Development of a Transformer-Based Proxy Model for Enhanced Reservoir Simulation

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Abstract

In the oil and gas industry, reservoir flow simulation is an essential tool for analyzing reservoir behavior and predicting production and injection curves for wells. Furthermore, it enables the assessment of uncertainties related to geological factors (such as geometry, property distribution, the presence and transmissibility of faults), rock and fluid properties (compressibility, relative permeability, viscosity), and even the initial fluid distribution (positions of oil/water and gas/oil contacts and initial saturations).

However, conventional 3D three-phase simulators are computationally expensive, with processing times ranging from minutes to days for real-world models.

In this work, we propose a proxy model for 3D three-phase flow simulation, inspired by the architecture of the BERT model (Bidirectional Encoder Representations from Transformers) but extensively modified to incorporate reservoir-specific features. Sequence embeddings were replaced with a distance matrix in the attention layer, representing spatial relationships between reservoir points and mitigating the impact of distant regions. Furthermore, timestep extrapolation was integrated into the model, enabling accurate predictions for future states beyond the training horizon. The architecture is organized into two interdependent modules: one that learns physical properties of the reservoir and another that estimates simulated fluid production. This modular structure facilitates transfer learning, enabling efficient adaptation to new reservoirs at reduced computational cost. The dataset comprises millions of simulations of different reservoir models and realizations, ensuring a robust solution that captures the behavior of both black-oil and compositional models.

The proposed proxy is trained by varying the location and classification of wells, integrating different geological realizations, and adjusting various reservoir model configurations, ensuring its generalization. The model architecture is optimized for execution on multiple GPUs, allowing for inferences (or "simulations") in seconds, depending on the reservoir grid size and the number of GPUs used. Preliminary results estimate an error below 7% in SMAPE (Symmetric Mean Absolute Percentage Error), ensuring robust and reliable accuracy for practical applications.

Keywords Proxy · Reservoir simulation · Transformer · Deep Learning

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Introduction

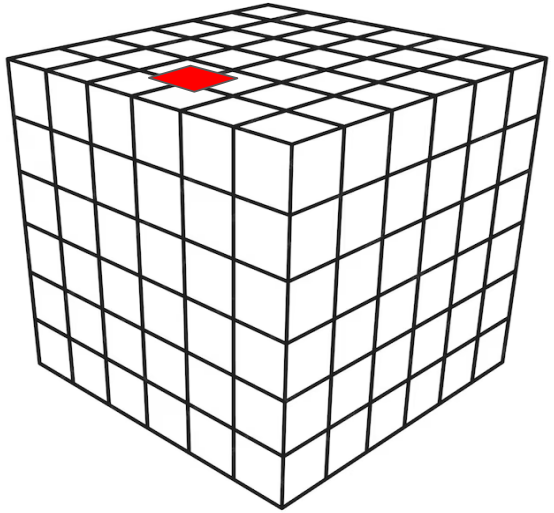
- Reservoir flow simulation is essential but computationally intensive.
- 3D three-phase models may take from minutes to days to run.
- A proxy is a simplified model that approximates the input-output behavior of a full simulator
- Deep Learning based proxy-models handle complex high-dimensional input spaces and suitable for multi-resolution domains (spatial and temporal)

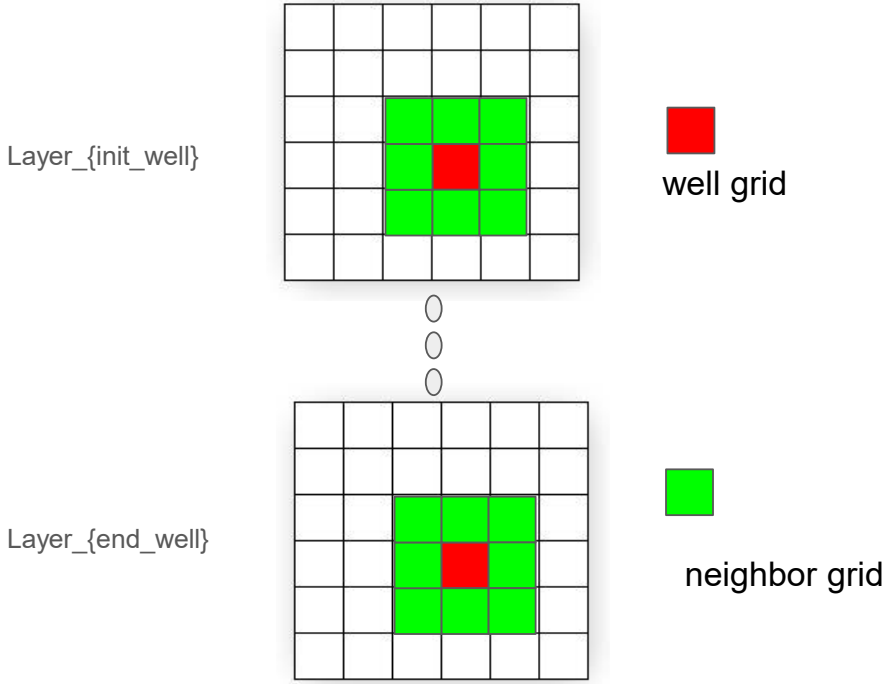
Proposed Approach

- Development of proxy model for 3D three-phase flow simulation.
- Architecture inspired by BERT (transformers based), adapted to spatial domains.
- Proxy model capable of speeding up simulations (from hours/days to seconds)
- Feasibility for high-throughput analyses
- Scalability to different reservoir types and model complexities.
- Integrability with control systems and APIs

Technical Details

- Philosophy of approach
  - Estimates properties and fluid production grid by grid.

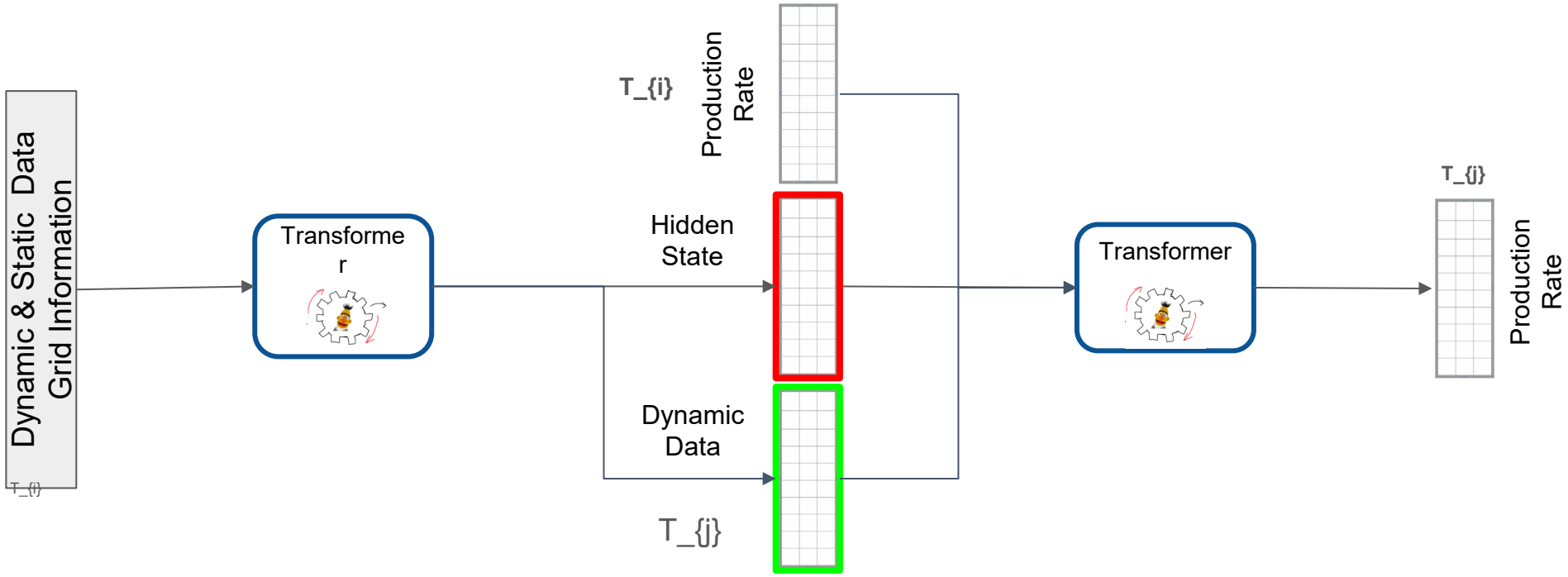




Technical Details

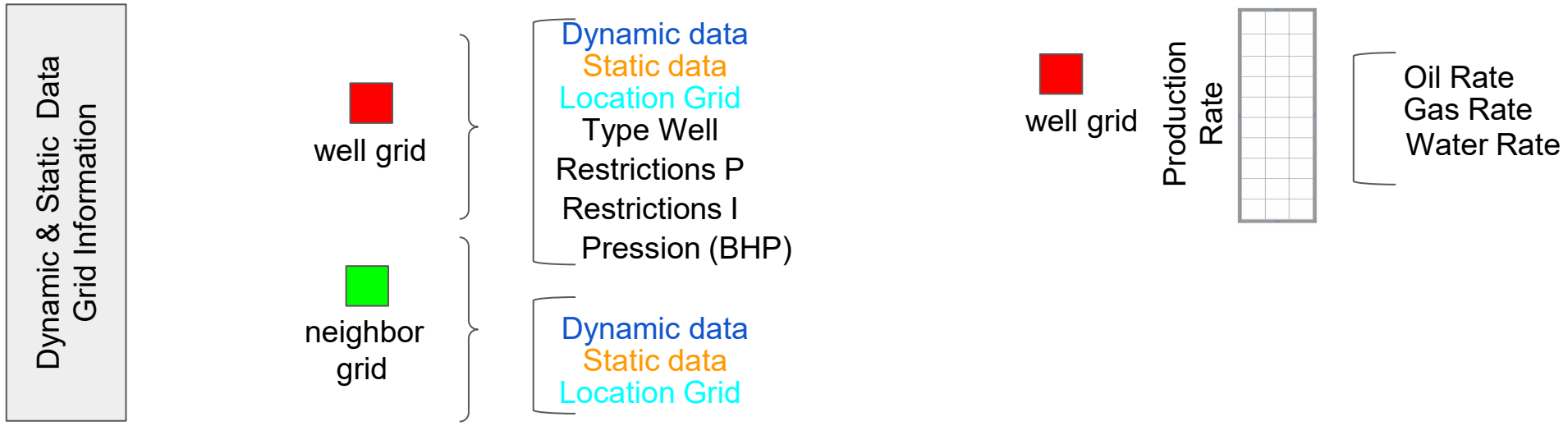
Modular architecture.

- One module for learns physical reservoir properties.
- Another for estimates a fluid production.



Technical Details

Input/output



Static data								Dynamic data					Location Grid		
PERMI I	PERMI J	PERMI K	POR	Net to Gross Ratio	Net Pay	Gross Block Volume	Grid Thickness	Pressure	Water Saturation	Oil Saturation	Oil Viscosity	Gas Viscosity	Grid Centroid X	Grid Centroid Y	Grid Top

Technical Details

The dataset consists of simulation data derived from four different reservoir models.

- UNISIM Benchmark
- Olympus
- Model 04 (CMG)
- Buzios (Petrobras)

Use random well locations and locations generated by the OCTOPUS system.

- SMAPE

Results

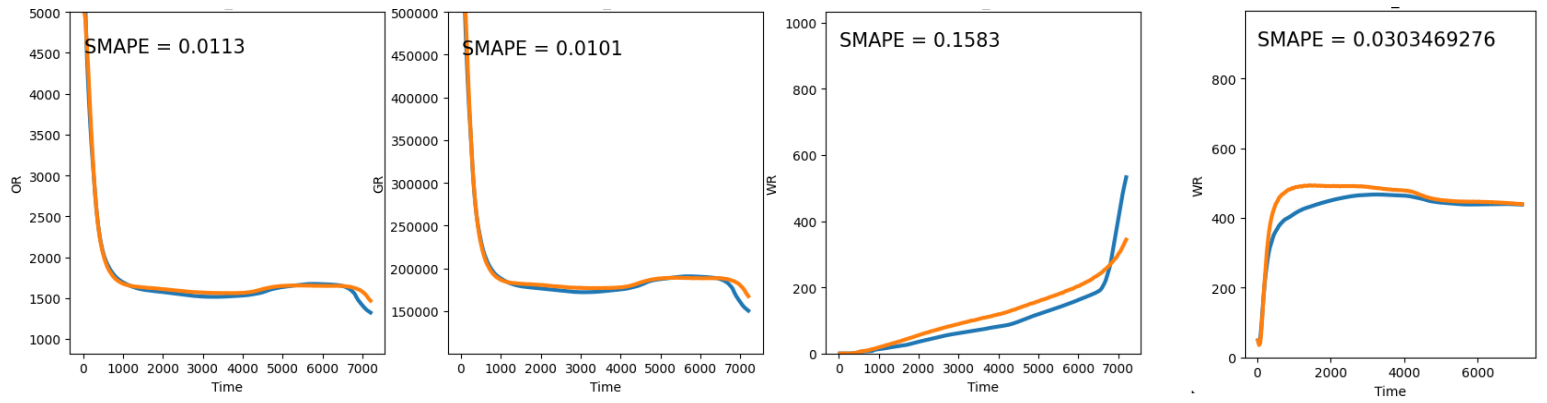
- Average SMAPE error around 7% across all test cases.
- Inference time in second (depending on GPU and the reservoir size).
- Easily integrable via API/microservice (e.g. Octopus System)

	Producer			Injetor	
	Oil Rate (%)	Gas Rate (%)	Water Rate (%)	Water Rate (%)	
UNISIM	4.29	4.29	6.78	2.69	
Model 04	5.06	5.68	16.85	2.54	
Olympus	5.60	7.30	10.23	3.72	
Buzios	13.39	13.76	12.11	5.02	
All	7.08	7.75	11.49	3.49	7.45 %

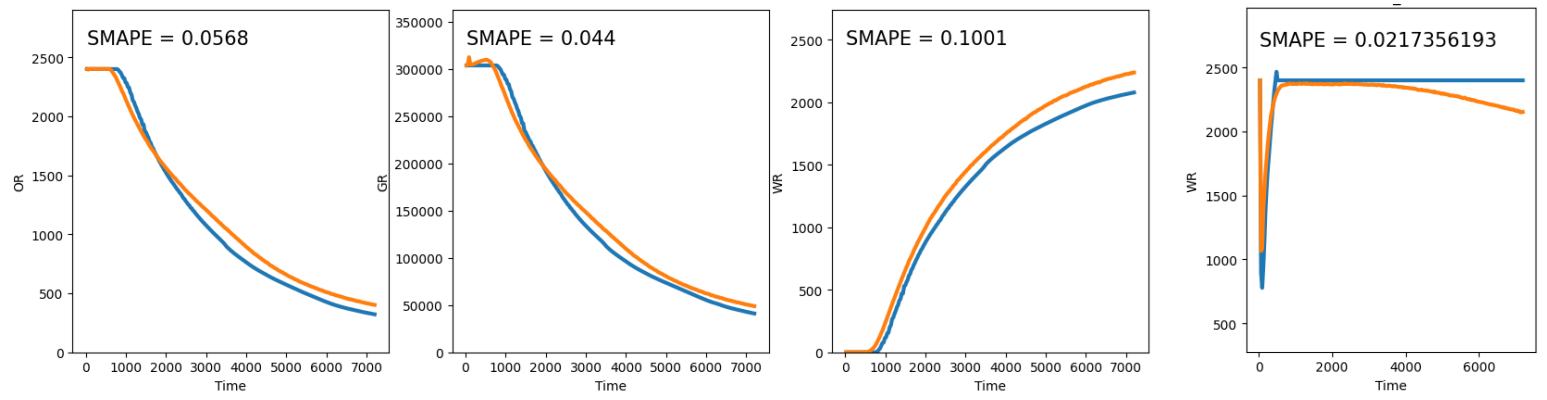
Results

- Random sample around the average

Unisim



Model 04



Results

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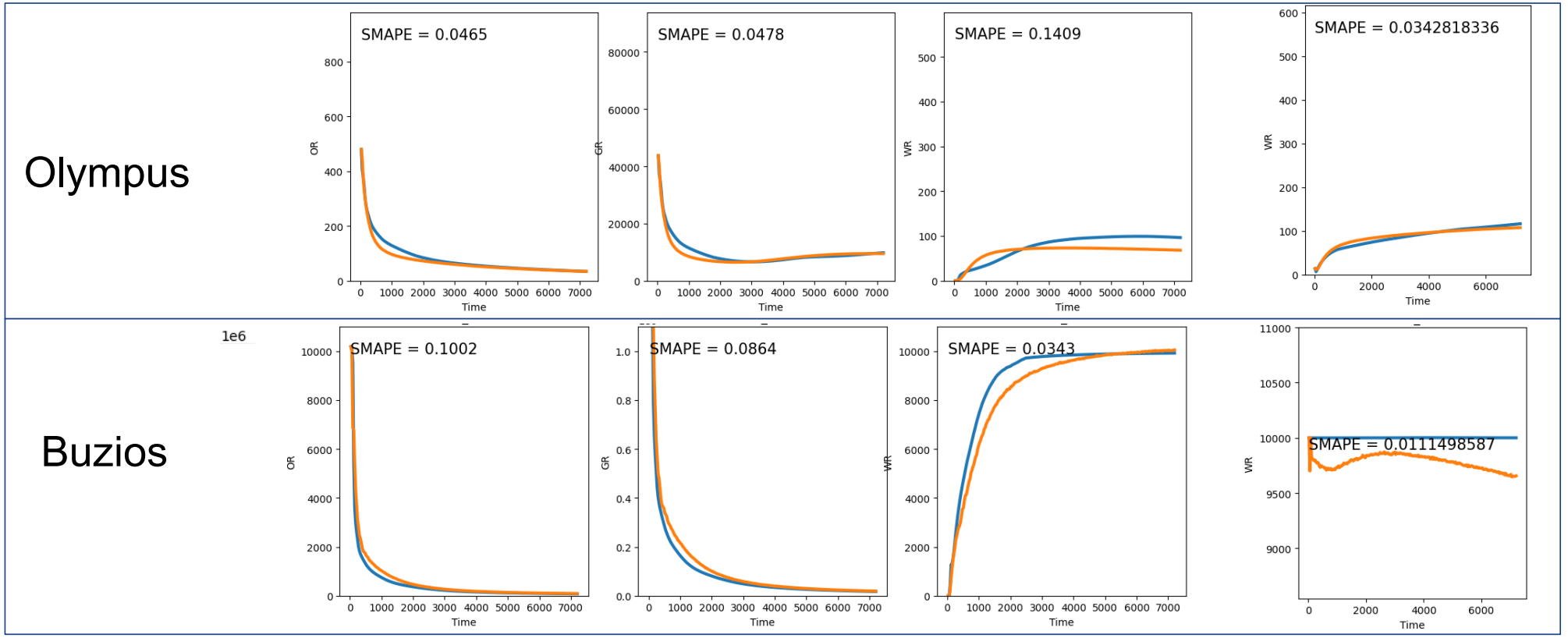

Final Remarks

- The proposed approach was successfully validated reduces simulations cost and promising results.
- Proxies supports integrations with existing workflow via APIs
- The modular design promotes transfer learning and fine tuning for new reservoirs models.
- The architecture proved to be flexible and scalable, supporting future extensions to compositional model.
- Implement parallel model techniques to improve training cost in multiplas GPUs.

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