MIT EARTH RESOURCES LABORATORY
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Earth Resources Laboratory

Porous media reconstruction using Deep Texture Synthesis

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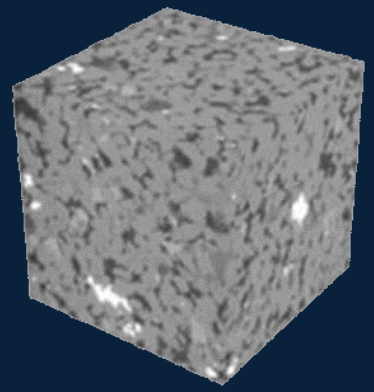
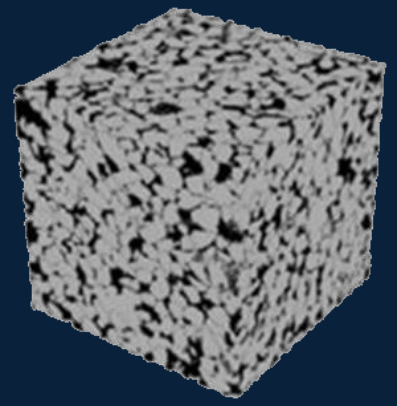
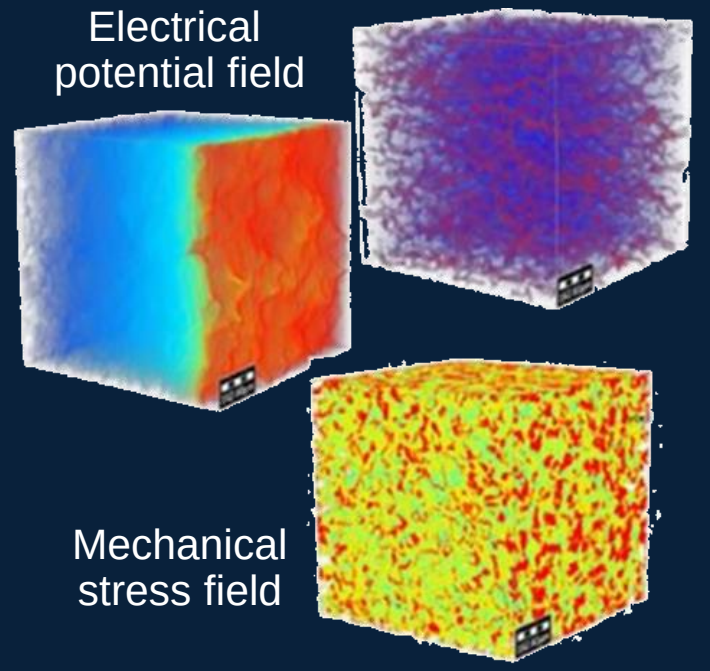
Digital Rock Physics is a game changer for the industry

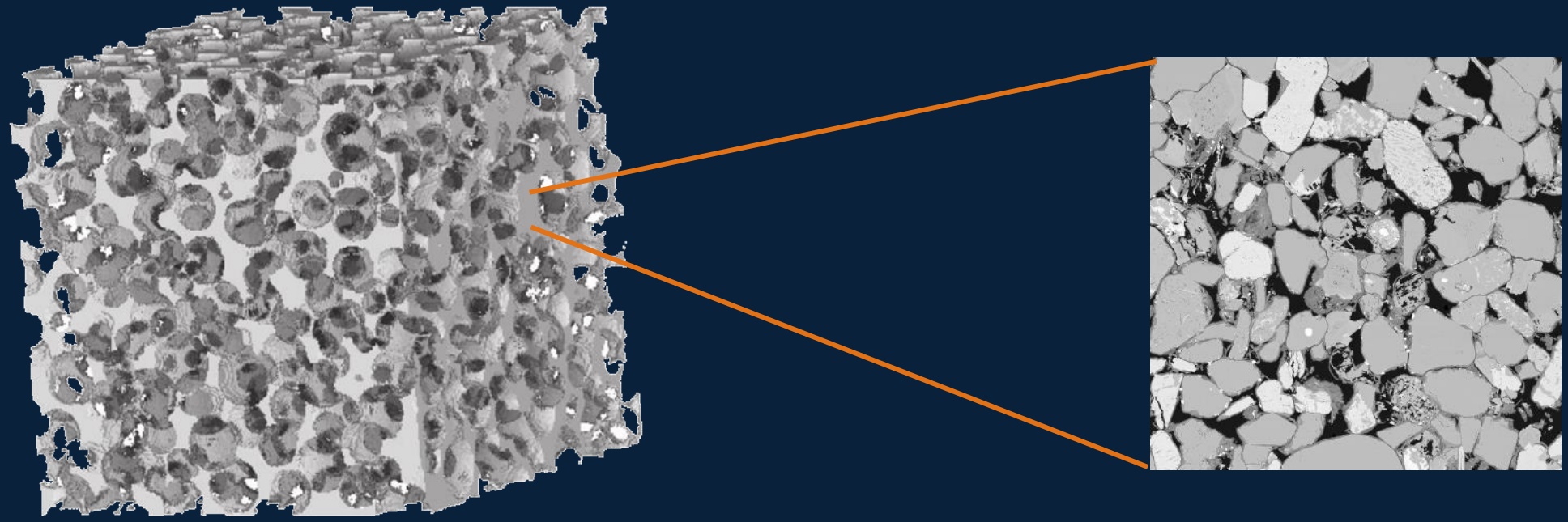
Imaging (μ-CT) → Image processing & segmentation → Computations → Physical properties







Higher imaging resolution is available in 2D



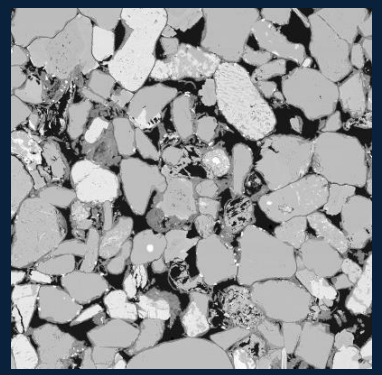
Micro-CT scan
Resolution: a few µm

SEM scan
Resolution: a few nm

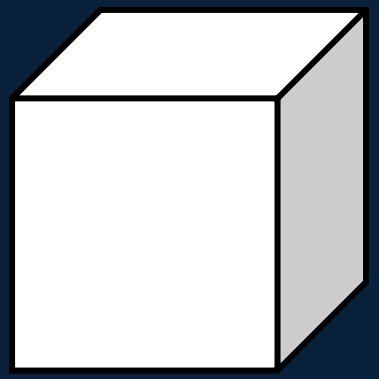
SEM images exhibit structures that are invisible at the micrometer scale!

Contribution: Exploitation of SEM images in Digital Rock Physics

What we did:



Ground truth



Synthetic solid

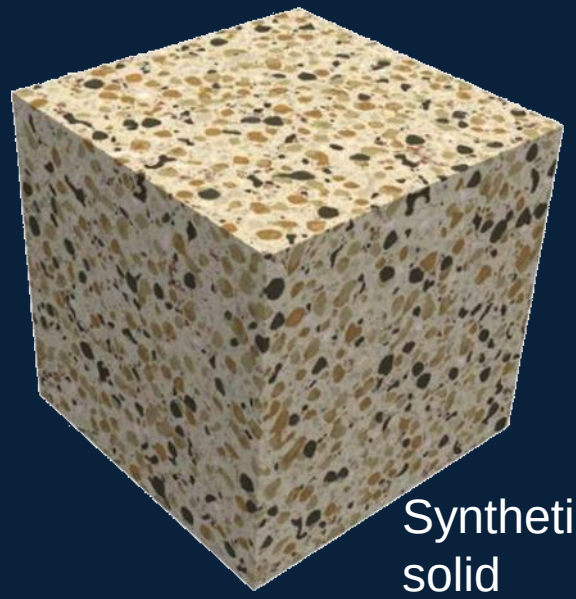
Quality criterion: preservation of macroscopic physical properties

Solid Texture Synthesis can be used to achieve the reconstruction task

Porous medium ≈ Stationary and isotropic random process = **Texture**

Texture example

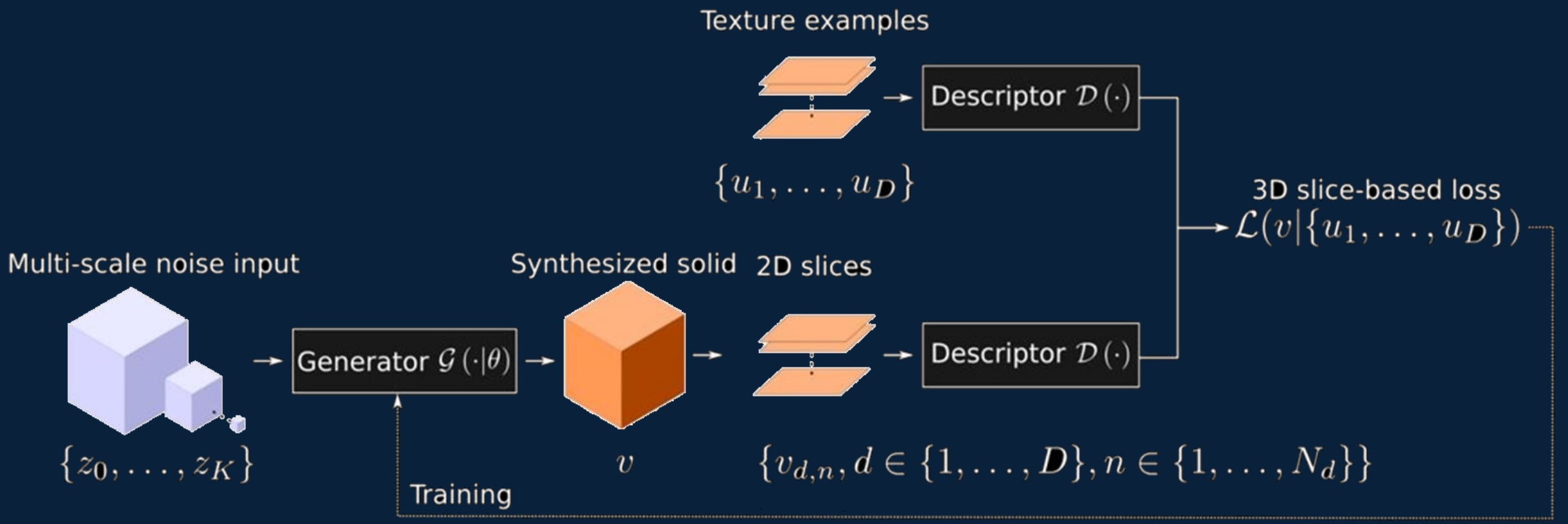
Solid Texture **Synthesis**



Synthetic solid

Objective: Every slice of the synthetic solid "looks like" the 2D texture example

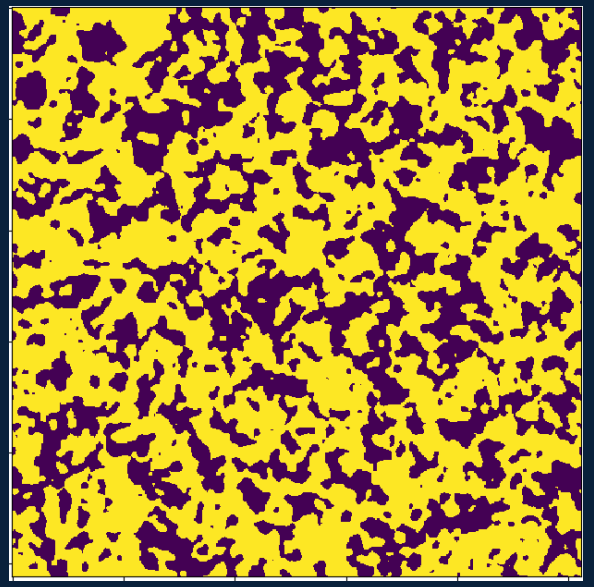
Solid Texture Synthesis Solution: Deep Convolutional Neural Networks



The solution has several advantages

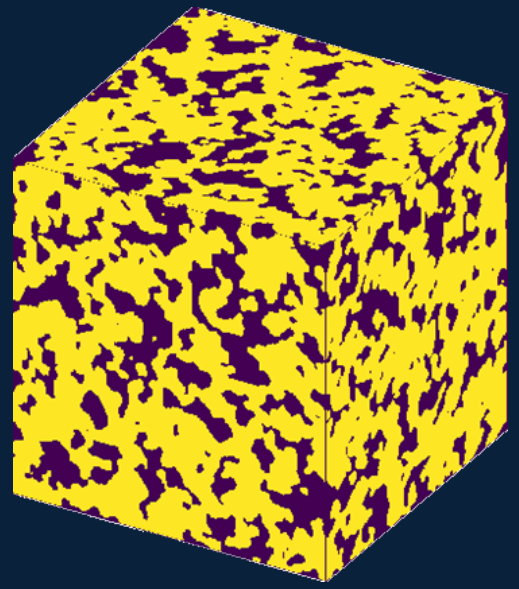
- Learns the distribution of the original porous medium
- Seed images and generated samples can be of arbitrary size (textures are infinite)
- Able to naturally produce periodic samples
- Training is straightforward (no need to train a descriptor)

Results are visually pleasing for porous media



2D ground truth (512^2)

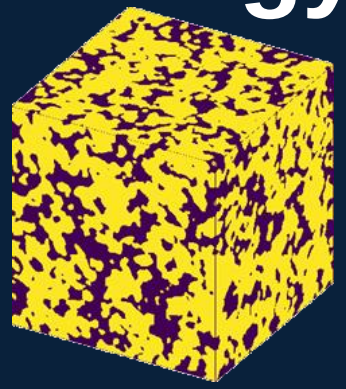
Training and Sampling



3D generated sample (256^3)

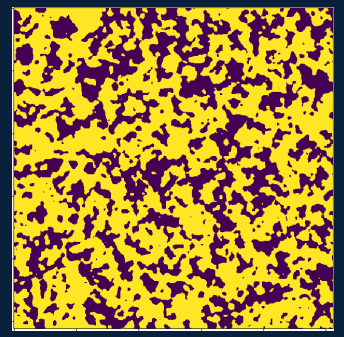
But are the physical properties preserved in the process?

Validation methodology



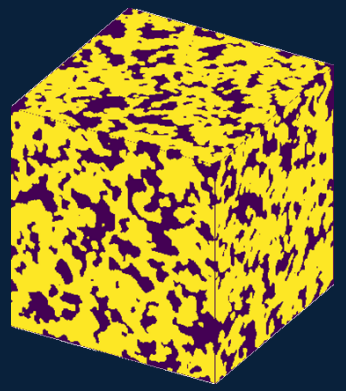
Synthetic "ground truth"

Take any slice



Slice of ground truth

Train & sample



Generated samples

Compare

We use metrics that are relevant in Digital Rock Physics

- Two-point correlation function $S_2(r)$

- Effective electrical conductivity σ_{eff}

Two-point correlation captures second-order statistics

Porous medium = random process: $f(\vec{x}) = \begin{cases} 1, & \text{pore phase} \\ 0, & \text{solid phase} \end{cases}$

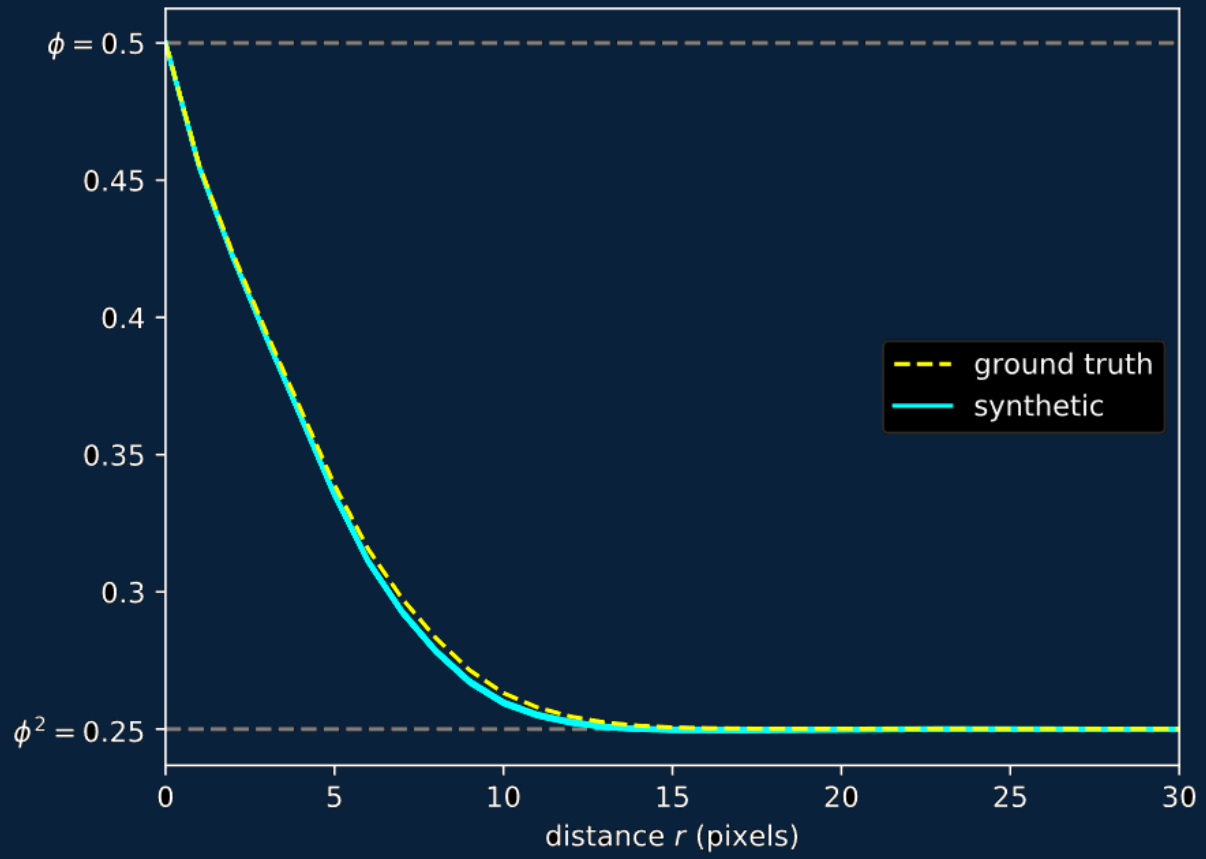
Porosity: $\phi \triangleq \mathrm{E}_{\vec{x}}[f(\vec{x})]$

Autocorrelation: $S_2(\vec{r}) \triangleq \mathrm{e}_{\vec{x}}[f(\vec{x})f(\vec{x}+\vec{r})]$

Assuming isotropy: $S_2(\vec{r}) \rightarrow S_2(r)$

Observation: $S_2(0) = \phi,\ S_2(\infty) = \phi^2$

Two-point correlation is preserved by the reconstruction



Effective electrical conductivity is an important physical property

Global law (Ohm): $I = -\sigma_{\text{eff}}\,\Delta V$

Induced current

Applied potential difference

Local law (Kirchhoff):

Electric field

Local potential

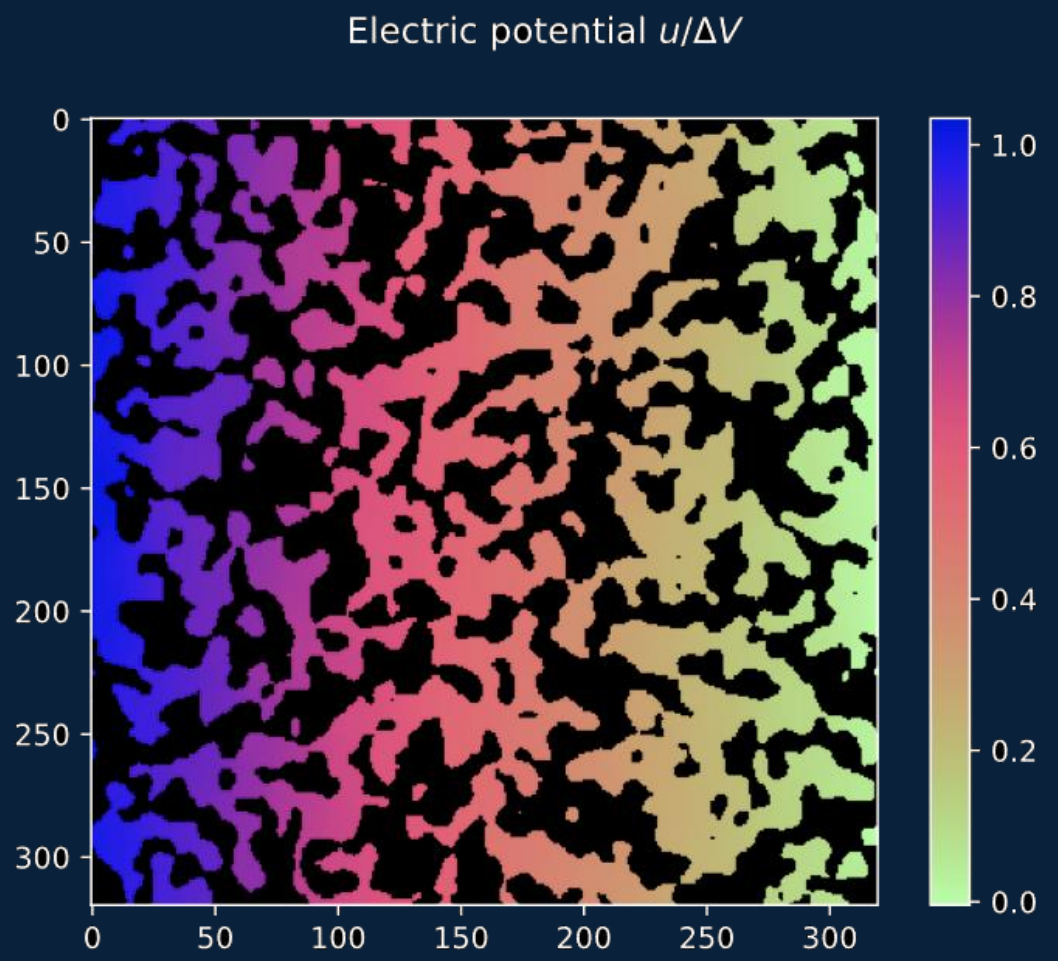
$$\vec{E} = -\nabla u$$

$$\nabla \cdot \vec{E} = 0$$

Strong connections with hydraulic permeability!

Effective electrical conductivity is preserved by the reconstruction

Effective electrical conductivity	$\sigma_{\text{eff}}/\sigma$
Ground truth	0.2507
Mean of 10 synthetic samples	0.2552
Stdev of 10 synthetic samples	0.0012
Relative error	**1.8%**



Deep texture synthesis is an effective approach to exploit 2D images

- In Digital Rock Physics, incorporating high-resolution 2D information could create higher-quality porous media models
- Our approach: reconstruct 3D from 2D using recent techniques for the texture synthesis problem
- The solution has properties that make it attractive for Digital Rock Physics
- Important physical properties are successfully preserved