Reconstruction of Three-Dimensional Micro-Structures From Two-Dimensional Microscopic Images Using Texture Synthesis and Phase Field Method

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Micro-structures become increasingly important in modern engineering and scientific applications, as the scale of functional device decreases. Examples include battery cathode where micro-porosity increases surface area for energy storage; controlled release drug where interconnected drug phase influences release rate and duration; and tight hydrocarbon reservoir where oil and gas in submicron pores dictates the energy future of our society due to its massive reserve.

Thanks to the unprecedented resolution represented by X-Ray Micro-Computed Tomography (Micro-CT, with resolution 15 nm - 50 um), Focused Ion Beam Scanning Electron Microscopy (FIB-SEM, with resolution between 3 nm - 100 nm), and transmission Electron Tomography (eTomo, with resolution between 0.2 nm - 5 nm), three-dimensional (3D) micro-imaging becomes a critical tool in micro-structure characterization. However, 3D micro-imaging experiment remains to be costly, hence limits the potential for broader adoption. Long imaging time and strict sample requirements further refrain the tools from applications involving liquid content and dynamic conditions including but not limited to the gradients of pressure, temperature, and mass transport.

Two-dimensional (2D) micro-images, in comparison, are more easily available. They provide important insight to the morphology and distributions of the micro-structures, with low cost-to-information ratio.

This project uses 2D micro-images to reconstruct 3D micro-structures. Statistical information from 2D images are extracted with an artificial-intelligence based image processing software [4]. These statistical models are then used as an input for both texture synthesis method (Figure 1 [1]) and sphere-packaging method [3], with reasonably good results. Furthermore, phase field function[2] is solved using all the pixels of the 2D image as input, to reconstruct a corresponding 3D volume. The reconstruction method can be further constrained by statistical information and additional 2D images in one or multiple orientations. The accuracy of the reconstructed 3D volume in comparison with the actual 3D data acquired with Micro-CT and FIB-SEM will be reported. Imaging-modality considerations will be discussed. Computing efficiency and implementation caveats will be summarized and reported.

References:

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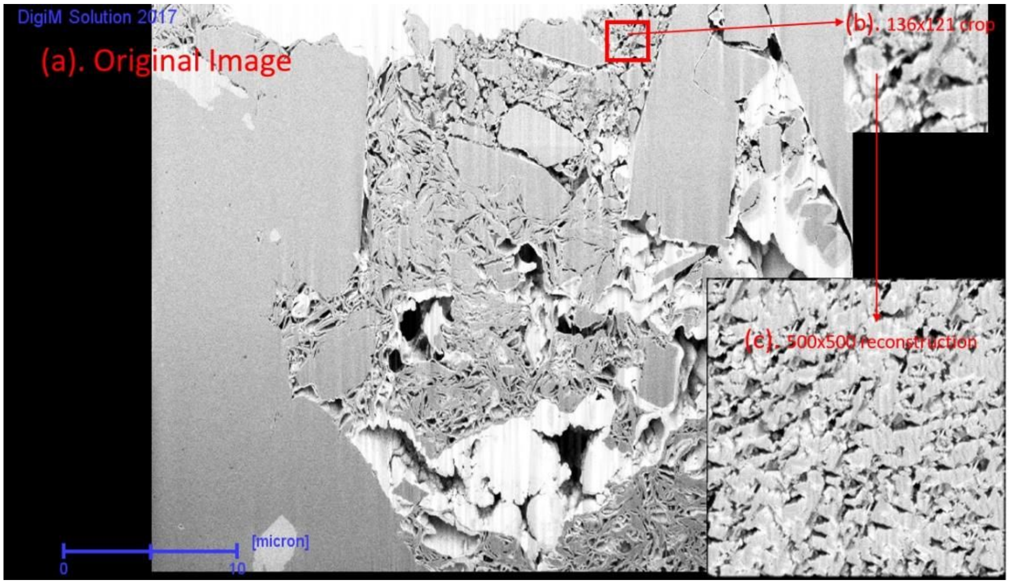
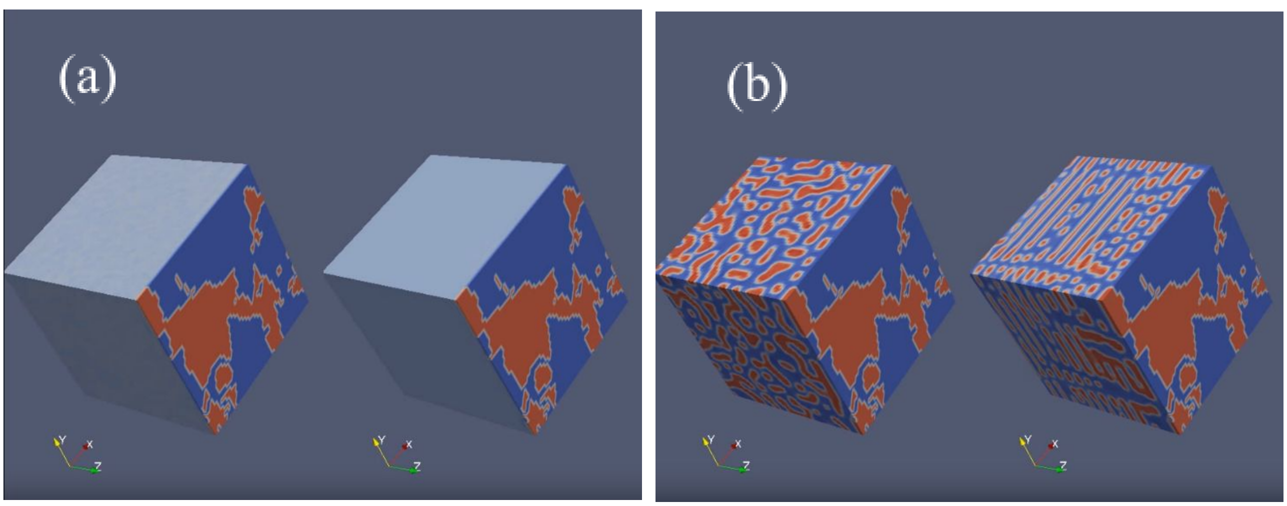


Figure 1. Reconstruction of tight sandstone intergranular porosity using GPU accelerated texture synthesis. (a). Original SEM image with heterogeneity and imaging artifact that made it unsuitable for petrophysical modeling; (b). Small area representative for intergranular porosity; (c). Reconstructed intergranular porosity from (b) using texture synthesis on a more representative larger area that is suitable for petrophysical characterization.



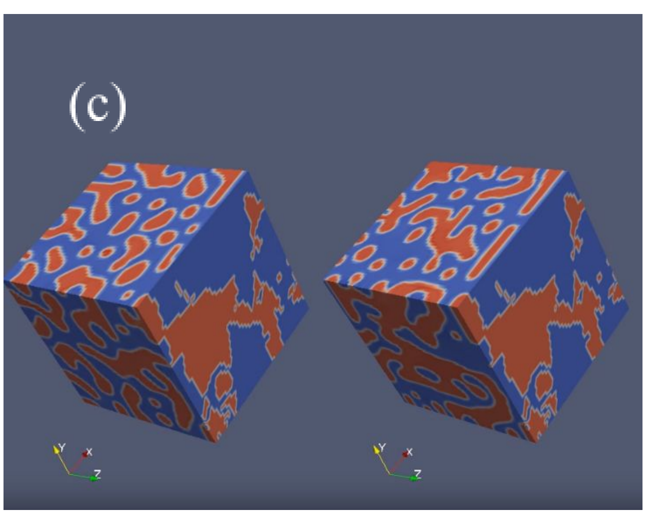


Figure 2. Reconstruction of 3D tight carbonate micro-porosity network using phase field simulation initialized with one 2D segmented SEM image. Figures (a)-(c) represent increasing iteration numbers. For each figure, the left simulation uses a random function to initialize the 3D domain; the right simulation uses the 2D image to initialize the full 3D domain.