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Machine-Learning Methods: Analysis of Rock Images and Beyond

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Machine-Learning (ML) methods provide a more accurate and robust approach to the processing of images, including high-resolution images of pore systems acquired with micro-CT and SEM techniques. Micro-CT volumes generally are several mm^3 with voxel resolution of ~ 1 micron, while FIB-SEM 3D volumes are 1.0E-6 mm^3 with voxel resolution of 5-10 nm. The images reflect differences in X-Ray adsorption (micro-CT) and electron density (SEM), both of which can provide large contrast between mineral grains and pores. In an ideal situation the samples are characterized by a histogram of measured intensities that is binary, which makes segmentation of grains and pores very straightforward. The reality is that image quality is often compromised by instrument noise, overlapping phases in a given voxel and other factors that generate an intensity histogram that is less discrete and more difficult to process. A machine-learning based segmentation tool provides a more robust solution to the phase separation challenge by including a wide range of statistical measures of each voxel in the image. Along with the basic image intensity value for each voxel, the accumulated statistics include information on nearest-neighbor and next-nearest-neighbor properties derived from a series of filters and gradient measurements. Training strategies can differ amongst users and their experiences, but a common approach is to emphasize the regions near pore-grain interfaces. Since the ML-based segmentation includes nearest-neighbor information, it can be used to distinguish phases with similar intensity but distinctly different surface textures as observed by the user. Image quality is the main control over the number of discrete solid phases that can be discriminated by the ML-based segmentation, with examples of up to five mineral phases captured from high-resolution SEM images validated against bulk XRD mineralogy results. Segmentation of pore space is validated through visual inspection followed by comparison of static properties, e.g. porosity and pore-size distribution, and finally dynamic properties such as permeability, capillary pressure, relative permeability and upscaling. These algorithms and workflows can be applied to other large dataset such as image logs, whole core CT and core photos.