From 3D images of pore space to pore network models: Image processing and local flow modelling

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1 Introduction

Pore network models (PNM) are widely used for more than 50 years to study transports in porous media at the pore scale. The basic idea of this approach is that the intrinsic complexity of porous media can be addressed considering a large number of simple elements (the pores) connected through simple rules. Most of the PNM are based on building blocks having predetermined geometries (spheres, cubes, cylinders with circular, triangular or square section, etc…) positioned on regular grids. Connection rules are determined studying the considered transport between two pores. To generate the PNM corresponding to a given porous media, parameters are defined fitting some global measurements like porosity, pore size distribution, etc…Now that 3D imaging techniques allow very precise representations of pore space geometry, it is logical to try building PNM directly from 3D images after extracting all the relevant topological and geometrical aspects of the considered porous medium. But, even if 3D images are now easy to obtain, the construction of a representative PNM using only information directly extracted from the 3D images appears to be still difficult.

In this talk we present a methodology for such a construction. In the first part the image processing steps are detailed and in the second, the local flow corresponding to intrinsic permeability estimate is considered.

2 Image processing

The starting point of this study is a 3D binary image of a porous sample, segmentation is not considered albeit it is a crucial step that strongly affects the final results.

To decompose the pore space in simple elements, the pores, a definition of what is a pore is necessary. After some attempts, and considering the difficulty of stating a definition effective for any 3D voxelized image, we only postulated that at any intersection of potential flow paths there is a porel (pore space element). Skeletonization appears as the natural tool to detect these intersections. Many algorithms, most based on the notion of homotopic thinning, exist to produce a skeleton defined as a homotopic subset, of lesser dimensionality, of the pore space. Recent works in the field of discrete geometry clarified the mathematical framework (see [1]) and skeletonization can be considered as a reliable process. The main drawback of skeletonization is its sensitivity to noise, i.e. very small changes in the binary image might induce large modifications of the skeleton. In the case of 3D images obtained by segmentation of noisy grey level images, inaccuracy in the segmentation produces different topological artefacts (surfaces, multiple branches, etc.) that are generally attenuated using adapted filters [2]. In [1], the authors adopted a different approach: all the cases where a single voxel generates a 0D, 1D or 2D artefact have been identified and filtering a 3D image consists in, first detecting the voxels corresponding to one of these cases and, second modifying it to eliminate the artefact. This approach is more efficient than classical filtering as shown in [1].

From the clean skeleton it is easy to detect the junction points where porels will be placed. Because we are dealing with discrete images, several junctions might be identified in the same volume, giving an over-partitioning. This is solved defining merging rules between identified porels. The different steps described above are illustrated by an example in figure 1.

Once the number and location of porels are determined, the porel volumes are constructed using a watershed algorithm with the maximum ball centred on each porel location as seeds. The resulting pore space partition covers entirely the pore space and the intersections of its elements (porels) are surfaces. The skeleton can be directly used to build the graph corresponding to the future pore network. Unfortunately this graph is not correct in cases, very common but generally ignored in the literature, where the surfaces limiting a porel are not or solid or common to two porels; some surfaces are separating more than two porels (figure 2).

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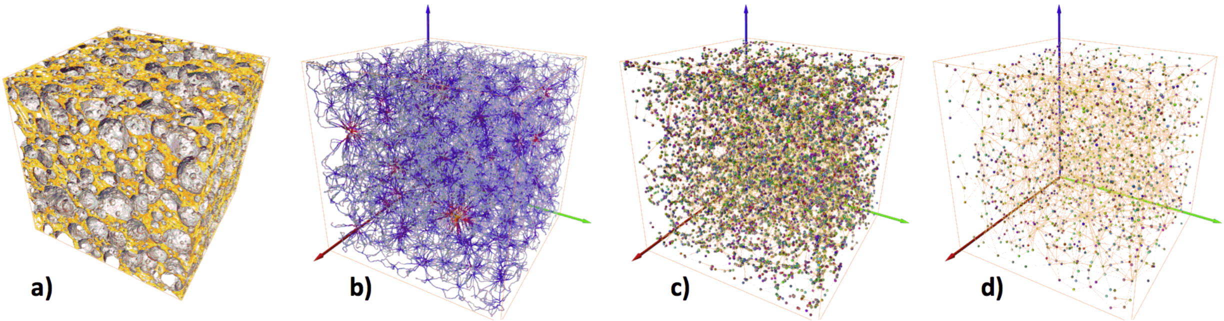

Figure 1: Illustration of the different steps between; a) the 3D image (500^3 voxels, solid phase in yellow), b) the skeleton (colour depends on the distance map), c) the first graph, d) the graph after merging of overlapping porels.

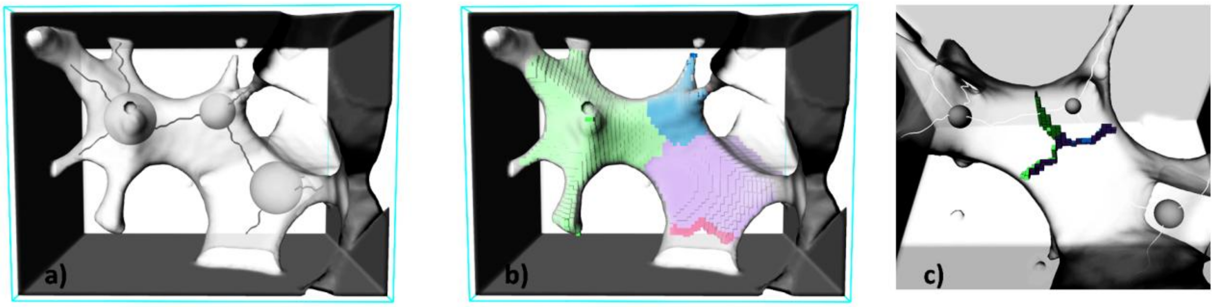

Figure 2: Example of a surface separating more than two porels; a) the skeleton and the porels location, b) the porels, c) the surfaces between porels.

In order to handle these cases as well as the porels at the boundaries of the domains, a new graph is built directly from the partition without direct reference to the skeleton. The construction of the PNM is based on this graph.

3 Local flow modelling

The graph built as presented above is composed of nodes (the porels centres) and branches connecting porels. To compute the permeability of the porous sample, the Stokes equations is integrated, over each porel for the mass conservation one, and along the branch connecting two porels for the momentum conservation one. It is easy from these integrations to prove the existence of coefficients linking the pressure values at the porel centres and the flow rates associated to the corresponding branch, and from that obtain the linear system to be solved for permeability evaluation. Assuming the uniqueness of these coefficients (i.e. assuming that they are totally determined by the local geometry), a procedure allowing to compute them solving a local flow problem is presented. Comparing the results provided by the PNM and the direct numerical modelling of the flow at the global scale, i.e. through the entire domain (figure 3), we explore the problem of uniqueness for different pore scale geometry.

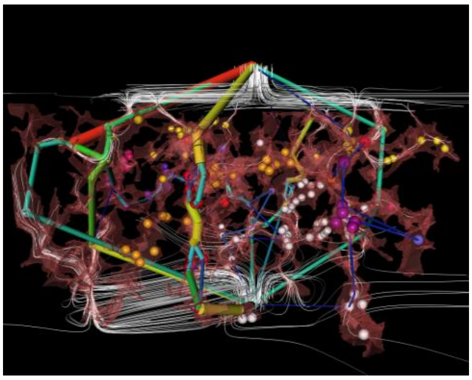

Figure 3: Comparison of the PNM results with a direct numerical computation.

References

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