



Synergistic Information Disentanglement for Omni-modal Slide Representation Learning in Computational Pathology

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Overview: From Redundancy Alignment to Synergistic Omni-modal Pretraining

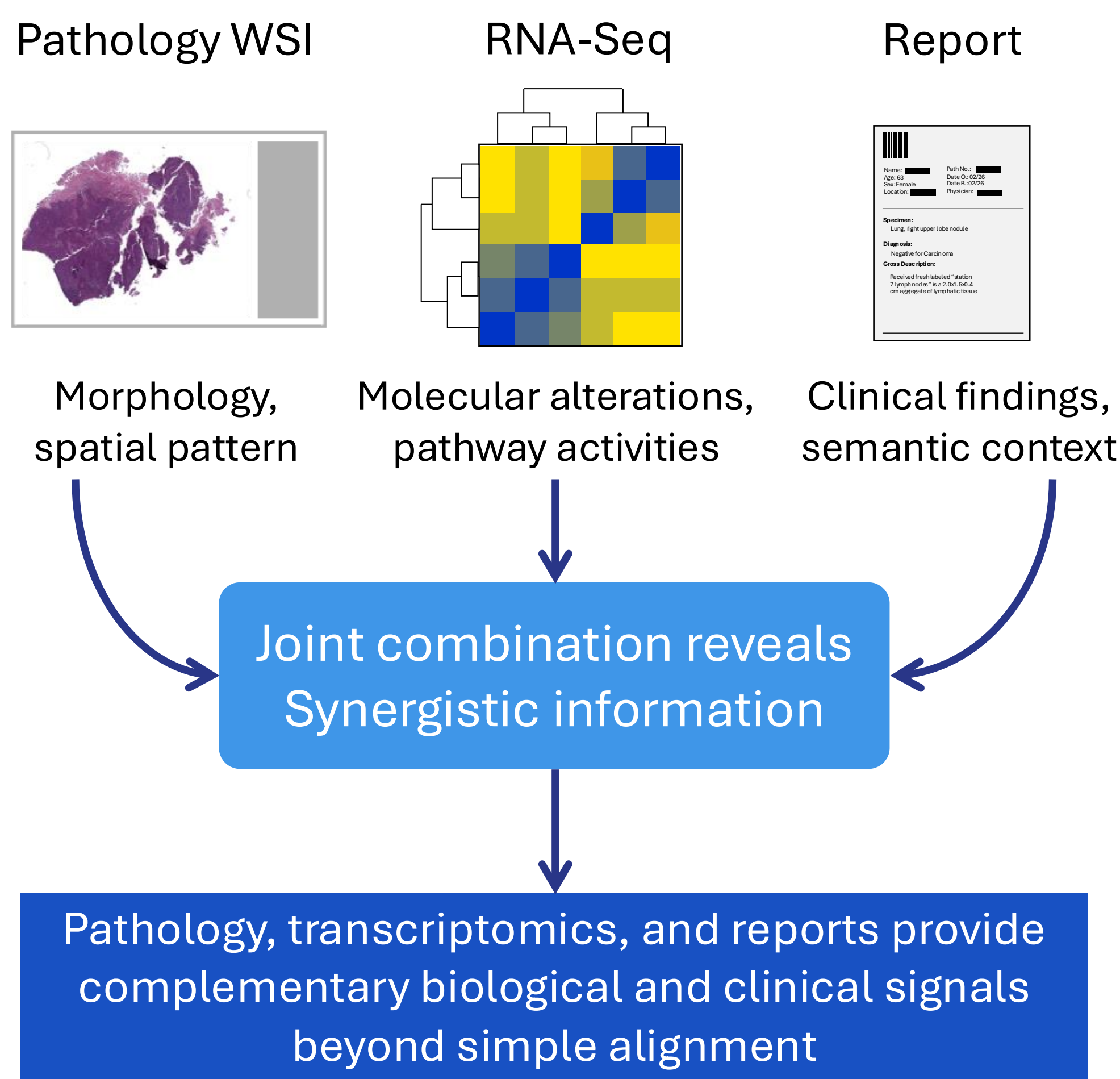
Background: Existing slide-level multimodal self-supervised learning often emphasizes shared redundancy and contrastive alignment. This may under-utilize complementary evidence from pathology, transcriptomics, and reports, and can cause modality collapse.

Contribution: We propose **Φ -Omni**, an omni-modal self-supervised framework for slide representation learning. It introduces a Synergistic Information Bottleneck (SIB) and the Φ ID objective grounded in PID to expand synergy while compressing redundancy.

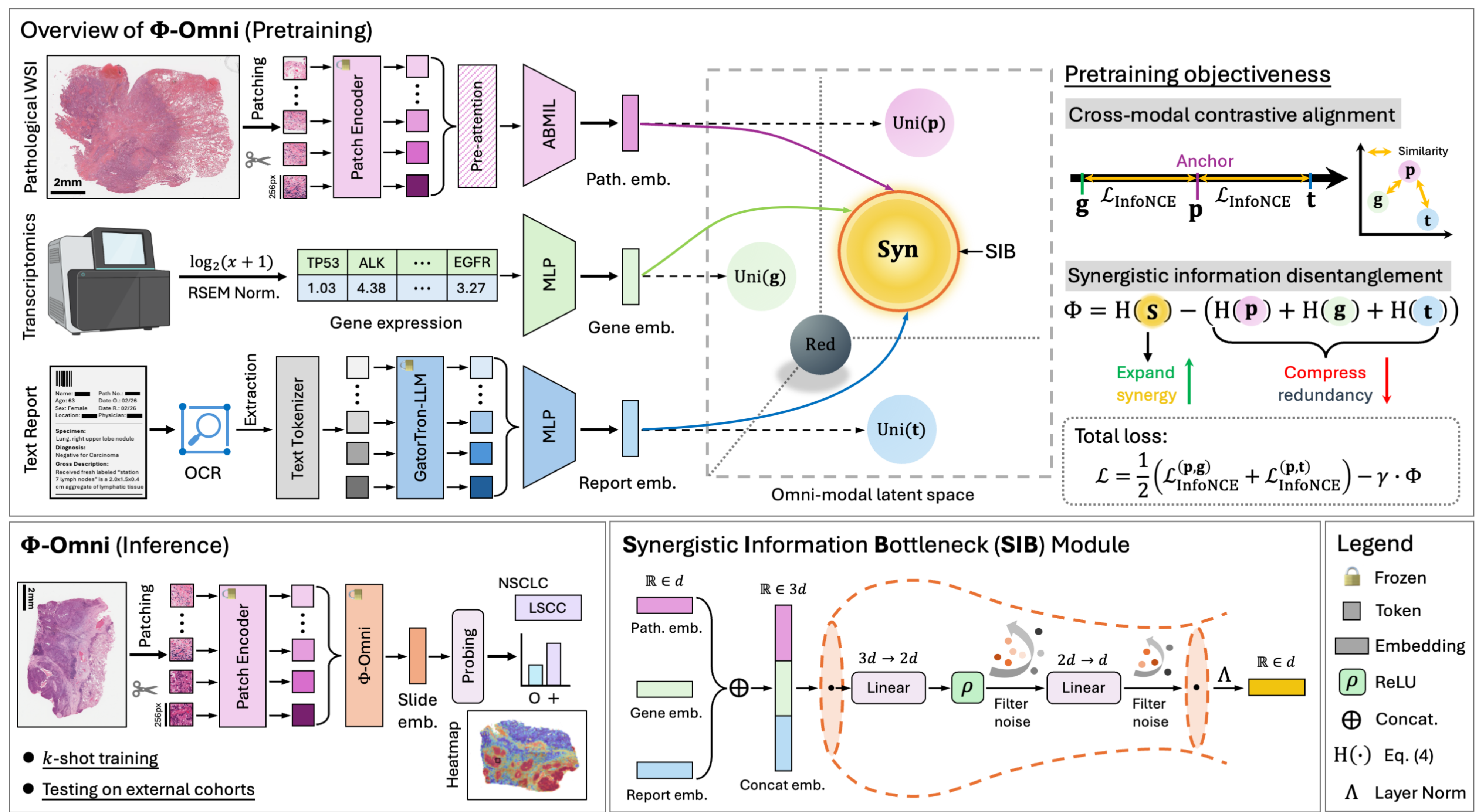
Results: Pretrained on TCGA-BRCA ($n=1,031$) and TCGA-NSCLC ($n=919$), **Φ -Omni** achieves superior few-shot performance across five external cohorts and eight downstream tasks, which outperforms supervised MIL and SSL baselines.

Current & future work: Our study shows that synergy-driven multimodal pretraining can produce transferable WSI encoders for robust unimodal few-shot adaption, which can be extended to broader cohorts, richer modalities, and clinically deployable pathology FMs.

Motivation: Omni-modal Evidence $\neq$ Simple Redundancy



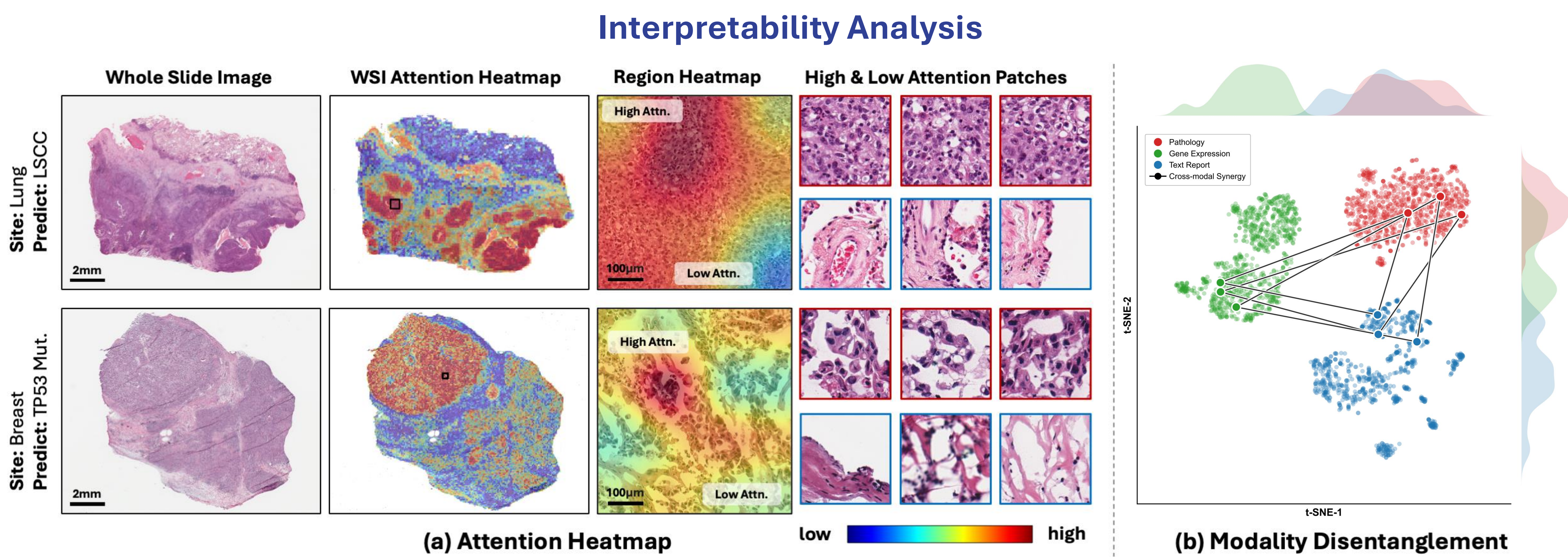
Φ -Omni framework



Quantitative Results

Table 1. Few-shot breast and lung cancer subtyping. Evaluation via macro-AUC on BRACS and CPTAC-NSCLC two cohorts. Best in **bold**, second best is underlined. **Table 2. Few-shot molecular status prediction.** Evaluation via macro-AUC on three cohorts from CPTAC ($k=25$). Best in **bold**, second best is underlined.

Model/Data	BRACS ($\uparrow$)				CPTAC-NSCLC ($\uparrow$)			
	$k=1$	$k=5$	$k=10$	$k=25$	$k=1$	$k=5$	$k=10$	$k=25$
MIL								
ABMIL [5]	55.9 $\pm$ 2.8	64.8 $\pm$ 2.0	75.4 $\pm$ 2.6	82.3 $\pm$ 0.8	72.2 $\pm$ 12.4	91.9 $\pm$ 5.2	95.7 $\pm$ 2.7	98.3 $\pm$ 1.0
CLAM [16]	55.5 $\pm$ 3.0	65.4 $\pm$ 3.2	74.9 $\pm$ 2.0	82.3 $\pm$ 1.2	74.3 $\pm$ 14.1	93.6 $\pm$ 3.1	96.5 $\pm$ 2.3	98.5 $\pm$ 0.7
TransMIL [18]	57.1 $\pm$ 2.7	68.9 $\pm$ 2.2	75.6 $\pm$ 1.2	82.3 $\pm$ 1.9	71.7 $\pm$ 12.2	91.8 $\pm$ 3.0	95.2 $\pm$ 1.4	98.6 $\pm$ 0.5
ILRA [26]	55.0 $\pm$ 1.8	62.5 $\pm$ 2.8	70.0 $\pm$ 1.6	79.0 $\pm$ 1.7	66.7 $\pm$ 15.9	87.1 $\pm$ 2.5	92.4 $\pm$ 1.7	97.0 $\pm$ 1.1
Linear probe								
CTransPath* [24]	56.7 $\pm$ 2.8	63.3 $\pm$ 2.9	64.7 $\pm$ 1.4	68.9 $\pm$ 1.6	71.3 $\pm$ 11.1	88.0 $\pm$ 4.9	92.3 $\pm$ 2.1	96.0 $\pm$ 1.1
UNiv2* [1]	55.8 $\pm$ 3.2	66.0 $\pm$ 2.0	70.6 $\pm$ 1.7	76.4 $\pm$ 1.5	72.9 $\pm$ 15.3	91.4 $\pm$ 4.2	95.3 $\pm$ 1.7	97.5 $\pm$ 1.0
CONCH* [15]	58.4 $\pm$ 8.4	69.5 $\pm$ 2.8	73.4 $\pm$ 2.1	79.0 $\pm$ 1.7	83.1 $\pm$ 9.3	<u>95.8 $\pm$ 2.0</u>	<u>97.0 $\pm$ 0.7</u>	98.5 $\pm$ 0.5
mSTAR* [27]	56.1 $\pm$ 3.0	66.0 $\pm$ 2.3	70.2 $\pm$ 2.0	75.4 $\pm$ 1.3	74.9 $\pm$ 11.9	92.1 $\pm$ 4.2	95.5 $\pm$ 1.7	97.8 $\pm$ 0.8
GPFM* [17]	56.4 $\pm$ 2.7	66.2 $\pm$ 2.8	70.9 $\pm$ 2.0	75.8 $\pm$ 1.3	73.2 $\pm$ 10.8	90.3 $\pm$ 4.9	95.3 $\pm$ 1.9	97.8 $\pm$ 1.0
CHIEF [25]	<u>64.2 $\pm$ 3.2</u>	73.6 $\pm$ 2.1	77.5 $\pm$ 1.4	81.9 $\pm$ 1.1	72.7 $\pm$ 10.9	91.0 $\pm$ 4.7	94.6 $\pm$ 1.6	97.4 $\pm$ 0.7
TANGLE [6]	62.2 $\pm$ 2.3	74.1 $\pm$ 2.4	78.1 $\pm$ 1.2	82.4 $\pm$ 0.8	79.3 $\pm$ 10.2	95.3 $\pm$ 4.3	96.9 $\pm$ 2.1	98.8 $\pm$ 0.2
MADELEINE [7]	61.3 $\pm$ 4.5	73.4 $\pm$ 2.4	76.7 $\pm$ 2.0	82.3 $\pm$ 1.3	81.3 $\pm$ 9.6	94.7 $\pm$ 2.7	96.6 $\pm$ 1.1	98.2 $\pm$ 0.6
Φ -OMNI (Ours)	65.2 $\pm$ 2.6	76.5 $\pm$ 2.2	79.9 $\pm$ 1.0	83.3 $\pm$ 0.8	81.7 $\pm$ 11.3	97.5 $\pm$ 1.6	98.8 $\pm$ 0.5	99.4 $\pm$ 0.2



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