Stochastic 3D rock reconstruction using GANs

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Porous media

- The behaviour of a fluid moving through sedimentary rock is controlled by the rock's pores structure at the micron scale
- The study of such structures in porous media plays a key role in many scientific applications [1]
- Micro computed tomography (micro-CT) scanners allows to acquire high-resolution 3D images of porous media at the scale of individual pores

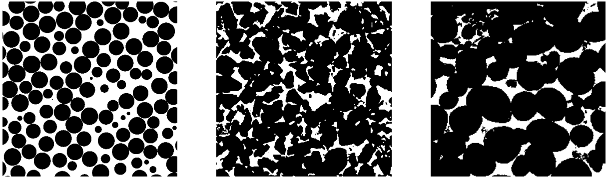


Figure 1: Cross-sections of three 3D images of porous media, turned into binary images to highlight the grain structure

Studying porous media

- To evaluate the variability of such morphology in a specific rock type, a large number of rock samples should be studied
- Using micro-CT scans to this purpose is often considered unfeasible due to the time and cost required for the acquisition
- This motivated the development of stochastic reconstruction methods that, when provided with few rock scans, aim at generating novel rock images exhibiting the same kind of pore structures

Stochastic reconstruction method

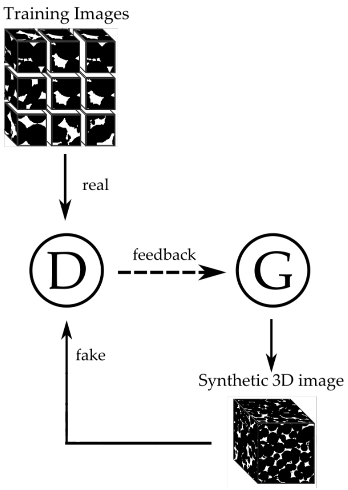
- Many methods are based on measuring some spatial statistical properties of the training images (e.g., the two–point pore–grain correlation) and producing novel images having similar values of these properties
- Simulated annealing with many statistical descriptors [2] and multi-resolution [3]
- High-order multi-point statistical properties [4, 5]
- Patch-based algorithms [6]
- Patch-based incorporating fast Fourier transform and a multi-scale approach [7]
- Nevertheless, to this day, statistical reconstruction is still very demanding in terms of computation, preventing its use for large 3D samples.

Generative models

- Generative models are a natural fit for our rock reconstruction problem
- The generation of new images using generative models is extremely fast after the initial training phase, thus avoiding the main drawback of traditional methods
- In 2017, Mosser et al. have investigated the use of GANs for the reconstruction of three-dimensional porous media [8]
- A few other studies followed [9], [10].

Method

- Improve network architecture with respect to the original study
- Introducing modern components (e.g., dropout, batch normalization, leaky relu)
- Tuning the network architecture
- More detailed and rigorous testing (cross-validation)



Evaluation

- Objective/quantitative evaluation of generative models is difficult [11]
- For porous media there are some well-established morphological criteria [12]
- Two-point statistics. The probability that two points x and $x + r$, separated by a lag vector r, are both located in pore phase P

$$S_2(r) = \mathbf{P}(x \in P, x + r \in P) \text{ for } x, r \in \mathcal{R}^3 \tag{1}$$

- Minkowski functionals: porosity ϕ, specific surface area S_V and Euler characteristics χ. The porosity is the ratio of void volume, i.e. $\phi = V_{\text{pore}}/V$, it measures the ability of the medium to store fluids. The specific surface area is the amount of surface per unit of volume, i.e. $S_V = \frac{1}{V}\int dS$. It controls the speed of adsorption and dissolution processes. The Euler characteristics is defined as

$$\chi = \frac{1}{4\pi V}\int \frac{1}{r_1 r_2} dS \tag{2}$$

Experimental study

- Three image datasets: Beadpack, Berea and Ketton rocks
- We trained the GANs five times for each dataset
- After each training, we generated 20 images, totalling 100 images per dataset
- We compared the generated images against a random sample of real images

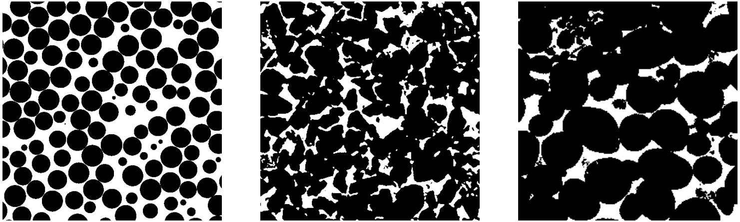


Figure 2: Beadpack, Berea and Ketton rock samples

Results – Beadpack – Visual comparison

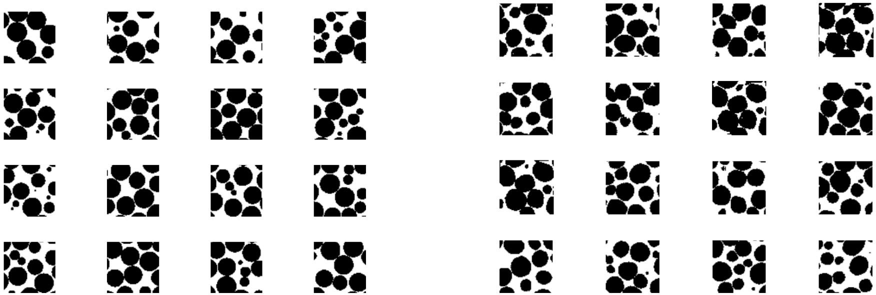
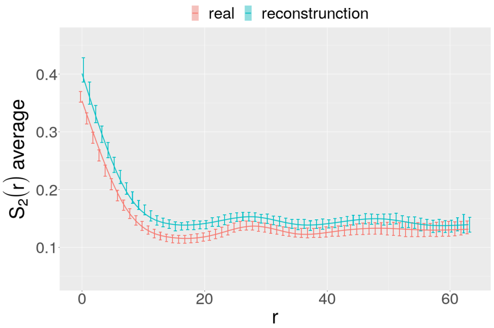
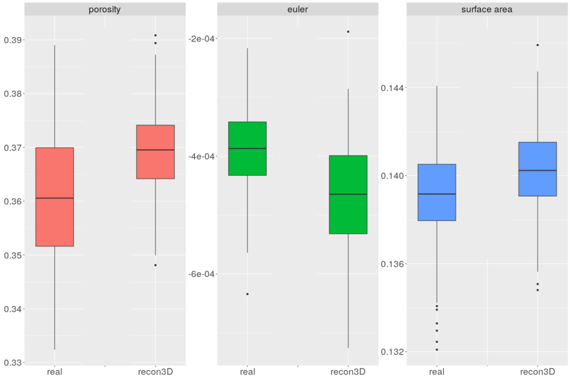


Figure 3: A set of 16 real images (left) and 16 reconstructions (right), with each column corresponding to a different training of the GAN.

Results – Beadpack – Quantitative evaluation





Thank you!

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