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3D Geological Volume Generation Using 2D GAN Training and Slice Stacking

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Abstract Summary

We present a novel and computationally efficient method for generating 3D geological facies models using 2D-trained Generative Adversarial Networks (GANs). Traditional 3D GAN training demands substantial computational resources, often large amounts of GPU memory. In contrast, our approach leverages 2D slice-based training, requiring a minimum of 16 GB, while maintaining high-quality geological realism.

Introduction

Generative Adversarial Networks (GANs) have demonstrated strong potential for generating synthetic geological images (Goodfellow et al., 2014). However, training GANs in 3D is computationally intensive, often requiring over 40 GB of GPU memory, whereas 2D GANs can achieve high-quality results with a minimum of 16 GB, considering the size and data type: geological volumes. Motivated by this efficiency gap, we developed a novel approach that leverages 2D GAN training to generate 3D geological volumes through slice-wise inference, significantly reducing computational demands (Yang et al., 2022).

Method and/or Theory

Our geological volume is represented as a 4D tensor, where the first dimension corresponds to the number of channels representing geological facies (proportion of each facies in each pixel), followed by the spatial dimensions x, y, and z.

The images for training are composed of patches that are extracted from the 4D big volume from the training dataset using strides to keep the connection between the patterns.

Sun et al. (2023) proposed a conditional GAN-based framework that reconstructs 3D facies models sequentially upward, mimicking sedimentary processes in aggrading systems. Their method generates each new 2D slice conditioned on the cumulative facies distribution of all previously generated layers, ensuring vertical consistency and geological realism. While effective, this approach requires sequential inference and conditioning, which can limit flexibility and increase inference time. In contrast, our method generates 3D volumes by interpolating between latent vectors assigned to the top and bottom boundaries, enabling parallel slice generation without sequential dependency. This allows for faster inference and greater scalability, particularly for large volumes, while still preserving geological coherence through latent space continuity.

Our method involves training a GAN model on 2D geological slices and generating a full 3D volume through slice stacking. The training of the model for 2D geological slice generation was designed to ensure that nearby vectors in the latent space produce images with only small visual variations, such that a path through the latent space results in smoothly transitioning images into the output space. Accordingly, random latent vectors were sampled for the boundary layers of the volume (base and top), and an interpolation between these vectors was used to generate the intermediate layers. Then, we perform inference slice-by-slice using the trained 2D model. This approach allows us to generate large 3D volumes without the need for high-end hardware or 3D training. The interpolation of volume edges provides contextual guidance, helping maintain geological consistency throughout the volume.

Results

The proposed method yielded high-quality 3D geological facies models with significantly reduced computational cost. The slice-by-slice inference approach proved effective in preserving structural features and geological realism. We are currently investigating the influence of neighboring slices on the generation process to further enhance facies continuity, testing SoftMax weighted class smoothing and majority vote for 3D. This strategy demonstrates a practical and scalable solution for generating complex 3D geological models using 2D GAN training.

The choice of latent seed plays a critical role in the generation of 3D geological facies models using 2D GANs. Since each 2D slice is generated independently, the seed determines the latent vector used as input to the generator, directly influencing the visual characteristics of the resulting slice. When a fixed seed is used across all slices, the generated volume tends to exhibit high spatial consistency but may lack geological variability. Conversely, using different seeds for each slice introduces greater diversity but can lead to discontinuities or abrupt transitions between layers. To address this, we explored latent space interpolation between boundary seeds, which enables smooth transitions and improved geological coherence across slices. This strategy balances variability and continuity, enhancing the realism of the generated 3D volumes.

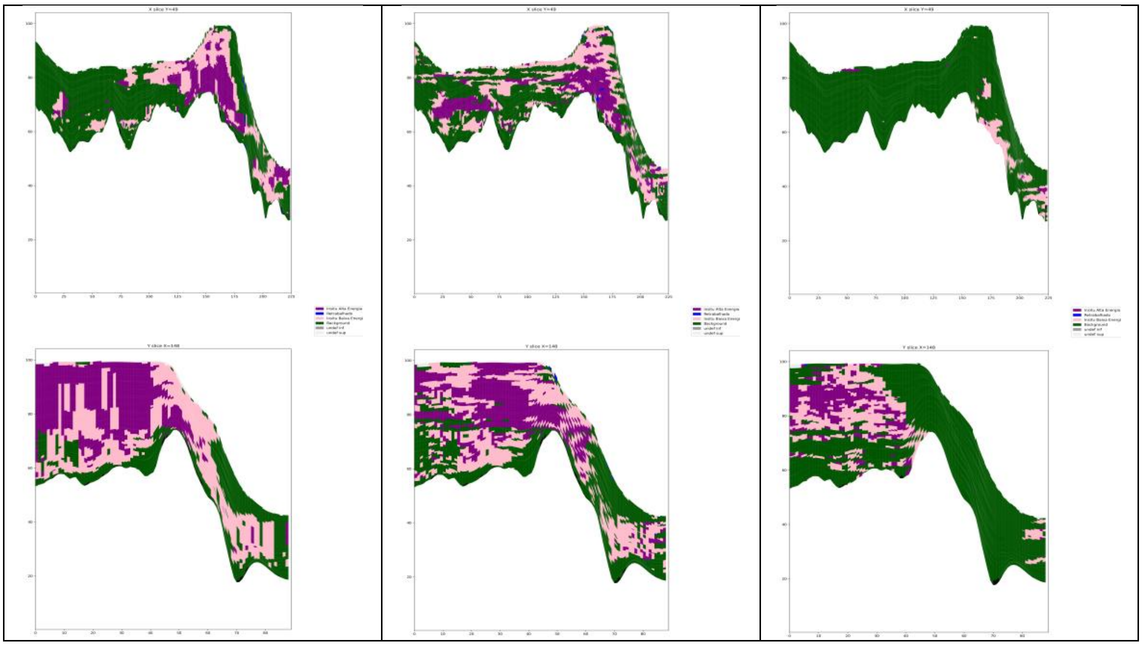

Figure 1: Inference results showing orthogonal slices in X and Y directions composed of 3D geological volume. (left) an inference result using a fixed seed for each 2D slice inference, (center) an inference result using different seeds for each 2D slice inference, and (right) an inference result using different seeds for each 2D slice inference combined with latent vector interpolation.

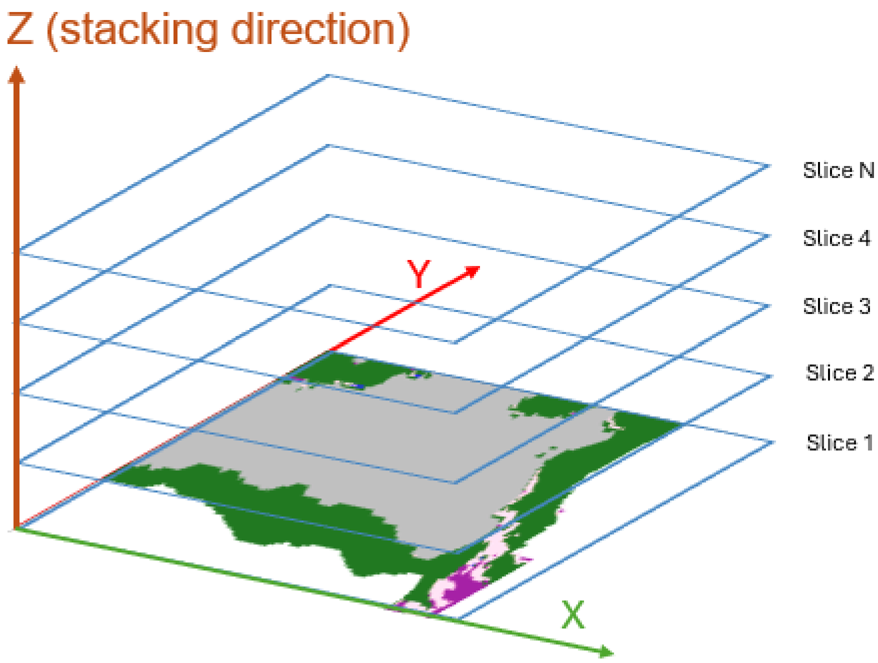

Figure 2: Conceptual diagram of stacking process.

Conclusions

This 2D GAN-based approach presents a practical and scalable solution for generating high-quality 3D geological facies models with significantly reduced computational requirements. By leveraging slice-wise inference and latent space interpolation, the method preserves structural features and geological realism without the need for high-end hardware. Ongoing research is focused on enhancing inter-slice continuity and facies correlation, with current efforts exploring techniques such as SoftMax-weighted class smoothing and majority voting. These advancements aim to further improve the geological consistency and robustness of the generated 3D models.

References

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