MGPATH: A VISION-LANGUAGE MODEL WITH MULTI-GRANULAR PROMPT LEARNING FOR FEW-SHOT WHOLE SLIDE PATHOLOGY CLASSIFICATION

Anh-Tien Nguyen Institut für Predictive Deep Learning for Medicine and Healthcare
Justus-Liebig-Universität Gießen
Gießen 35392, Germany

Duy H. M. Nguyen & Nghiem T. Diep & Trung Q. Nguyen & Daniel Sonntag
German Research Center for Artificial Intelligence (DFKI)
Kaiserslautern 67663, Germany

Nhat Ho
The University of Texas at Austin
Austin, TX 78712, United States

Jacqueline M. Metsch & Miriam C. Maurer & Hanibal Bohnenberger
University Medical Center Göttingen
Göttingen 37075, Germany

Anne-Christin Hauschild
Institut für Predictive Deep Learning for Medicine and Healthcare
Justus-Liebig-Universität Gießen
Gießen 35392, Germany
anne-christin.hauschild@uni-giessen.de

ABSTRACT

In this study, we *propose a prompt learning method* that adapts large vision-language models for few-shot pathology classification. Starting with the Prov-GigaPath foundation model - pre-trained on 1.3 billion pathology image patches - *we extend it into a vision-language model by adding adaptors* and aligning it with medical text encoders via contrastive learning on 923K image-text pairs. In contrast to previous approaches that combine prompts with frozen features using prefix embeddings or self-attention, *our multi-granular attention mechanism* evaluates interactions between learnable prompts, individual image patches, and patch groups, capturing both fine details and broader context. We further enhance accuracy with an unbalanced optimal transport-based visual-text distance that mitigates pertubations from data augmentation. Experiments on lung and kidney pathology imaging modalities show that our method outperforms state-of-the-art competitors and improves performance across various architectures, including CLIP, PLIP, and the Prov-GigaPath integrated PLIP.

1 INTRODUCTION

Whole slide images (WSIs) provide high-resolution views of tissue samples and are the gold standard for cancer diagnosis. However, they can contain billions of pixels, making annotation and interpretation costly. Obtaining sufficiently large, annotated datasets is also challenging, which has spurred the development of few-shot and weakly supervised methods-especially multiple instance learning (MIL). Yet, MIL can struggle to capture meaningful regions in complex tissue structures.

Visual language models (VLMs) Lu et al. (2023); Huang et al. (2023); Ikezogwo et al. (2024) address this by integrating slide-level features and textual descriptions. Although effective, these approaches face three issues: (i) frozen features and basic attention overlook multi-granular interactions; (ii) reliance on architectures like CLIP Radford et al. (2021), which is not trained on pathology data; and (iii) the typical use of cosine similarity, which can fail with multiple prompts or augmentations.

We introduce MGPath, a VLM tailored for whole-slide pathology classification. First, we extend Prov-GigaPath—pre-trained on 1.3 billion pathology patches—into a vision-language model via contrastive learning with the PLIP text encoder Huang et al. (2023), itself trained on 200K pathology image-text pairs. We strengthen alignment using 923K additional image-text pairs from `ARCH`, `PatchGastricADC22`, and `Quilt-1M`, training only lightweight adaptors. Next, multi-granular prompt learning represents multi-scale patches in a spatial graph, and learnable prompts interact with these hierarchical tokens via a specialized attention mechanism. Finally, optimal transport (OT) robustly aligns visual embeddings with diverse text prompts, adapting to augmentations and modeling partial alignments. Experiments on lung and kidney benchmarks confirm consistent improvements over 14 state-of-the-art MIL and VLM methods. Notably, MGPath surpasses `CONCH` Lu et al. (2024) and `QUILTNET` Oluchi Ikezogwo et al. (2023) by about 6% accuracy on the same dataset.

2 Related Works

Recent progress in large-scale pre-trained pathology models has split into two main categories. Vision models (e.g., `Virchow` Ikezogwo et al. (2024), `Hibou` Nechaev et al. (2024), `UNI` Chen et al. (2024), `Prov-GigaPath` Xu et al. (2024)) learn robust representations from massive datasets, with `Prov-GigaPath` (1.3B patches) leading at high-resolution detail. Vision-language models (VLMs) (e.g., `PLIP` Huang et al. (2023), `CONCH` Lu et al. (2024), `QUILTNET` Ikezogwo et al. (2024)) integrate textual context for enhanced slide interpretation. In parallel, multiple instance learning (MIL) treats a WSI as a "bag" of patches, but pooling-based methods (mean/max) can dilute rare disease signals. Attention-based MIL, GNNs, and Transformer-based approaches Lu et al. (2021); **?**); Ilse et al. (2018); Li et al. (2021); Shao et al. (2021); Zheng et al. (2022) have been explored to better highlight relevant regions. Meanwhile, VLMs leverage contrastive learning to align images and text, and some employ multi-magnification images plus multi-scale text prompts Shi et al. (2024); Han et al. (2024). Building on these ideas, our `MGPath` leverages a large pre-trained pathology VLM and introduces parameter-efficient multi-granular prompt learning to adapt to few-shot settings.

Prompt tuning is key to adapting large pre-trained models, as seen in multimodal systems like CLIP. Instead of handcrafted templates, methods such as `CoOp` Zhou et al. (2022b), `CoCoOp` Zhou et al. (2022a), and `MaPLe` Khattak et al. (2023) learn prompts for domain generalization Ge et al. (2023); Yao et al. (2024), knowledge prototypes Zhang et al. (2022b); Li et al. (2024), or diversity Lu et al. (2022); Shu et al. (2022). However, these focus on natural images rather than the multi-scale, structurally complex data in WSIs. While some works Shi et al. (2024); Qu et al. (2024) apply prompts via self-attention to frozen features, they can miss intricate tissue structures. By contrast, our multi-granular prompt learning framework applies attention to both individual patches and spatial groups, better aligning with WSIs' hierarchical complexity.

3 Method

3.1 Bridging Pathology Visual and Text Encoders

To leverage `Prov-GigaPath`'s pre-trained visual features, we implement lightweight adaptors that map patch-level image features into the embedding space of the `PLIP` text encoder. These adaptors enable joint image-text training with minimal parameter updates, since only the adaptor weights are fine-tuned.

Given pathology image-text pairs $\{(\mathbf{I}_i, \mathbf{T}_i) | \, i = 1, 2.., N\}$, let $E_I(.)$ be the `Prov-GigaPath` vision encoder for patch-level features, and $E_T(.)$ the `PLIP` text encoder. For each batch of size B, the image and text embeddings are $\mathbf{x}_i = E_I(\mathbf{I}_i) \in \mathbb{R}^{d_v}$, $\mathbf{t}_i = E_T(\mathbf{T}_i) \in \mathbb{R}^{d_t}$.

We then design two trainable adaptors, $A_I(.)$ and $A_T(.)$, to project $(\mathbf{x}_i, \mathbf{t}_i)$ into a shared dimension $\mathbb{R}^d$, optimizing the noise contrastive loss Oord et al. (2018):

$$\mathcal{L}_{con} = \mathbb{E}_B \left[-\log \frac{\exp\left(\cos(A_I(\mathbf{x}_i), A_T(\mathbf{t}_i))/\tau\right)}{\sum_j \exp\left(\cos(A_I(\mathbf{x}_i), A_T(\mathbf{t}_j))/\tau\right)} \right], \tag{1}$$

where $\cos(.)$ is the cosine similarity, and τ denotes for temperature of the softmax function. Both the `Prov-GigaPath` vision encoder and the `PLIP` text encoder remain frozen, while only $A_I(.)$ and $A_T(.)$ are trained. Once Eq. equation 1 is optimized, the adaptor outputs serve as visual and text embeddings for downstream tasks. We refer to this model as `GigaPath-PLIP`.

3.2 Multi-Magnification Descriptive Text Prompts

Designing effective text prompts is crucial for enhancing vision-language models (VLMs) in whole-slide image (WSI) analysis. Pathologists typically assess WSIs by first examining tissue structures at low magnification, then zooming in to observe finer details such as nuclear shape and size. Recent works Shi et al. (2024); Han et al. (2024) have harnessed this multi-scale approach by introducing dual-scale descriptive text prompts, yielding considerable gains in classification performance. Building on this idea, we further refine and extend the strategy to boost model effectiveness. The prompt template is described in the appendix section.

At each low/high scale, rather than inserting a single learnable text prompt of length K alongside a frozen contextual prompt from large language models (LLMs) Shi et al. (2024); Han et al. (2024), we propose using M learnable prompts. This strategy captures different sub-regions or structural features within each patch that might be missed by a single prompt. Specifically, we define visual descriptive text prompts for both low- and high-resolution scales as follows:

$$\begin{aligned} \mathbf{T}_i^{(l)} &= \left\{ \left([\omega_i^{(l)}]_1 \, [\omega_i^{(l)}]_2 \ldots [\omega_i^{(l)}]_K [\text{LLM context}] \right) |_{i=1}^{M} \right\} \\ \mathbf{T}_i^{(h)} &= \left\{ \left([\omega_i^{(h)}]_{(1)} \, [\omega_i^{(h)}]_2 \ldots [\omega_i^{(h)}]_K [\text{LLM context}] \right) |_{i=1}^{M} \right\}, \end{aligned} \tag{2}$$

where $[\omega_i^{\beta}]_j, j \in [1, ..., K], i \in [1, .., M]$ are KM *trainable textual prompts* for each resolution $\beta \in \{l, h\}$.

3.3 Granularity-aware Visual Prompt Learning

3.3.1 Patches-based prompting

A frozen image encoder $E_I(.)$ (or $A_I(E_I(.))$ for `GigaPath-PLIP`) maps each patch I into feature vectors $H = \{H^{(l)} \in \mathbb{R}^{N_l \times d}, H^{(h)} \in \mathbb{R}^{N_h \times d}\}$ where d is the feature dimension. To consolidate the large set of patch features into a final slide-level representation, we introduce a set of learnable visual prompts $\mathbf{p}_v \in \mathbb{R}^{N_p \times d}$, which progressively merge patch features in $H^{(l)}$. Concretely, we treat $\mathbf{p}_v$ as the Query and all features in $H^{(l)}$ as the Keys $K_p^{(l)}$ and Values $V_p^{(l)}$ in a self-attention mechanism Vaswani (2017). We then associate $\mathbf{p}_v$ with the patch features as:

$$\mathbf{p}_{v,p}^{(l)} = \text{Normalize}\left(\text{SoftMax}\left(\frac{\mathbf{p}_v {K_p^{(l)}}^T}{\sqrt{d}} \right) V_p^{(l)} \right) + \mathbf{p}_v, \tag{3}$$

3.3.2 Spatial Patch Group-based Prompting

To quantify spatial correlations across multiple instances of I, we extract the coordinates for all its patches. Let $I^{(l)} = \left\{ I_1^{(l)}, I_2^{(l)}, ..., I_{N_l}^{(l)} \right\}$ denote the patches and $H^{(l)} = \left\{ H_1^{(l)}, H_2^{(l)}, ..., H_{N_l}^{(l)} \right\}$ their corresponding features. We construct a graph $G^{(l)} = (V^{(l)}, E^{(l)})$ to capture regional tissue structure, where $V^{(l)} = I^{(l)}$, and $E^{(l)} \in \{0, 1\}^{N_l \times N_l}$. Edges in $E^{(l)}$ are defined by linking each path to its $K-$nearest neighbors in the coordinate space. We set the node feature embedding $X^{(l)} = H^{(l)} \in \mathbb{R}^{N_l \times d}$, so each vertex $v_i^{(l)}$ is associated with a feature $x_i^{(l)} = H_i^{(l)}$.

We design a trainable message-passing network $g_\epsilon(.)$ using the graph attention layer (GAT) **?** to capture the feature representation of each node and its local neighbors. The GAT layer performs message passing as follows:

$$\begin{aligned} \alpha_{i,j} &= \frac{\exp\left(\sigma(a_s^T \Theta_s \, x_i^{(l)} + a_t^T \Theta_t \, x_j^{(l)})\right)}{\sum_{k \in \mathcal{N}(i) \cup \{i\}} \exp(\sigma(a_s^T \Theta_s \, x_i^{(l)} + a_t^T \Theta_t \, x_k^{(l)}))} \\ x_i^{(l)'} &= \alpha_{i,i} \Theta_s \, x_i^{(l)} + \sum_{j \in \mathcal{N}(i)} \alpha_{i,j} \Theta_t \, x_j^{(l)}, \end{aligned} \tag{4}$$

where $x_i^{(l)'}$ is aggregated features of $x_i^{(l)}$ with its local region after GAT layer, $\sigma(.)$ is the `LeakyReLU` activation function, $\mathcal{N}(i)$ denote the neighboring nodes of the i-th node, $\alpha_{i,j}$ are the attention coefficients and $a_s, a_t, \Theta_s, \Theta_t$ are weight parameters of $g_\epsilon(.)$.

After performing message passing with $g_\epsilon(.)$, we obtain an updated graph $G^{(l)'}$, where each node encapsulates its respective local feature region. We then aggregate all the feature nodes in $G^{(l)'}$ into a single vector $H_{gr}^{(l)}$, which acts as another set of Keys $K_{gr}^{(l)}$ and Values $V_{gr}^{(l)}$ for region-level features. Following the same approach as equation 3, we associate the prompt $\mathbf{p}_v$ with these group-level features:

$$\mathbf{p}_{v,gr}^{l} = \text{Normalize}\left(\text{SoftMax}\left(\frac{\mathbf{p}_v K_{gr}^{(l)^T}}{\sqrt{d}}\right) V_{gr}^{(l)}\right) + \mathbf{p}_v. \tag{5}$$

The final output of our multi-granular is computed as:

$$\mathbf{p}_v^{(l)} = (1-\alpha) \cdot \mathbf{p}_{v,p}^{(l)} + \alpha \cdot \mathbf{p}_{v,gr}^{(l)}, \tag{6}$$

3.4 Optimal Transport for Visual-Text Alignment

In this study, we employ optimal transport (OT) to measure the alignment between visual prompt-guided slide features $\mathbf{p}_v^{(l)}$ and $\mathbf{p}_v^{(h)}$, and descriptive text prompts $\mathbf{T}^{(l)}$ and $\mathbf{T}^{(h)}$. According to our best knowledge, we are the first to adapt OT for WSIs.

Given the visual prompt-guided slide features $\mathbf{p}_v^{(l)} \in \mathbb{R}^{N_p \times d}$ in equation 6 and the text prompts $\mathbf{T}^{(l)}$ in equation 2, we obtain the textual embedding $\mathbf{p}_t^{(l)}$ by applying E_T to $\mathbf{T}^{(l)}$, i.e., $\mathbf{p}_t^{(l)} = E_T(\mathbf{T}^{(l)})$. Let $\mathbf{T}_c^{(l)}$ denote the input text prompts for class c, $\left(\mathbf{p}_t^{(l)}\right)_c$ be the corresponding textual embedding, and $\left(\mathbf{p}_v^{(l)}\right)_c$ be the visual prompt-guided slide features associated with the same class c. We apply OT to minimize the distance between $\mathbf{T}_c^{(l)}$ and $\left(\mathbf{p}_v^{(l)}\right)_c$, denoted by $d_{\text{OT}}\left(\mathbf{T}_c^{(l)}, \left(\mathbf{p}_v^{(l)}\right)_c\right)$. Then, the cost matrix $\boldsymbol{C}$ is computed as $\boldsymbol{C} = \left(\mathbf{1} - \boldsymbol{F}^T \, \boldsymbol{G}\right) \in \mathbb{R}^{M \times N_p}$, where $\left(\mathbf{p}_t^{(l)}\right)_c \rightarrow \boldsymbol{F} = \left\{\boldsymbol{f}_i|_{i=1}^{M}\right\}$ and $\left(\mathbf{p}_v^{(l)}\right)_c \rightarrow \boldsymbol{G} = \left\{\boldsymbol{g}_j|_{j=1}^{N_p}\right\}$. We can produce $d_{\text{OT}}\left(\mathbf{T}_c^{(h)}, \left(\mathbf{p}_v^{(h)}\right)_c\right)$ by using the same procedure at high-resolution image patches. Then, the prediction probability is written as:

$$\text{P}_c = \frac{\exp(2 - \sum_{k \in \{l,h\}} d_{\text{OT}}\left(\mathbf{T}_c^{(k)}, \left(\mathbf{p}_v^{(k)}\right)_c\right))}{\sum_{c'=1}^{C} \exp(2 - \sum_{k \in \{l,h\}} d_{\text{OT}}\left(\mathbf{T}_{c'}^{(k)}, \left(\mathbf{p}_v^{(k)}\right)_c\right))}, \tag{7}$$

where λ_k controls contribution of each-resolution. Finally, we can train the model with the cross-entropy as:

$$\mathcal{L}_{class} = \text{Cross}(\text{P}, \text{GT}), \tag{8}$$

with $\text{Cross}(.)$ be the cross-entropy and GT denotes slide-level ground-truth.

4 EXPERIMENTS

Datasets for contrastive learning. PatchGastricADC22 Tsuneki & Kanavati (2022) contains about 262K patch-level images from H&E-stained gastric adenocarcinoma specimens, each paired with diagnostic captions from Mita Hospital, Japan. QUILT-1M Ikezogwo et al. (2024) comprises approximately 653K images and one million pathology image-text pairs obtained from 1,087 hours of educational histopathology videos on YouTube. ARCH Gamper & Rajpoot (2021) provides a multiple-instance captioning dataset featuring bag- and tile-level pathology images. For our contrastive training, we focus on tile-level samples from these datasets, yielding roughly 923K total images.

Downstream tasks. We evaluated our method on two TCGA datasets: TCGA-NSCLC and TCGA-RCC obtained from the Cancer Genome Atlas Data Portal The Cancer Genome Atlas (TCGA). We follow the data splitting settings of ViLa-MIL Shi et al. (2024) for dividing TCGA-NSCLC and TCGA-RCC into training, validation, and test sets.

4.1 RESULTS

Table 1: Comparison of methods on TCGA-NSCLC, and TCGA-RCC datasets with few-shot settings. Results are shown for AUC, F1, and Accuracy (ACC).

Methods	# Param.	TCGA-NSCLC			TCGA-RCC		
		AUC	F1	ACC	AUC	F1	ACC
Max-pooling	197K	53.0±6.0	45.8±8.9	53.3±3.4	67.4±4.9	46.7±11.6	54.1±4.8
Mean-pooling	197K	67.4±7.2	61.1±5.5	61.9±5.5	83.3±6.0	60.9±8.5	62.3±7.4
ABMIL Ilse et al. (2018)	461K	60.5±15.9	56.8±11.8	61.2±6.1	83.6±3.1	64.4±4.2	65.7±4.7
CLAM-SB Lu et al. (2021)	660K	66.7±13.6	59.9±13.8	64.0±7.7	90.1±2.2	75.3±7.4	77.6±7.0
CLAM-MB Lu et al. (2021)	660K	68.8±12.5	60.3±11.1	63.0±9.3	90.9±4.1	76.2±4.4	78.6±4.9
TransMIL Shao et al. (2021)	2.54M	64.2±8.5	57.5±6.4	59.7±5.4	89.4±5.6	73.0±7.8	75.3±7.2
DSMIL Li et al. (2021)	462K	67.9±8.0	61.0±7.0	61.3±7.0	87.6±4.5	71.5±6.6	72.8±6.4
GTMIL Zheng et al. (2022)	N/A	66.0±15.3	61.1±12.3	63.8±9.9	81.1±13.3	71.1±15.7	76.1±12.9
DTMIL Zhang et al. (2022a)	986.7K	67.5±10.3	57.3±11.3	66.6±7.5	90.0±4.6	74.4±5.3	76.8±5.2
IBMIL Lin et al. (2023)	N/A	69.2±7.4	57.4±8.3	66.9±6.5	90.5±4.1	75.1±5.2	77.2±4.2
ViLa-MIL Shi et al. (2024)	8.8M/47M	74.7±3.5	67.0±4.9	67.7±4.4	92.6±3.0	78.3±6.9	80.3±6.2
CONCH (Lu et al. (2024))	110M	89.46±10.2	78.5±9.31	78.78±9.1	88.08±4.59	78.21±4.2	71.67±19.4
QUILT Ikezogwo et al. (2024)	63M	79.66±13.19	72.30±13.35	72.42±13.24	96.92±1.6	78.46±5.55	86.34±1.56
MGPATH (CLIP)	1.6M/39M	77.2±1.3	70.9±2.0	71.0±2.1	92.1 ± 2.8	76.5 ± 5.2	81.7 ± 2.9
MGPATH (PLIP)	592K	83.6 ± 4.5	76.41 ± 4.8	76.5 ± 4.8	94.7 ± 1.6	78.6 ± 4.9	83.6 ± 3.5
MGPATH (PLIP-G)	5.35M	**93.02±2.99**	**84.64±4.75**	**84.77±4.67**	**98.2±0.31**	**88.33±3.41**	**91.72±1.74**

Table 2: Ablation studies on multi-granular (M-Gran), ratio combines two attention levels (α), and message passing network types.

Configurations	TCGA-NSCLC		
	AUC	F1	ACC
MGPATH (CLIP)	76.2±2.2	69.0±3.5	69.3±2.8
- w/o M-Gran (CLIP)	74.6±2.2	67.8±2.4	67.8±2.5
MGPATH (PLIP-G)	91.7±3.6	84.2±4.6	84.4±4.5
- w/o M-Gran (PLIP-G)	90.6±4.5	82.4±5.7	82.5±5.7
MGPATH, $\alpha = 0.2$	76.2±2.2	69.0±3.5	69.3±2.8
- $\alpha = 0.5$	73.7±3.1	67.4±2.6	67.8±2.7
- $\alpha = 0.8$	72.2±5.2	66.4±5.5	66.8±5.2
	TCGA-RCC		
MGPATH (CLIP)	92.1±2.8	76.5±5.2	81.7±2.9
- w/o M-Gran (CLIP)	91.6±3.5	72.3±6.4	80.2±4.4
MGPATH (PLIP-G)	98.1±0.6	85.7±1.1	89.9±2.0
- w/o M-Gran (PLIP-G)	98.1±0.6	85.0±4.0	89.3±3.0

As shown in Table 1, MGPATH, based on CLIP50, achieves top recording performances and providing significant improvements over other VLMs with similar architectures such as ViLa-MIL. Furthermore, PLIP backbone particularly improved MGPATH. For instance, on TCGA-NSCLC using backbone CLIP50, MGPATH achieves an acuracy of 71.0%, compared to 67.0% of ViLa-MIL. Moreover, using the PLIP backbone provides an additional 6% improvement on TCGA-NSCLC, demonstrating MGPATH's adaptability and effectiveness across different backbones.

By incorporating distilled pathology features from Prov-GigaPath Xu et al. (2024)—pre-trained on 1.3 billion pathology images—MGPATH(PLIP-G) achieves new state-of-the-art accuracies of 84.77% on TCGA-NSCLC and 91.72% on TCGA-RCC.

Our MGPATH also sets new state-of-the-art performance in zero-shot tasks. As shown in Table 4, it achieves the highest average performance across two datasets, surpassing both CONCH and PLIP.

4.2 ABLATION STUDIES

Multi-Granular Prompt Learning. In Table 2, MGPATH with multi-granular (M-Gran) outperforms the variant without it (rows 1–2 for CLIP and 3–4 for PLIP-G) on TCGA-NSCLC, with a similar trend observed on TCGA-RCC. The table also indicates that a 0.2/0.8 ratio of graph-based to prototype-guided attention yields the best performances.

OT as Alignment between Contextual Prompts. Table 3 confirms the benefits of incorporating optimal transport (OT) into MGPath on the TCGA-NSCLC and TCGA-RCC datasets. Notably, using OT (rows 1 and 2) boosts performance compared to cosine similarity (rows 3 and 4). Moreover, the results indicate that the optimal number of prompt vectors can vary by dataset.

Table 3: Contribution of OT and multiple descriptive text prompts

Methods	TCGA-NSCLC		
	AUC	F1	ACC
MGPATH (OT, 4 text prompts)	76.2±2.2	69.0±3.5	69.3±2.8
MGPATH (OT, 2 text prompts)	77.2±1.3	70.9±2.0	71.0±2.1
MGPATH (Cosine, 2 text prompts)	75.8±3.7	68.3±4.5	68.4±4.5
	TCGA-RCC		
MGPATH (OT, 4 text prompts)	92.1±2.8	76.5±5.2	81.7±2.9
MGPATH (OT, 2 text prompts)	92.1±2.6	75.6±3.9	80.4±2.4
MGPATH (Cosine, 4 text prompts)	91.8±2.8	75.9±4.3	80.5±2.6

Table 4: Zero-shot classification performance on TCGA-Lung, and TCGA-RCC. Metrics include balanced accuracy (B-Acc) and weighted F1-score (W-F1).

Zero-shot	TCGA-NSCLC		TCGA-RCC		Average	
	B-Acc	W-F1	B-Acc	W-F1	B-Acc	W-F1
QuiltNet	61.3	56.1	59.1	51.8	57.23	49.33
CONCH	**80.0**	**79.8**	72.9	69.1	72.3	70.03
PLIP	70.0	68.5	50.7	46.0	61.8	59.43
PLIP-G (Our)	72.7	72.6	**81.3**	**81.4**	**74.67**	**74.63**

4.3 DISCUSSION

In this study, we propose MGPATH, which achieves significant improvements in few-shot and zero-shot WSI classification across multiple datasets. However, we do not explore other potential challenges, leaving room for further investigation in future work. For instance, integrating VLMs models with other pathology foundation models such as CONCH, or extending the approach to segmentation tasks.

5 CONCLUSION

Whole slide images (WSIs) have become indispensable in clinical practice—particularly for cancer diagnosis—analyzing their complex, hierarchical, high-resolution structures remains a significant challenge for automated methods. Although recent VLM (vision-language model) research leveraging few-shot and weakly supervised learning has achieved promising results with limited annotations, these approaches often overlook the hierarchical relationships among the learnable prompts, individual patches, and patch groups. Furthermore, they lack the precision needed to capture fine-grained alignments between image-text pairs. In this study, we propose `MGPATH`, a VLM which integrates `Prov-GigaPath` with `PLIP`, to overcome these limitations. Our granular prompt learning approach effectively captures hierarchical tissue interactions, resulting in significant improvements in WSIs classification. Experimental results demonstrate that our `MGPATH` achieves state-of-the-art results in WSIs classification. We expect that this work will inspire future research that integrates vision-language models with multi-granular prompt learning - enabling the capture local, global, and spatial information in WSI complex structure - alongside optimal transport methods, ultimately advancing few-shot learning in pathology.

6 ACKNOWLEDGEMENT

The study was supported by the *German Ministry of Education and Research (BMBF)* under grant agreement *No. 01KD2208A (project FAIrPaCT)*.

The authors gratefully acknowledge the computing time granted by the Resource Allocation Board and provided on the supercomputer Emmy/Grete at NHR-Nord@Göttingen as part of the NHR infrastructure. The calculations for this research were conducted with computing resources under the project *nim00014*.

The authors gratefully acknowledge the computing time granted by the KISSKI project. The calculations for this research were conducted with computing resources under the project *kisski-umg-fairpact-2*.

REFERENCES

Richard J Chen, Tong Ding, Ming Y Lu, Drew FK Williamson, Guillaume Jaume, Andrew H Song, Bowen Chen, Andrew Zhang, Daniel Shao, Muhammad Shaban, et al. Towards a general-purpose foundation model for computational pathology. *Nature Medicine*, 30(3):850–862, 2024.

Jevgenij Gamper and Nasir Rajpoot. Multiple instance captioning: Learning representations from histopathology textbooks and articles. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 16549–16559, 2021.

Chunjiang Ge, Rui Huang, Mixue Xie, Zihang Lai, Shiji Song, Shuang Li, and Gao Huang. Domain adaptation via prompt learning. *IEEE Transactions on Neural Networks and Learning Systems*, 2023.

Minghao Han, Linhao Qu, Dingkang Yang, Xukun Zhang, Xiaoying Wang, and Lihua Zhang. Mscpt: Few-shot whole slide image classification with multi-scale and context-focused prompt tuning. *arXiv preprint arXiv:2408.11505*, 2024.

Zhi Huang, Federico Bianchi, Mert Yuksekgonul, Thomas J Montine, and James Zou. A visual–language foundation model for pathology image analysis using medical twitter. *Nature medicine*, 29(9):2307–2316, 2023.

Wisdom Ikezogwo, Saygin Seyfioglu, Fatemeh Ghezloo, Dylan Geva, Fatwir Sheikh Mohammed, Pavan Kumar Anand, Ranjay Krishna, and Linda Shapiro. Quilt-1m: One million image-text pairs for histopathology. *Advances in neural information processing systems*, 36, 2024.

Maximilian Ilse, Jakub Tomczak, and Max Welling. Attention-based deep multiple instance learning. In *International conference on machine learning*, pp. 2127–2136. PMLR, 2018.

Muhammad Uzair Khattak, Hanoona Rasheed, Muhammad Maaz, Salman Khan, and Fahad Shahbaz Khan. Maple: Multi-modal prompt learning. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 19113–19122, 2023.

Bin Li, Yin Li, and Kevin W Eliceiri. Dual-stream multiple instance learning network for whole slide image classification with self-supervised contrastive learning. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 14318–14328, 2021.

Zhuowei Li, Long Zhao, Zizhao Zhang, Han Zhang, Di Liu, Ting Liu, and Dimitris N Metaxas. Steering prototypes with prompt-tuning for rehearsal-free continual learning. In *Proceedings of the IEEE/CVF Winter Conference on Applications of Computer Vision*, pp. 2523–2533, 2024.

Tiancheng Lin, Zhimiao Yu, Hongyu Hu, Yi Xu, and Chang-Wen Chen. Interventional bag multi-instance learning on whole-slide pathological images. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 19830–19839, 2023.

Ming Y Lu, Drew FK Williamson, Tiffany Y Chen, Richard J Chen, Matteo Barbieri, and Faisal Mahmood. Data-efficient and weakly supervised computational pathology on whole-slide images. *Nature biomedical engineering*, 5(6):555–570, 2021.

Ming Y Lu, Bowen Chen, Andrew Zhang, Drew FK Williamson, Richard J Chen, Tong Ding, Long Phi Le, Yung-Sung Chuang, and Faisal Mahmood. Visual language pretrained multiple instance zero-shot transfer for histopathology images. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 19764–19775, 2023.

Ming Y Lu, Bowen Chen, Drew FK Williamson, Richard J Chen, Ivy Liang, Tong Ding, Guillaume Jaume, Igor Odintsov, Long Phi Le, Georg Gerber, et al. A visual-language foundation model for computational pathology. *Nature Medicine*, 30(3):863–874, 2024.

Yuning Lu, Jianzhuang Liu, Yonggang Zhang, Yajing Liu, and Xinmei Tian. Prompt distribution learning. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 5206–5215, 2022.

Dmitry Nechaev, Alexey Pchelnikov, and Ekaterina Ivanova. Hibou: A family of foundational vision transformers for pathology. *arXiv preprint arXiv:2406.05074*, 2024.

Wisdom Oluchi Ikezogwo, Mehmet Saygin Seyfioglu, Fatemeh Ghezloo, Dylan Stefan Chan Geva, Fatwir Sheikh Mohammed, Pavan Kumar Anand, Ranjay Krishna, and Linda Shapiro. Quilt-1m: One million image-text pairs for histopathology. *arXiv e-prints*, pp. arXiv–2306, 2023.

Aaron van den Oord, Yazhe Li, and Oriol Vinyals. Representation learning with contrastive predictive coding. *arXiv preprint arXiv:1807.03748*, 2018.

Linhao Qu, Kexue Fu, Manning Wang, Zhijian Song, et al. The rise of ai language pathologists: Exploring two-level prompt learning for few-shot weakly-supervised whole slide image classification. *Advances in Neural Information Processing Systems*, 36, 2024.

Alec Radford, Jong Wook Kim, Chris Hallacy, Aditya Ramesh, Gabriel Goh, Sandhini Agarwal, Girish Sastry, Amanda Askell, Pamela Mishkin, Jack Clark, et al. Learning transferable visual models from natural language supervision. In *International conference on machine learning*, pp. 8748–8763. PMLR, 2021.

Zhuchen Shao, Hao Bian, Yang Chen, Yifeng Wang, Jian Zhang, Xiangyang Ji, et al. Transmil: Transformer-based correlated multiple instances learning for whole slide image classification. *Advances in neural information processing systems*, 34:2136–2147, 2021.

Jiangbo Shi, Chen Li, Tieliang Gong, Yefeng Zheng, and Huazhu Fu. Vila-mil: Dual-scale vision-language multiple instance learning for whole slide image classification. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 11248–11258, 2024.

Manli Shu, Weili Nie, De-An Huang, Zhiding Yu, Tom Goldstein, Anima Anandkumar, and Chaowei Xiao. Test-time prompt tuning for zero-shot generalization in vision-language models. *Advances in Neural Information Processing Systems*, 35:14274–14289, 2022.

The Cancer Genome Atlas (TCGA). Genomic Data Commons Data Portal (GDC). `https://portal.gdc.cancer.gov/projects/TCGA-BRCA`. Accessed 07 Jul. 2023.

Masayuki Tsuneki and Fahdi Kanavati. Inference of captions from histopathological patches. In *International Conference on Medical Imaging with Deep Learning*, pp. 1235–1250. PMLR, 2022.

A Vaswani. Attention is all you need. *Advances in Neural Information Processing Systems*, 2017.

Hanwen Xu, Naoto Usuyama, Jaspreet Bagga, Sheng Zhang, Rajesh Rao, Tristan Naumann, Cliff Wong, Zelalem Gero, Javier González, Yu Gu, et al. A whole-slide foundation model for digital pathology from real-world data. *Nature*, pp. 1–8, 2024.

Hantao Yao, Rui Zhang, and Changsheng Xu. Tcp: Textual-based class-aware prompt tuning for visual-language model. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 23438–23448, 2024.

Hongrun Zhang, Yanda Meng, Yitian Zhao, Yihong Qiao, Xiaoyun Yang, Sarah E Coupland, and Yalin Zheng. Dtfd-mil: Double-tier feature distillation multiple instance learning for histopathology whole slide image classification. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 18802–18812, 2022a.

Yue Zhang, Hongliang Fei, Dingcheng Li, Tan Yu, and Ping Li. Prompting through prototype: A prototype-based prompt learning on pretrained vision-language models. *arXiv preprint arXiv:2210.10841*, 2022b.

Yi Zheng, Rushin H Gindra, Emily J Green, Eric J Burks, Margrit Betke, Jennifer E Beane, and Vijaya B Kolachalama. A graph-transformer for whole slide image classification. *IEEE transactions on medical imaging*, 41(11):3003–3015, 2022.

Kaiyang Zhou, Jingkang Yang, Chen Change Loy, and Ziwei Liu. Conditional prompt learning for vision-language models. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 16816–16825, 2022a.

Kaiyang Zhou, Jingkang Yang, Chen Change Loy, and Ziwei Liu. Learning to prompt for vision-language models. *International Journal of Computer Vision*, 130(9):2337–2348, 2022b.

A APPENDIX

A.1 MULTI-MAGNIFICATION DESCRIPTIVE TEXT PROMPTS

To maintain robust prompt generation across varying WSI magnifications, we design shared prompts that integrate both high- and low-scale descriptive elements as contextual embeddings. In particular, we utilize the API of a frozen language model (GPT-4) and provide the query shown in Figure A.1.

LLM Prompt

```
What visually descriptive features characterize {class name} at
both low and high resolutions within the whole-slide image?  Please
summarize into a single paragraph.
```

Figure 1: LLM template prompt.

A.2 IMPLEMENTATION DETAILS

We used the `ViLa-MIL` preprocessing pipeline for tissue region selection and patch cropping. For `CLIP50` and `PLIP`, we extracted tile-level embeddings from their frozen vision encoders—1024-dimensional for `CLIP50` and 512-dimensional for `PLIP`—and used `Prov-GigaPath` to generate 1536-dimensional embeddings. To align these embeddings with `PLIP`'s frozen text encoder, we introduced two MLP-based adaptors that project both encoders into a shared feature space via contrastive learning on the datasets described in Section 4.

We employ a Graph Attention Network (GAT) to capture local spatial relationships between WSI patches, treating each tile-level embedding as a node connected to its left, right, top, and bottom neighbors. We then merge the patch group-based spatial attention term $\mathbf{p}_{v,gr}$ with the patch-based attention $\mathbf{p}_{v,p}$ using Equation 6. A hyper-parameter $\alpha \in [0, 1]$ regulates the balance between spatial context and prototype-based guidance.