for clarity, the best-performing method in each task (excluding the baseline) is highlighted in green, while the second-best method is highlighted in yellow. If random masking achieves the highest score, the corresponding result is underlined. This visualization allows us to focus on the relative contributions of different POS categories without being overshadowed by the random masking baseline.

The results reveal that different parts of speech contribute most strongly to tasks that align with their linguistic functions, while also offering useful cues beyond their primary roles. NOUN masking not only achieves the strongest performance on object-centric tasks such as existence task, but also shows competitive results on counting and action tasks. VERB masking, as expected, performs well on action task, but it also improves performance on counting task. Similarly, adjective masking achieves strong results on counting task. By contrast, PROPEN masking underperforms in many tasks.

For the function POS group, we observe that DET masking perform the best overall, achieving the highest scores in plurality, counting, and Foil-it! tasks, while also showing competitive performance in spatial relation task. AUX masking yield the strongest results on coreference tasks and additionally perform on counting. PRON also contribute most effectively to coreference. ADP, on the other hand, achieve their best results on action actant swap task.

When comparing the best-performing POS masking results against the no-masking baseline, we find mixed outcomes. Existence Quantifier shows no significant improvement through masking, while Plurality experiences a modest drop of 1.61. In contrast, Counting tasks benefit substantially, with gains of 1.12%, 4.74%, and 7.74% for the Balanced, Small Number, and Adversarial sub-tasks, respectively. Spatial Relation shows only a minor decrease of 0.58%, while Action Replacement improves by 2.44% but Actant Swap drops slightly by 0.45%. Coreference tasks improve by approximately 3%, whereas Foil-it! shows no significant difference.

Masking Method	Existence quantifiers	Plurality number	Counting			VALSE		Action		Coreference		Foil-it!	Avg
			balanced	small number	adversarial	Sp.Re ¹ relations	replacement	actant swap	standard	clean			
Random Masking	65.06	61.43	54.64	57.81	62.83	61.61	68.04	51.88	49.70	43.37	85.79	60.20	
Non-function	NOUN	67.63	62.60	52.59	54.64	64.39	59.84	68.15	48.87	51.31	49.21	85.69	60.45
	VERB	60.37	60.50	54.83	56.30	61.52	57.68	68.24	48.62	51.31	42.40	83.45	58.66
	ADJ	60.85	60.55	54.00	56.84	67.01	57.68	65.68	50.92	50.34	44.74	83.01	59.24
	ADV	62.56	58.74	53.08	57.32	59.92	58.10	65.74	49.11	49.04	41.30	84.28	58.11
	PROPN	61.51	59.23	52.49	56.25	61.26	55.86	64.31	50.85	50.36	43.03	82.62	57.98
Function	DET	60.14	63.33	53.47	57.86	65.40	59.06	66.67	50.43	50.09	38.99	87.94	59.40
	AUX	56.73	60.60	51.76	57.32	60.59	56.48	65.04	50.65	49.33	51.39	84.62	58.59
	PRON	56.05	61.33	50.39	54.88	58.87	58.93	64.36	48.05	53.23	50.48	83.40	58.18
	ADP	66.27	61.23	53.52	57.03	66.04	58.28	67.73	52.14	50.05	46.13	86.38	60.44
No Masking	67.61	64.94	53.71	53.12	59.27	60.42	65.8	52.59	50.47	48.31	87.60	60.35	

Table 4.2
VALSE benchmark for image-text matching result.

4.3 Visual Question Answering

Table 4.3 presents the VQA2.0 test-dev performance after fine-tuning on the VQA task for each POS masking strategy, with results reported for Yes/No, Number, and Other question types. NOUN masking achieved the highest overall accuracy (70.29%), closely followed by random masking (70.28%). Within the non-functional group, NOUN masking performed best, while VERB (69.13%) and ADJ (69.09%) achieved similar scores. ADV masking yielded the lowest performance (64.12%), largely due to reduced accuracy in the Number and Other categories. For functional categories, DET and ADP masking achieved similar overall results (68.98% and 68.96%), with AUX (67.09%) and PRON (66.55%) performing lower. Comparing the best-performing non-function and function POS masking strategies shows a performance difference of 1.31%.

¹ Spacial Relation

Masking Method	Yes/No	VQA2.0 test dev		
		Number	Other	Overall
Random Masking	87.88	49.64	59.63	70.28
NOUN	87.84	49.49	60.03	70.29
Non-function VERB	87.17	48.39	58.43	69.13
Non-function ADJ	86.69	48.86	58.64	69.09
Non-function ADV	83.10	43.83	52.49	64.12
Non-function PROPN	85.07	46.38	56.60	67.71
Function DET	87.35	49.49	57.68	68.98
Function AUX	85.25	46.59	56.24	67.09
Function PRON	84.13	46.29	56.15	66.55
Function ADP	87.07	48.82	58.07	68.96

Table 4.3

VQA2.0 test-dev benchmark result.

4.4 Masking Ratio

In this experiment, we report the effect of masking probability on both the Flickr30K and VQA benchmarks by comparing 0%, 70%, and 100% masking levels. For Flickr30K, we focus on exploring POS masking for non-functional POS categories, as shown in Table 4.4. For the VQA task, we compare NOUN masking—identified as the best-performing strategy on VQA, as shown in Table 4.5.

For the Flickr30K benchmark, we observe that the no-masking method outperforms models trained with the MLM objective. Specifically, it achieves a 7.45%, and 5.31% improvement in TR and IR r@1, respectively, compared to NOUN masking with 70% masking probability, which is the best among the masking-based methods. We also observe performance improvements when increasing the masking probability for VERB, ADV, and PROPN categories. On the other hand, performance deteriorates as masking probability increases for NOUN and ADJ masking.

For the VQA results, models trained with the MLM objective consistently outperform those trained without masking, showing an average improvement of approximately 2% in overall accuracy. The improvement occurs most significantly

on the Other question type, improving by 2.81% and 2.60% for NOUN masking at 70% and 100% masking probabilities, respectively. Under NOUN masking, increasing the masking probability to 100% results in slight improvements for the Yes/No and Number question types, while performance slightly declines for the Other category.

Masking Method	Masking probability	Flickr30K					
		TR			IR		
		r@1	r@5	r@10	r@1	r@5	r@10
No Masking	0	74.60	92.50	95.90	58.04	83.82	90.04
NOUN	70	67.15	88.60	94.65	52.73	80.45	87.79
	100	65.80	90.40	94.90	53.34	78.94	86.72
VERB	70	54.85	82.85	90.05	43.82	73.84	82.82
	100	56.70	83.40	90.70	44.52	74.24	83.52
ADJ	70	62.30	87.30	92.40	47.39	75.47	84.06
	100	62.20	87.30	92.50	47.08	75.78	84.22
ADV	70	46.85	76.25	85.75	36.40	66.38	76.78
	100	50.10	78.80	87.90	37.74	67.78	78.00
PROPN	70	44.85	74.40	84.10	34.91	64.09	75.01
	100	49.10	78.30	85.90	36.06	66.88	77.22

Table 4.4
Flickr30K benchmark image retrieval result.

Masking Method	Masking Probability	VQA2.0 test dev			
		Yes/No	Number	Other	Overall
NOUN	70	87.84	49.49	60.03	70.29
NOUN	100	87.88	49.81	59.82	70.24
No Masking	0	87.42	49.43	57.22	68.78

Table 4.5
VQA2.0 test-dev benchmark result.

CHAPTER 5

DISCUSSION

This chapter discusses the result of our experiments and reflects on their implications in relation to the main research questions: How does masking each POS affect the performance and training loss of VL models during pre-training, and how does it influence downstream performance on visual question answering (VQA). We begin by analyzing how masking different POS affects model performance during pre-training and downstream evaluation, with a focus on the linguistic relevance of each POS category. We then examine what the model learns beyond the masked word itself, exploring whether POS-aware masking encourages deeper contextual understanding. This is followed by a comparison between POS-based, random, and no-masking strategies to assess the overall contribution of masked language modeling (MLM) in vision–language (VL) training. Finally, we discuss the broader implications of our findings, highlight the limitations of our approach, and suggest directions for future work.

5.1 The Effect of Each POS in Visual Pre-training and Downstream Task

Our experimental findings highlight that masking different POS during pre-training leads to distinct outcomes. On the Flickr30K benchmark, DET masking achieved the highest retrieval performance across both TR and IR tasks, followed by NOUN masking among the non-functional POS group. Intuitively, one might expect nouns typically carrying more semantic should outperform determiners. However, the results reveal the opposite, suggesting that determiners are easier for the model to learn. When combined with the loss curves, we observe that retrieval performance correlates more closely with the ITM and ITC objectives than with the MLM task. The ranking of each POS masking method aligns with the ITM and

ITC loss curves, where lower loss corresponds to higher retrieval accuracy. This suggests that for retrieval tasks, masking simpler tokens such as determiners may reduce the burden on the MLM task and ultimately lead to better performance. We find that POS masking strategies which produce lower ITM and ITC losses during pre-training tend to yield stronger retrieval performance.

In contrast, the VALSE benchmark evaluates the model’s fine-grained linguistic understanding. Here, we find that selectively masking specific POS categories consistently outperforms random masking, and that each POS masking strategy also performs well on tasks related to its corresponding linguistic function. This indicates that the MLM objective plays a more substantial role in tasks requiring fine-grained understanding, and that performance is highly sensitive to which tokens are masked. These results highlight the importance of strategic token selection in enhancing the model’s fine-grained performance.

Similarly, in the VQA task, we observe that even some POS categories that performed poorly in retrieval still enable the model to retain fine-grained image understanding. Specifically, most non-functional POS lead to better performance compared to functional POS. This result emphasizes that masking more content words leads to better fine-grained alignment. When compared to training without masking, models trained with the MLM objective demonstrate clear improvements, suggesting that MLM facilitates the learning of detailed visual–linguistic representations critical for question answering.

5.2 Limitations

One limitation of this study is the imbalance in POS distribution, as observed in the POS histogram. Certain POS categories, such as nouns, appear far more frequently than others, which may introduce bias in the model’s learning process and affect the generalizability of the results. While this imbalance reflects the natural distribution of language in real-world datasets, it may confound our interpretation

of how each POS contributes to VL learning. Additionally, our experiments are limited to a specific set of benchmarks; evaluating the effects of POS masking across a broader range of datasets would be necessary to confirm the consistency and robustness of the observed phenomena.

CHAPTER 6

CONCLUSION

6.1 Conclusion

6.2 Future work

- Scalability for when combine with each pos - Compare with another method.

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