ADVANCEMENTS IN AUTOMATED VIRTUAL UNWRAPPING AND INK DETECTION OF CARBONIZED HERCULANEUM SCROLLS

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The Vesuvius Challenge exists to noninvasively read the carbonized Herculaneum scrolls. Recent efforts have transitioned from isolating excerpts to establishing an automated pipeline capable of reading the entire collection. This paper reviews the technical progress made in X-ray tomography, automated segmentation, and machine learning-based ink detection between 2025 and 2026.

Data acquisition was significantly scaled up at facilities like Diamond Light Source and the European Synchrotron Radiation Facility (ESRF). The scanning process was streamlined through automated photogrammetry, generating 3D models to design form-fitting 3D-printed cases with Teflon wrapping for secure transport. Scans were captured at unprecedented resolutions, including 2.4 μm and 0.55 μm, to balance high resolution, low blur from scattering, and strong phase contrast. High-resolution scanning proved critical; for example, scanning Scroll 4 (PHerc. 1667) at 2.4 μm revealed 5-6 mm sized letters that were completely invisible in previous 8 μm scans.

In the domain of virtual unwrapping, the First Automated Segmentation Prize (FASP) yielded breakthroughs that reduced manual annotation time from hundreds of hours to just four hours. Solutions utilized volumetric segmentation models to produce surface predictions and surface tracing methods to assemble contiguous sheets. Novel global optimization methods were also developed, such as deforming an Archimedean spiral to fit the scroll's surface predictions while preserving topological integrity through a smooth diffeomorphism. Furthermore, the semi-automated unwrapping software, VC3D, received major updates including remote volume streaming and a Neural Tracer that automatically outputs mesh parts without binarization of input surfaces.

Topologically accurate surface detection was further accelerated by a $200,000 Kaggle competition, which utilized models like ResEncUNet.

Ink detection methodologies evolved from surface-based (2.5D) approaches to direct 3D volume analysis. A 3D ink detection model was successfully trained for Scroll 5 (PHerc. 172) to work directly on the unflattened volume scroll. Additionally, generalist ink-detection models were developed using curriculum learning to identify ink signals across multiple scrolls. To optimize these models, a swarm of automated agents was deployed to continuously research and refine model architectures, successfully doubling validation scores in certain cross-scroll tests.

These technical advancements resulted in significant papyrological discoveries. Approximately 70% of the lower ink-bearing region of Scroll 5 was digitally unwrapped. From this scroll, researchers recovered the first-ever noninvasively read title of a still-rolled scroll: Philodemus's On Vices. Further text extraction from the scroll revealed a passage criticizing public rumor-mongering, which included an exciting identification of a quotation from the Characters of Theophrastus regarding a repulsive man standing by a barbershop and perfume shop.

In conclusion, the integration of high-resolution phase-contrast X-ray tomography with advanced machine learning segmentation and generalist ink detection models has proven highly effective. These automated tools are actively bridging the gap between raw volumetric data and readable ancient texts, bringing the scientific community closer to fully unwrapping entire scrolls quickly and accurately.

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