A Variable Hydrological Element Construction and Visualization System *for* Advancing the Spatial Resolution in Hydrodynamic Simulation Process

Yucheng Shu, Min Chen, Guonian Lv

Key Laboratory of Virtual Geographic Environment (Nanjing Normal University), Ministry of Education, Nanjing, China

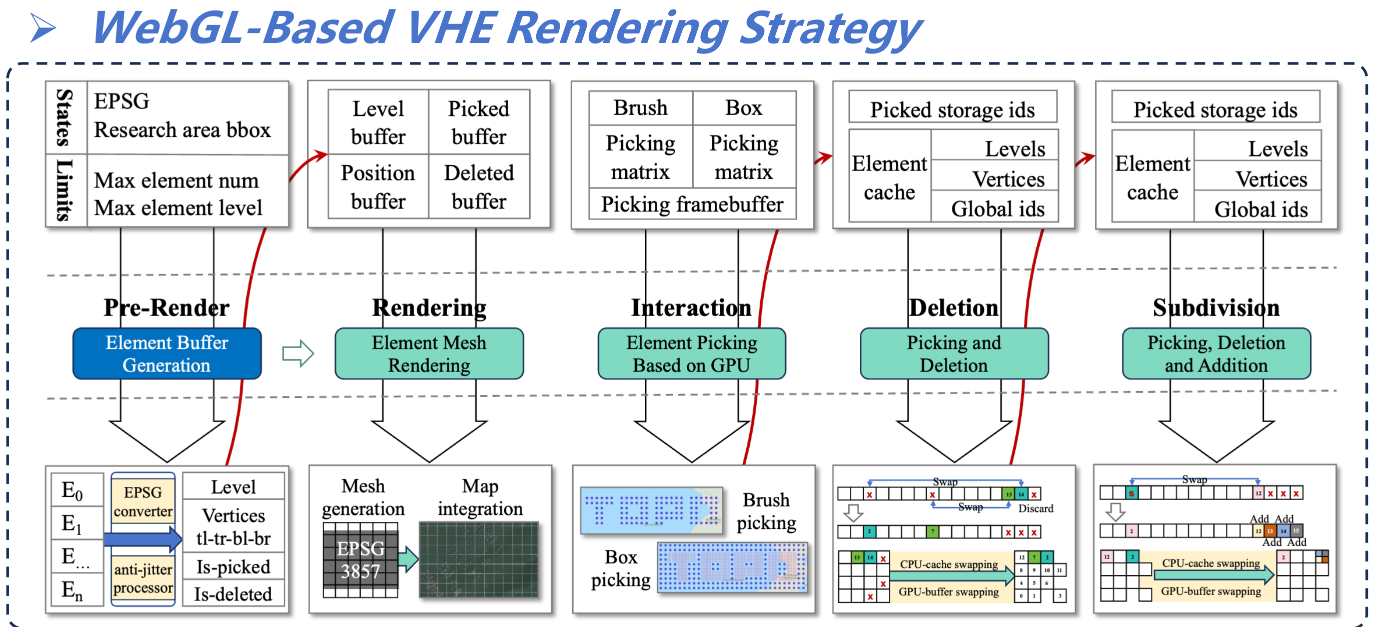
Introduction

While the Variable Hydrological Element (VHE) framework shows promise for improving hydrodynamic simulations, its practical application can be limited by construction tools that lack geographical context. To help address this, our study explores an approach for integrating VHE construction and visualization with web map platforms. We attempt to tackle several key challenges, including the management of discrepancies between local hydrological and global map coordinate systems. For this, we propose a transformation layer, enhanced by the Actor Architecture, to improve performance. To address the computational demands of rendering large-scale VHEs, a memory address consistency strategy is employed to better facilitate hardware-accelerated visualization. The system is designed to support various geographic data types (e.g., DEMs, vector/raster layers) to create a more streamlined workflow for VHE attribute aggregation. We tested this approach with a case study in Yuen Long, Hong Kong, and the initial results suggest that the system can handle VHE generation and visualization with reasonable efficiency. We hope this work contributes a useful step toward developing more effective, geographically-aware tools for hydrodynamic simulation support.

We open-source the prototype system and algorithm for future research at ***https://github.com/world-in-progress/nh-grid*** ***(algorithm prototype)***, ***https://github.com/world-in-progress/gridman*** ***(system frontend), and*** ***https://github.com/world-in-progress/nh-grid-server*** ***(system backend)*** .

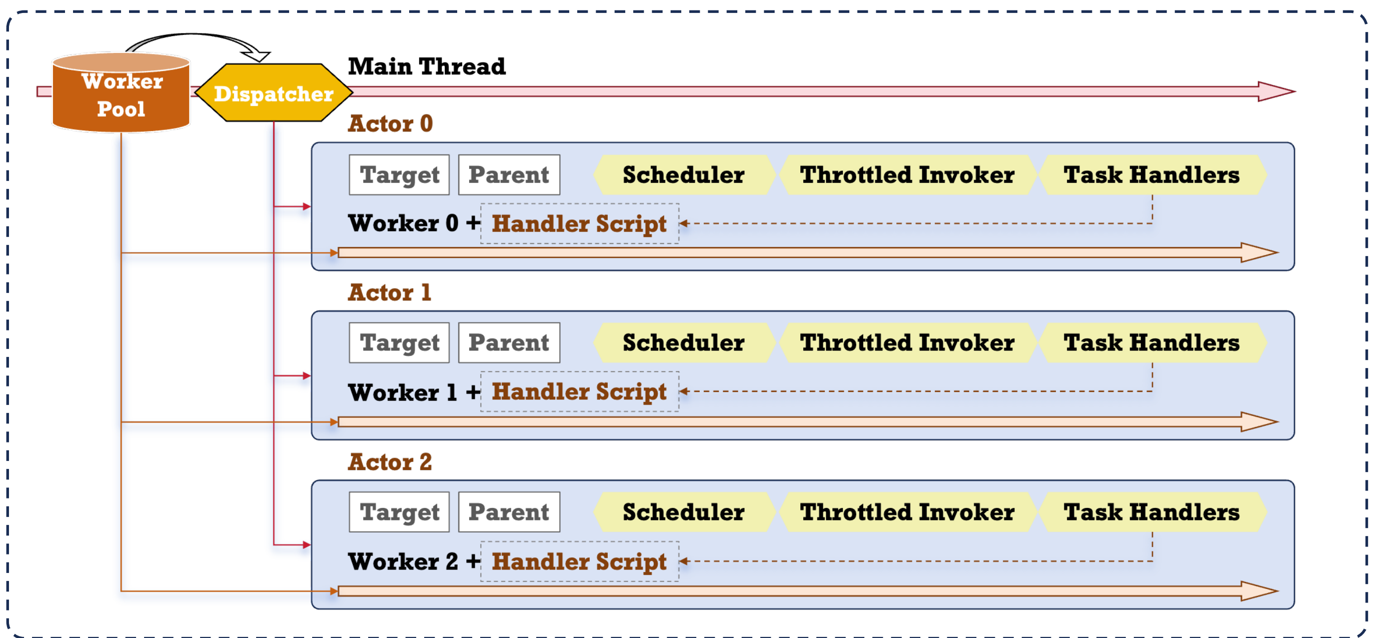
Methodology

➢ *WebGL-Based VHE Rendering Strategy*



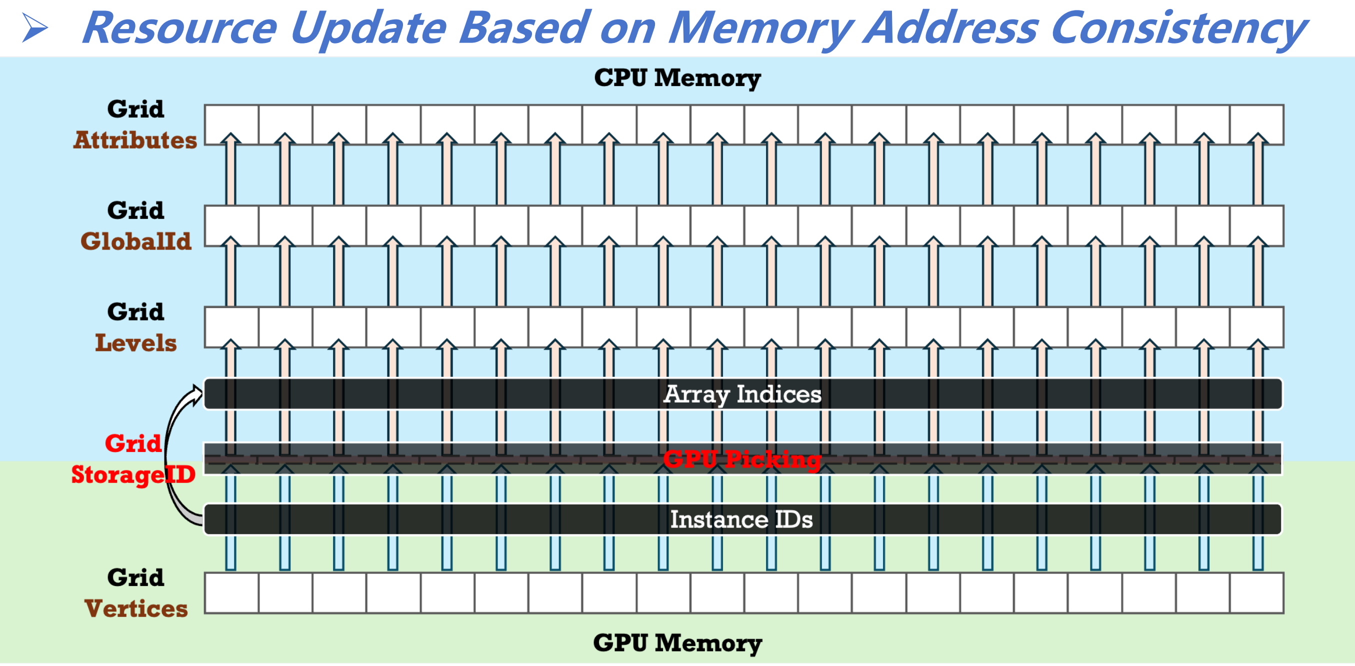
The integration of VHE on web map platforms requires consideration of the impact of different coordinate reference systems (CRS), the integration of tile-based rendering scenarios with a single world coordinate system, and the performance bottlenecks of rendering resource updates caused by interactions. This study overcomes these challenges through coordinate converter, anti-jitter processor, and buffer-friendly deletion and subdivision strategies.

➢ *Render Resource Manager Based on Actor Architecture*



To overcome the performance bottlenecks inherent in large-scale VHE operations—such as coordinate calculation, deletion, and subdivision—this study introduces a concurrent task-processing framework based on the actor model. This framework facilitates the parallel, batched processing of large VHEs, enabling the rapid distribution of tasks and aggregation of results through a zero-cost transfer mechanism for VHE attributes and rendering resource.

➢ *Resource Update Based on Memory Address Consistency*



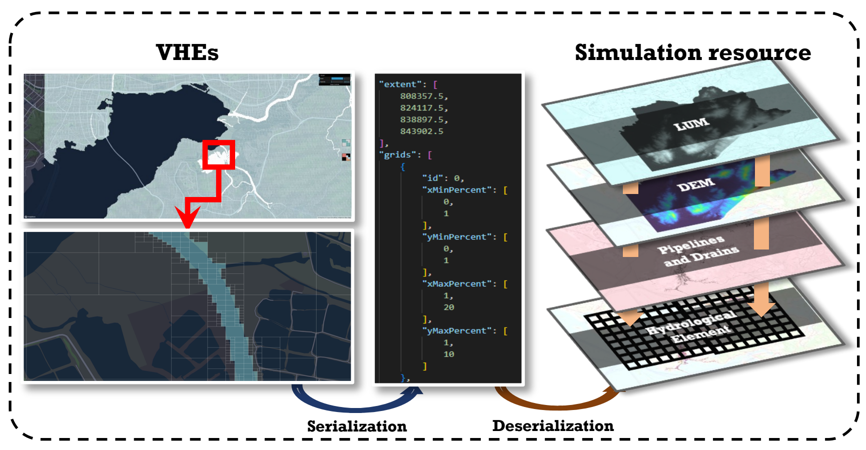
The performance is frequently constrained by the high-cost interaction between the CPU and GPU. This study introduces a storage management strategy that enforces a one-to-one structural correspondence between VHE attributes in system memory and their rendering counterparts in GPU memory, maintained via buffer indices. By directly random accessing, it bypasses query-based synchronization to significantly speed up large-scale GPU fetching and resource updates.

Main contributions:

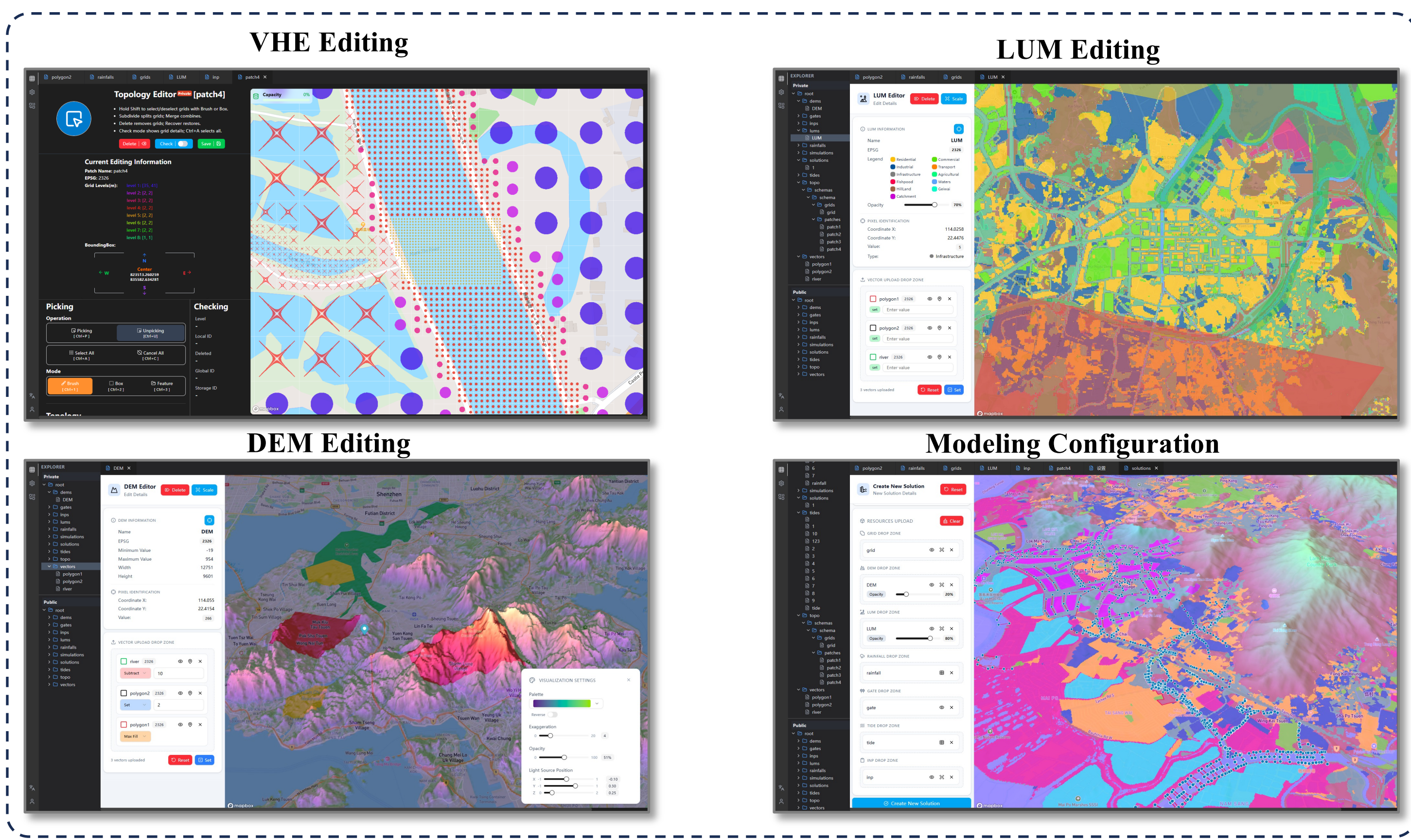
- ➢ ***A Rendering and Interaction Scheme for VHE on Map Platforms:*** This scheme enables the direct visualization, management, and editing of Variable Hydrological Elements (VHEs) on map platforms, effectively bridging the gap between hydrological models and rich geographical contexts.
- ➢ ***A Concurrent Computation Scheme Based on the Actor Architecture:*** This scheme utilizes the Actor Architecture to perform parallel computations, significantly accelerating the coordinate transformation, deletion, and subdivision processes that are required to display and interact with large-scale VHE datasets on web maps.
- ➢ ***A Resource Update Strategy Using Memory Address Consistency:*** This strategy aligns the data structures for VHE rendering and attributes between the CPU and GPU, enabling hardware-accelerated visualization and faster interactive picking with reduced storage and processing overhead.

Implementation

➢ *Prototype system for hydrodynamic simulation workflow*



Based on the methodology, a system was implemented with Yuen Long, Hong Kong, China as the experimental area. Based on VHEs, DEM, LUM, pipe network data, and drain data can be aggregated to construct hydrological elements that support simulation.



Conclusion

This study developed and implemented an integrated system for Variable Hydrological Element (VHE) construction and visualization on map platforms, effectively addressing the critical challenges of coordinate system discrepancies, performance bottlenecks, and inefficient data aggregation. By employing a transformation layer accelerated by the Actor Architecture and a memory address consistency strategy for hardware-accelerated rendering, the system enables the efficient, geographically-contextualized generation, editing, and attribute assignment of VHEs. The validation using Yuen Long, Hong Kong, as a case study confirms the system 's reliability and effectiveness, providing a robust platform that significantly enhances the accuracy and operational efficiency of advanced hydrodynamic simulations. Future work must address GPU memory limitations, which currently restrict scenes to ~16 million VHEs and hinder ultra-large-scale simulations. We will therefore focus on implementing a dense, tile-based system to optimize the management and updating of rendering resources..