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Tomviz: An Open-Source Platform for Electron Tomography

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Three-dimensional characterization of materials at the nano- and meso-scale has become possible with transmission and scanning transmission electron microscopes (S/TEM) [1,2]. As the use of three-dimensional (3D) tomography in materials science progresses, the community must develop innovative software platforms for real-time analysis and processing of chemical information provided by S/TEM spectrometers. While capable instrumentation is abundant, this rapidly expanding field is bottlenecked by the lack of advanced and streamlined software. Tomviz is an open-source project offers powerful tomographic pipelines that works on all major operating systems. Now *tomviz* has expanded to offer capabilities for visualizing real-time reconstructions and multi-channel chemistry of nanomaterials.

Using the *tomviz* platform, researchers can now visualize the 3D structure of materials in real-time while experimental projections are collected in an electron microscope (Fig. 1). *tomviz* monitors when new projections are collected (Fig. 1a), and continuously appends new images into the reconstruction process (Fig. 1b). The graphical interface allows objects to be rendered as shaded contours or volumetric projections and these objects can be rotated, cropped, or sliced while the reconstruction runs on a separate thread (Fig. 1c). Ultimately, interactive real-time visualization allows researchers to make early judgments and best answer scientific questions. Thus, scientist can go beyond superficial inspection to quantify specimen features or internal structure while simultaneously operating the microscope. This immediate feedback saves researchers days of effort as reconstructions are no longer processed offline.

Support for chemical and multi-modal tomography is now available on the *tomviz* platform enabling the visualization of multi-component volumes. Utilizing inelastic scattering modalities such as electron energy-loss spectroscopy (EELS) extends the capabilities of electron tomography by producing chemically sensitive 3D volumes at the nanometer scale. Recent developments in multi-modal data fusion links simultaneously acquired S/TEM signals resulting in substantially improved chemical maps [4]. We demonstrate EELS tomography (Fig. 2) on an experimental CuS (purple) - ZnS (green) nanocluster with an oxidized ZnO layer [5]. On *tomviz*, researchers can simultaneously characterize high-resolution structural information produced from high-angle annular dark-field (HAADF) and chemical components generated by EELS reconstructions. Multi-component chemical tomograms are seamlessly mapped to separate color channels to easily produce directly interpretable visualizations.

Tomviz offers unparalleled electron tomography throughput with tools for real-time 3D and chemical analysis — it is open-source and available to all institutions for download at www.tomviz.org [6]

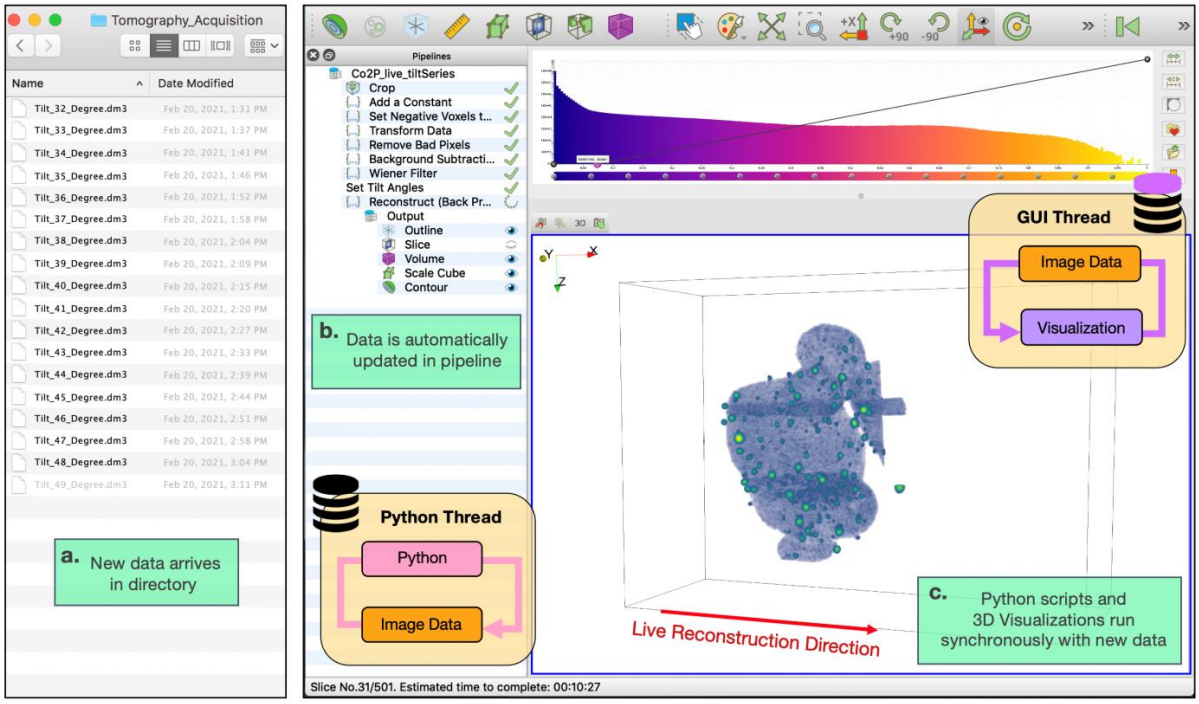

Figure 1: The *tomviz* graphical user interface monitors **a,** for recently acquired tilt projections within a directory and **b**, automatically reads new data into the pipeline. **c,** As tomographic reconstructions proceed, visualizations dynamically update and remain interactive for analysis. Interactive 3D visualizations, such as volumetric or contour surfaces, can be used in combination

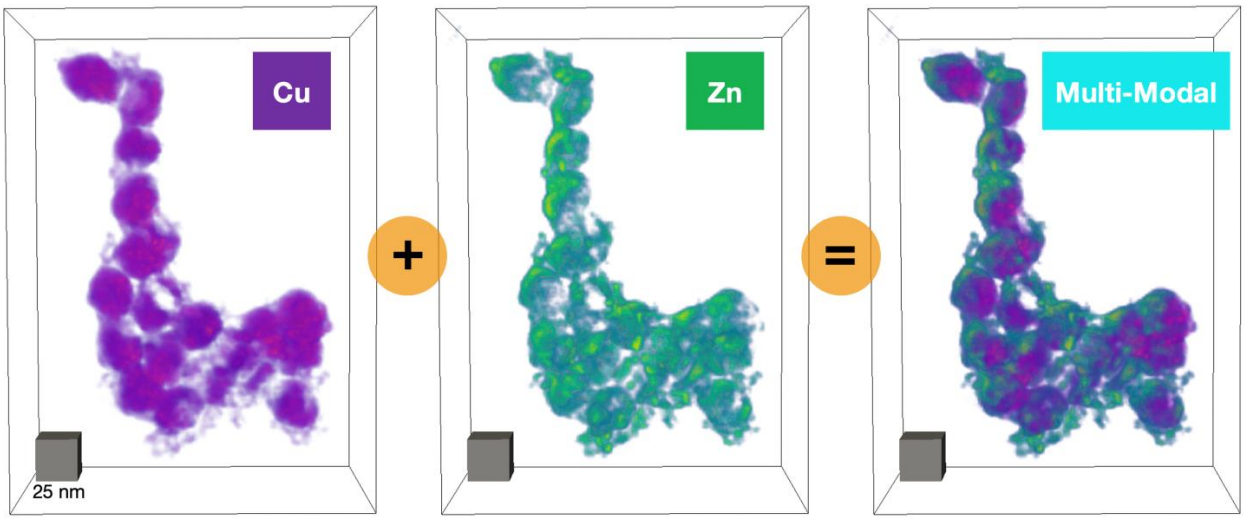

Figure 2: Chemical EELS tomography visualized on *tomviz*. 3D volumes of individual chemistries and a composite which highlights Zn and Cu rich regions can be simultaneously rendered on tomviz to facilitate material analysis.

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