Reparameterization of Complex Geological Models Using Neural Style Transfer

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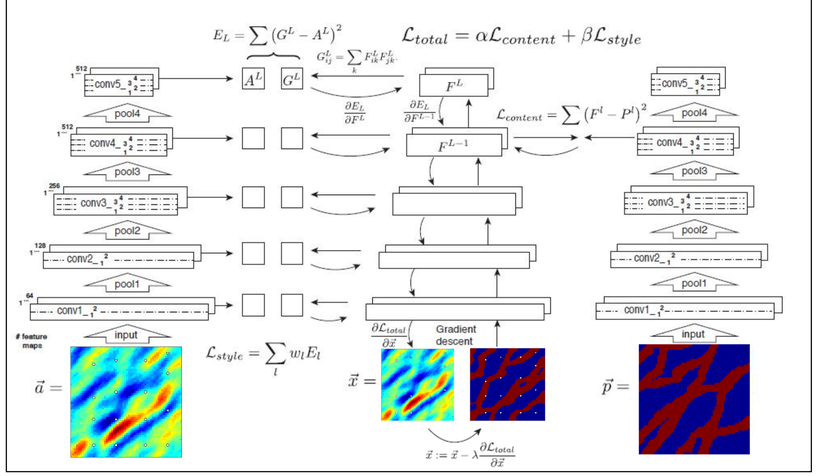
Introduction

In the field of reservoir engineering, lower dimensional reparameterization for complex geological models is an important but challenging problem. Properties for complex geological models such as facies are non-Gaussian. Existing methods such as principal component analysis (PCA) and optimization-based PCA (O-PCA) need improvement especially for unconditional models [1].

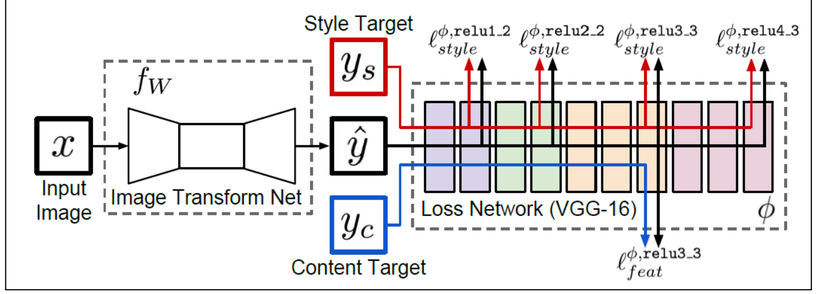
In this study, we explore the application of neural style transfer for the reparameterization of non-Gaussian geological models. Our idea is to use the neural style transfer algorithm as a post-processing step after traditional PCA transformation. The purpose is to apply the neural style transfer algorithm to transfer the Gaussian-like PCA model to match the style of the original non-Gaussian model.

Methodology

Neural Style Transfer



Fast Neural Style Transfer



Procedures & Equations

- Perform PCA on original models to reduce dimension

PCA:

$$X_c = [\mathbf{m}_1 - \bar{\mathbf{m}} \quad \mathbf{m}_2 - \bar{\mathbf{m}} \quad \ldots \quad \mathbf{m}_{N_r} - \bar{\mathbf{m}}]$$

$$X_c = \sqrt{N_r - 1} U \Sigma V^T = \sqrt{N_r - 1} \Phi V^T$$

$$\mathbf{m} = \Phi \boldsymbol{\xi} + \bar{\mathbf{m}}$$

- Perform neural style transfer using PCA model as content image, original model as style image

CNN-PCA:

$$L_t = \sum_{l=1}^{L} \alpha_l L_c^l + \lambda \sum_{l=1}^{L} \beta_l L_s^l + \omega L_h, \quad \text{Total loss}$$

$$L_c^l = \frac{1}{2 N_l D_l} \sum_{ij} (F_l[O] - F_l[I])_{ij}^2, \quad \text{Content loss}$$

$$L_s^l = \frac{1}{2 N_l^2} \sum_{ij} (G_l[O] - G_l[S])_{ij}^2. \quad \text{Style loss}$$

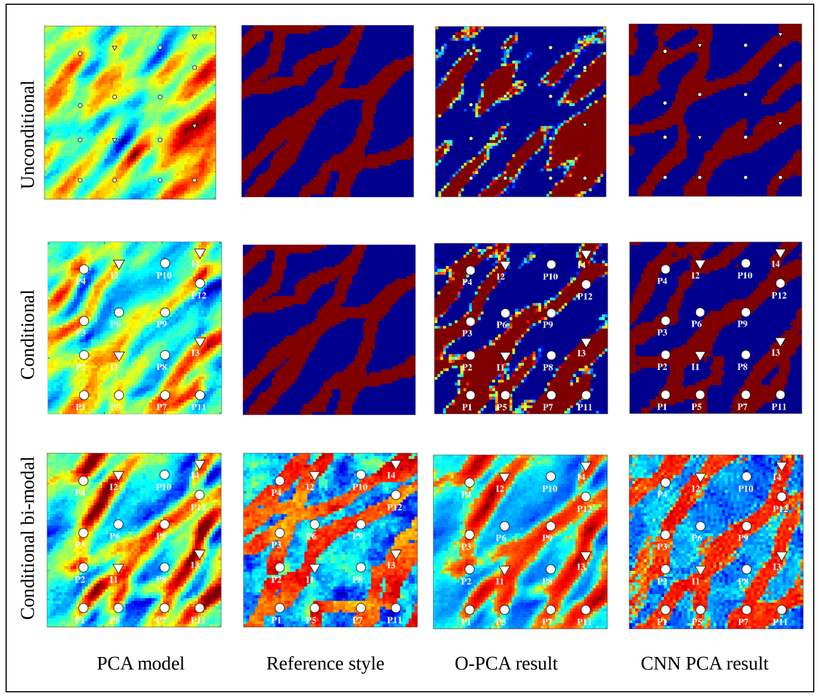
$$L_h = \sum_{ij} h_{ij} (I - O)_{ij}^2. \quad \text{Well data loss}$$

- Perform O-PCA to further post-process the model

O-PCA:

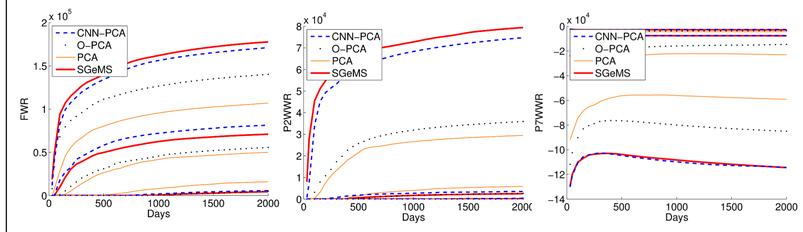
$$\mathbf{m} = \underset{\mathbf{x}}{\operatorname{argmin}} \left\{ ||\Phi \boldsymbol{\xi} + \bar{\mathbf{m}} - \mathbf{x}||_2^2 + \gamma \mathbf{x}^T (\mathbf{1} - \mathbf{x}) \right\}, x_i \in [0, 1]$$

Post-processed Reservoir Models

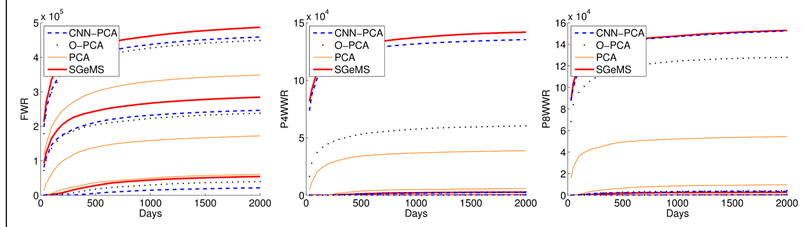


Flow Statistics

Unconditional models



Conditional models



Conclusions

- Applied both neural style transfer and fast neural style transfer algorithm for reservoir reparameterization problem.
- Included hard data loss in the style transfer algorithm to ensure that output model honors hard data.
- The CNN-PCA algorithm outperforms O-PCA method in terms of preserving channel connectivity and flow statistics, especially for unconditional models .

Reference

[1] L.A.Gatys, A.S. Ecker, and M. Bethge. Image style transfer using convolutional neural networks. *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition.* p2414-2423, 2016.

[2] J. Justin, A. Alexandre, and F.F. Li. Perceptual Losses for Real-Time Style Transfer and Super-Resolution. *European Conference on Computer Vision. Springer International Publishing*, 2016.

[3] H.X. Vo and L.J. Durlofsky. A new differentiable parameterization based on principal component analysis for the low-dimensional representation of complex geological models. *Mathematical Geosciences*, 46(7):775–813, 2014.