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Three-dimensional image processing and analysis: segmentation, contact angle and curvature mapping

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Recent advances in three-dimensional imaging, using X-ray micro-tomography (μCT), has allowed to observe fluid configurations in porous media and measure various pore-scale properties such as contact angle, curvature, fluid connectivity (1-6). In general, gray-scale images obtained from μCT are pre-processed to remove artefacts before reconstruction and then filtered to enhance signal-to-noise ratio. Typically, the filtered images are segmented into various phases using a watershed algorithm. However, with recent developments in machine learning algorithms (7), gray-scale images can be effectively segmented without applying a noise-reduction filter, which can produce more accurate segmentation without the risk of possible smoothening of the image (8). This is essential to compute various porous media properties.

The segmented images are traditionally used to characterize the geometry of the pore space and to construct a pore-network representation of it. Most recently, these images have been used to determine the in-situ wettability state of porous media by measuring effective contact angle at the three-phase contact line, either manually (2) or most recently automatically (1, 9). Furthermore, the segmented data can be processed to estimate fluid-fluid curvature (4, 6, 10), which can then be used to calculate capillary pressure using the Young-Laplace equation. Estimation of these pore-scale properties, along with our ability to image dynamic processes using fast synchrotron imaging (3, 11), provide a valuable tool to understand immiscible fluid displacement in porous media, which was mainly restricted to two-dimensional visualization in the past. Although most of the individual three-dimensional image processing methods have already been demonstrated in recent years, the novelty is to integrate them together for the interpretation of μCT fluid flow experiments towards a specific goal.

Apart from the above discussed advances in measuring pore-scale properties, in this talk, I will show some simple tools using an open-access ImageJ software to process tomographic data. Moreover, I will provide examples of image processing that has helped to understand biological systems, particularly, termite nests.

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Primary author: SINGH, Kamaljit (Department of Earth Science and Engineering, Imperial College London, London, UK)

Presenter: SINGH, Kamaljit (Department of Earth Science and Engineering, Imperial College London, London, UK)

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