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In situ Dynamic X-ray Tomography in the Laboratory

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Over the past decade, laboratory-based X-ray computed micro-tomography (micro-CT) has provided unique insights in the internal structure of complex materials and devices in a broad range of applications, from porous geological materials to structural engineering materials to electronic devices. Beyond static structural characterization, the non-destructive nature of micro-CT imaging, combined with dedicated X-ray transparent *in situ* equipment (eg. flow cells, tensile/compression stages, heating/cooling stages) has made it possible to monitor a changing pore structure or evolving material microstructure over time in 3D. *In situ* studies represent some of the most important scientific drivers of this technology, however, their widespread adoption has been limited to proof-of-concept excursions due to significant technical barriers preventing routine use.

While spatial resolutions and image quality have continued to improve significantly [1], recent advances in laboratory-based approaches have pushed achievable temporal resolutions from hours down to seconds, enabling the visualization of dynamic processes and real-time imaging [2]. Dynamic acquisitions, however, generate a vast amount of raw projection data, which needs to be reconstructed and further post processed and eventually quantified. It is therefore essential to devise workflow strategies to quickly identify the interesting moments prior to reconstruction to optimize the amount of data that is generated, but also incorporate the added time dimension in the 3D analysis workflow to improve image quality.

Here we present challenges and possibilities in dynamic micro-CT imaging related to acquisition, reconstruction and analysis. The methodology and dedicated workflow from acquisition through analysis is illustrated by way of example using fluid flow experiments performed in a custom-made X-ray transparent flow cell on artificial and geological porous structures. These multiphase flow experiments were focused on drainage processes, injection of non-wetting liquid (oil) in the pore network, and imbibition processes, injection of wetting phase (water) in the pore network. The experimental setup for both flow experiments was very similar and details can be found in Bultreys *et al.* [3]. The capabilities of dynamic reconstruction and the incorporation of temporal information in the 3D analysis of the pore space facilitate the automatic identification pore filling events and pinpoint these events in time. By reconstructing images from different time intervals and merging the appropriate temporal and local information for analysis, the speed and size of these events can be monitored. Finally, extrapolations to other classes of in situ experiments will be discussed.

References:

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[3] T Bultreys *et al*, Water Resources Research 51 (2015) p. 8668-8676.

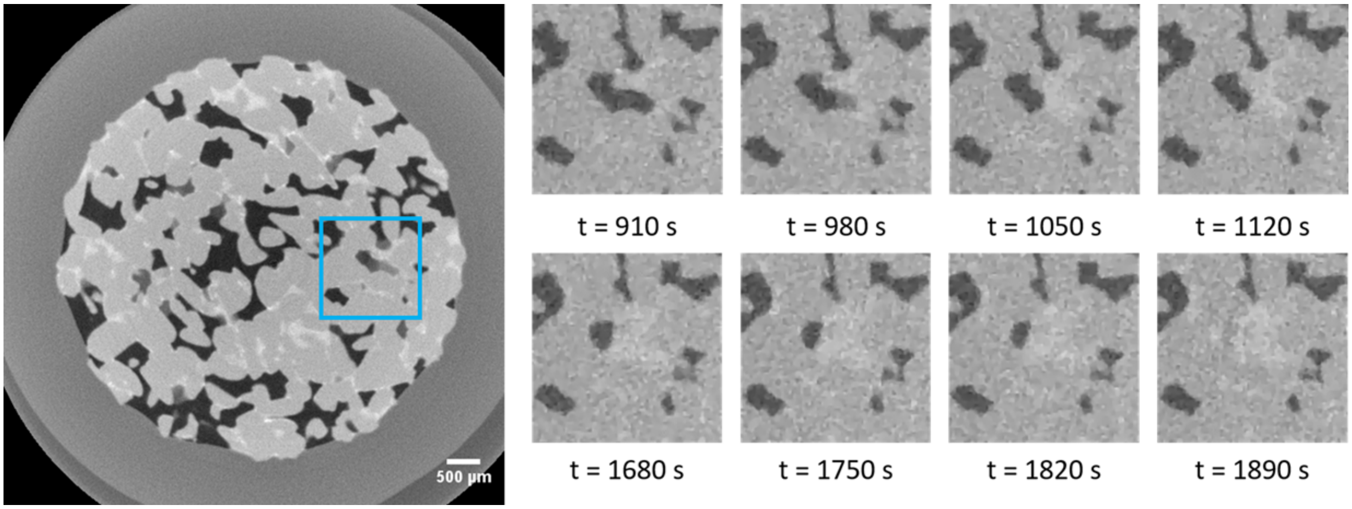

Figure 1. 2D virtual slice of 3D micro-CT data from a cylindrical volume (voxel size 13 µm) of a porous geological sample. Right: Detail of pore filling evolution during imbibition. Each reconstructed volume has a temporal resolution of 70 seconds.

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