

RACR-MIL: Rank-Aware Contextual Reasoning for Weakly Supervised Analysis of SCC Whole Slide Images

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INTRODUCTION

BACKGROUND

Squamous cell cancer (SCC): Second most common skin cancer with a rising incidence and mortality; affects multiple anatomies

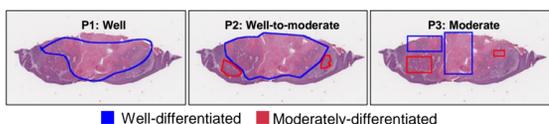
Staging protocol: Manual evaluation of tissue images to determine prognostic factors (grade, depth, perineural invasion)

MOTIVATION

Staging systems fail to reliably predict poor outcomes (46% upstaging rate)

Variability in diagnosing tumor grade due to lack of standardized protocol and subjectivity in determining high-risk focal areas

Clinicians cannot draw definitive conclusions on patient prognosis using risk factors



CONTRIBUTIONS

WEAKLY-SUPERVISED LEARNING

First comprehensive weakly-supervised framework for SCC analysis from whole slide image (WSI)

- Addresses diagnostic (tumor grade) and prognostic (metastasis risk) tasks
- Requires minimal annotations (only slide-level labels)

SELF-SUPERVISED PRETRAINING

Utilizes self-supervised learning to extract robust and generalizable image features

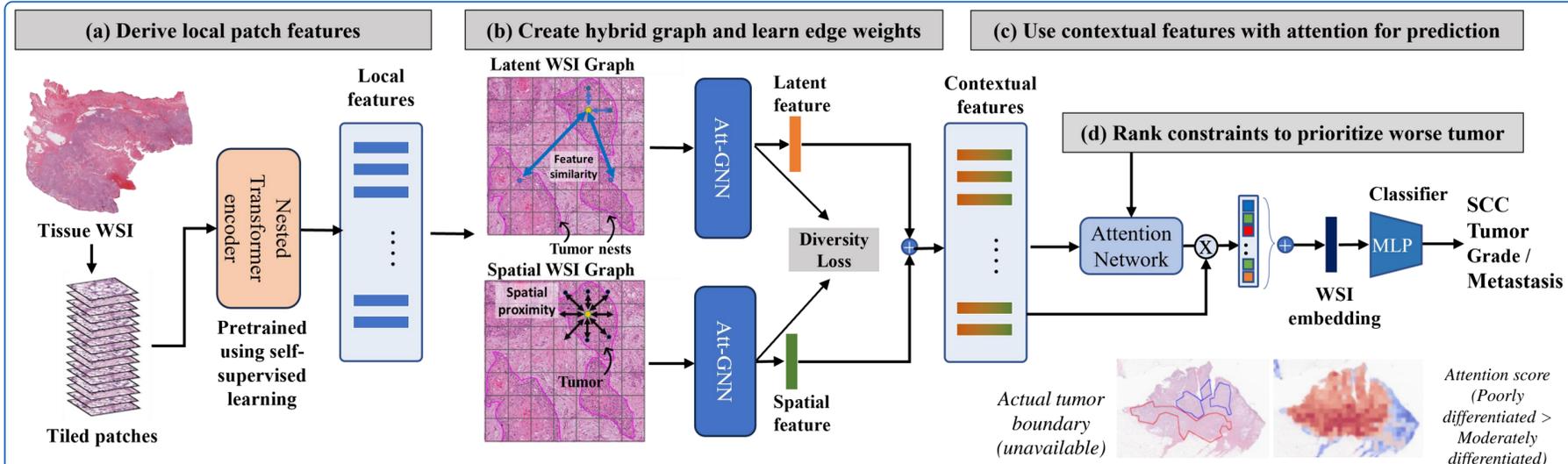
CONTEXTUAL LEARNING

Novel hybrid graph captures local tissue tumor microenvironment context and non-local phenotypic relations across distant tumor regions

REGION PRIORITIZATION

Emulates clinicians by emphasizing higher risk tumor regions using ranking-based attention mechanism

APPROACH

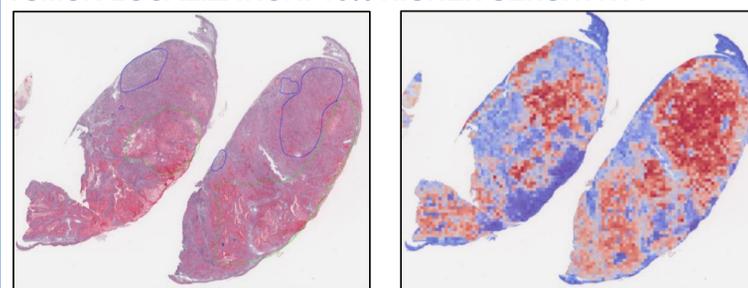


RESULTS

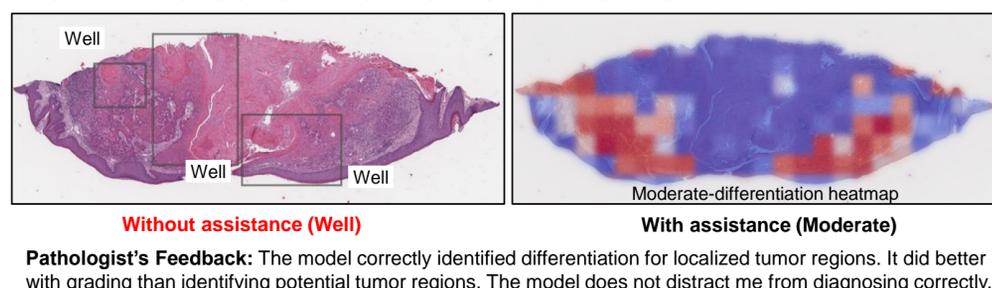
TUMOR GRADING: STRONG GENERALIZATION ACROSS DIVERSE ANATOMIES

Approach	CSCC					HNSC					LSCC				
	FI	Precision	Recall	AUC	MCC	FI	Precision	Recall	AUC	MCC	FI	Precision	Recall	AUC	MCC
Non-contextual															
Max Pooling	0.761 _{0.039}	0.770 _{0.040}	0.776 _{0.044}	0.942 _{0.011}	0.762 _{0.053}	0.561 _{0.037}	0.554 _{0.038}	0.583 _{0.034}	0.810 _{0.035}	0.395 _{0.062}	0.699 _{0.047}	0.714 _{0.050}	0.717 _{0.042}	0.919 _{0.020}	0.670 _{0.058}
Mean Pooling	0.758 _{0.027}	0.756 _{0.030}	0.771 _{0.030}	0.943 _{0.014}	0.754 _{0.041}	0.590 _{0.030}	0.581 _{0.032}	0.621 _{0.036}	0.818 _{0.026}	0.419 _{0.053}	0.742 _{0.064}	0.745 _{0.067}	0.751 _{0.067}	0.936 _{0.028}	0.716 _{0.077}
ABMIL	0.782 _{0.027}	0.774 _{0.035}	0.805 _{0.012}	0.954 _{0.009}	0.781 _{0.042}	0.604 _{0.034}	0.596 _{0.039}	0.623 _{0.033}	0.830 _{0.022}	0.445 _{0.051}	0.690 _{0.035}	0.709 _{0.044}	0.713 _{0.059}	0.930 _{0.025}	0.664 _{0.060}
GABMIL	0.770 _{0.021}	0.770 _{0.026}	0.787 _{0.017}	0.957 _{0.010}	0.780 _{0.020}	0.585 _{0.050}	0.574 _{0.050}	0.606 _{0.056}	0.821 _{0.027}	0.415 _{0.079}	0.702 _{0.060}	0.708 _{0.065}	0.713 _{0.067}	0.933 _{0.023}	0.671 _{0.075}
CLAM-MB	0.778 _{0.024}	0.775 _{0.030}	0.789 _{0.017}	0.954 _{0.011}	0.781 _{0.030}	0.600 _{0.034}	0.591 _{0.039}	0.620 _{0.033}	0.813 _{0.022}	0.435 _{0.051}	0.707 _{0.047}	0.715 _{0.048}	0.722 _{0.054}	0.932 _{0.024}	0.681 _{0.064}
Contextual															
PatchGCN	0.772 _{0.019}	0.762 _{0.023}	0.799 _{0.027}	0.950 _{0.010}	0.766 _{0.042}	0.582 _{0.024}	0.577 _{0.019}	0.597 _{0.035}	0.815 _{0.026}	0.415 _{0.044}	0.689 _{0.053}	0.703 _{0.059}	0.709 _{0.064}	0.934 _{0.019}	0.660 _{0.065}
WiKG	0.763 _{0.007}	0.770 _{0.014}	0.772 _{0.017}	0.940 _{0.011}	0.768 _{0.019}	0.586 _{0.039}	0.592 _{0.034}	0.600 _{0.044}	0.800 _{0.032}	0.432 _{0.050}	0.702 _{0.071}	0.707 _{0.069}	0.707 _{0.070}	0.906 _{0.032}	0.666 _{0.085}
TransMIL	0.718 _{0.041}	0.728 _{0.047}	0.731 _{0.047}	0.919 _{0.015}	0.727 _{0.049}	0.555 _{0.007}	0.549 _{0.009}	0.593 _{0.015}	0.806 _{0.025}	0.383 _{0.037}	0.696 _{0.072}	0.712 _{0.069}	0.703 _{0.076}	0.927 _{0.028}	0.669 _{0.074}
GTP	0.728 _{0.034}	0.737 _{0.042}	0.732 _{0.035}	0.934 _{0.019}	0.725 _{0.058}	0.541 _{0.039}	0.538 _{0.041}	0.574 _{0.041}	0.791 _{0.061}	0.378 _{0.061}	0.694 _{0.060}	0.701 _{0.064}	0.697 _{0.055}	0.918 _{0.027}	0.657 _{0.064}
DSMIL	0.761 _{0.042}	0.762 _{0.038}	0.774 _{0.052}	0.950 _{0.015}	0.770 _{0.040}	0.582 _{0.029}	0.576 _{0.027}	0.624 _{0.037}	0.817 _{0.024}	0.418 _{0.067}	0.676 _{0.057}	0.689 _{0.059}	0.699 _{0.056}	0.929 _{0.020}	0.663 _{0.072}
RACR-MIL	0.806 _{0.012}	0.795 _{0.018}	0.831 _{0.020}	0.958 _{0.007}	0.801 _{0.027}	0.614 _{0.029}	0.606 _{0.028}	0.640 _{0.044}	0.826 _{0.024}	0.450 _{0.058}	0.740 _{0.047}	0.747 _{0.050}	0.753 _{0.059}	0.939 _{0.021}	0.711 _{0.062}

TUMOR LOCALIZATION: 16% HIGHER SENSITIVITY



HIGHER DIAGNOSTIC EFFICIENCY FOR CLINICIANS



METASTASIS PREDICTION: ACHIEVES 78% AUC AND IDENTIFIES NOVEL HIGH RISK MORPHOLOGICAL PHENOTYPES FOR SKIN SCC

