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영문제목	A Sheaf-Consistent Schrödinger Bridge for Virtual Staining with Spatial and Biological Coherence

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Object (95 word)

Virtual staining is expected to cut the cost and processing time of immunohistochemical (IHC) biomarker assessment, yet gigapixel whole-slide images (WSIs) must be processed patch by patch under GPU memory limits. While Vision Foundation Models (VFMs) are widely utilized to process these patches in computational pathology, their self-attention mechanism assigns different embeddings to the same physical tissue depending on the surrounding field of view. Consequently, reassembled regions show boundary seams, stain-tone drift, and chromatin mismatches. We formalize this "context contamination" as a sheaf-theoretic problem and ask whether restoring the sheaf structure yields coherent WSI-scale translation.

Methods (79 word)

We propose SheafStain, framing VFM class and patch tokens as sheaf-like sections within a Schrödinger Bridge. The class tokens anchor biological identity while patch tokens map spatial features, guided by a backbone pre-trained on both Hematoxylin & Eosin and IHC that unifies conditioning and stain supervision. After empirically auditing sheaf axioms on 4,873 images, we evaluated reassembled 1024x1024 images, rather than conventional 256x256 crops, on BCI and MIST across HER2, ER, PR, and Ki-67 against six prior methods.

Results (69 word)

SheafStain achieved the best performance across FID, KID, DISTS, and DAB correlation in every dataset and stain combination. Compared to the strongest baseline, it reduced KID by 2.6 to 8.8 times and FID by 30 to 46%, while improving boundary-seam metrics by 6 to 13%. Furthermore, a HER2 Low/High classifier trained solely on SheafStain-synthesized slides reached the highest accuracy (0.766), F1 (0.844), and AUROC (0.794) on real test data.

Conclusions (31 word)

By injecting sheaf-consistent spatial context during generation rather than relying solely on post-processing, SheafStain substantially mitigates stitching seams and preserves biomarker-relevant morphology, moving patch-wise virtual staining closer to WSI-scale clinical utility.

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