Structure, key points

1. Introduction

* The limitation of 3D CT. The importance and motivation of 2D to 3D porous media reconstruction.
* Key issues / targets in porous media reconstruction:
  + Basic: natural connectivity in 3 directions.
  + Long range connectivity
  + Fine shape / boundary features
  + Spatial heterogeneity
  + Accurate multi-scale structure and cross-scale connectivity
* The development and limitations of existing reconstruction techniques:
  + Object based / process based
  + statistics based
    - Two point statistics based (e.g. simulated annealing)
    - Pixel based MPS (e.g. SNESIM, PAM)
    - Patch based MPS (e.g. CCSIM)
    - Texture synthesis (optimization based)
* Our contribution:
  + In this study we present a new 2D to 3D porous media reconstruction framework inspired by the field of solid texture synthesis that accurately preserves structural consistency to 2D training images and successfully predicts the petro-physical properties. We are able to reconstruct heterogeneous, anisotropic as well as multi-scale 3D structure from 2D training images using our general method. With the aid of parallelization, both accuracy and efficiency outperform or at least are comparable to state-of-the-art reconstruction algorithms.
  + More specifically, we studied and discovered two key techniques that greatly improves the capability and accuracy compared to previous methods:
    - Enrich the information in binary training image by distance map transformation.
    - Discovered that the tradition process in texture synthesis in order to reduce computation – PCA is the main reason for loss of fine features in the EM based algorithms. We adopt a K-coherence search technique to avoid the heavy computation caused by discarding PCA. (How to rephrase it so that it shows more importance and more brief?)
* The outline of the rest of the article is as follows. In section 2 the overview of our workflow and key techniques are described, including distance map transformation of training image, the influence of PCA in porous media reconstruction and the K-coherence search as the corresponding solution. Section 3 presents the detail steps of the methodology. In section 4 various porous media are reconstructed and analyzed, and the conclusion is given in section 5.

1. Methodology overview
   1. Workflow overview

E-M optimization based.

Multi-resolution

* 1. Distance map transformation

Explain by “Markovian property”

* 1. Influence of PCA

(Mainly focus on influence of PCA. The solution – K-coherence search is described further in 3.1.)

1. Detail steps of proposed algorithm
   1. Search step (E-step)

K-coherence search

Index histogram

* 1. Optimize step (M-step)

Discrete solver

Position and color histogram

Gaussian weighting scheme

* 1. Parallelization

Static workload schedule provides best cache usage and least communication cost

Minimum data synchronization

1. Evaluation Criteria
   1. MPC
   2. Minkowski functions: porosity, specific surface area, Euler-connectivity function
   3. Pore network statistics: pore network PSD, shape factor distribution, coordination number
   4. Predicted flow properties (single phase permeability, two phase flow rel. perm.)
2. Results and discussion
   1. Experiment environment

Detailed parameters

* 1. 3D actual data and training images

Berea, Fontainebleau, Grosmont, Cross-scale. (Andrä’s digital rock benchmark)

* 1. Reconstruction results
  2. Comparison with state-of-the-art algorithms? (visual and speed)

1. Conclusion

In this paper, we have presented a new framework for reconstructing 3D porous media using 2D training images, inspired by the solid texture synthesis algorithm. Based on our study we find that the distance map transformation greatly enriches the information of training images and could be used as a general pre-processing step for most training image based algorithms. On the other hand, the commonly used PCA process is proved to affect quality in the scenario of porous media reconstruction and should not be applied.

Our results demonstrate that we have successfully accomplished the difficult task of preserving both geometric and petro-physical properties for a wide variety of porous structures. The versatile capability and high quality exceed that of conventional reconstruction methods. With the easy implementation of parallelization, the efficiency of our method also outperforms or at least is comparable to previous algorithms.

This algorithm provides a general alternative for characterizing 3D porous media by using 2D thin sections. Moreover, as a scale-free algorithm it can be easily adjusted to cope with conditioning data and applied to geo-statistics reconstruction at larger scale.

For future work, we would like to further improve the capability by using multiple training images in each direction to deal with more heterogeneous structures which cannot be accurately characterized by single slice. Besides, 3D control map could be applied to reconstruct globally varying structure such as layered porous media.