MPM as a Multi-Physics Engine for Experimental Digital Twins, Surrogate Models with Uncertainty Quantification, and Regional Natural Hazard Recovery Simulations.

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Abstract:
Due to its "jack-of-all-trades" multi-physics and excellent properties for near real-time simulations, the Material Point Method (MPM) is integrated into the NHERI SimCenter's open-source computational workflow. It serves as a flexible multi-physics engine for the creation of experimental facility digital twins (e.g., wave flumes at Oregon State University), surrogate models for uncertainty quantification (UQ), and regional natural hazard recovery studies. The process of loosely-coupling two massively-parallel, high-performance implementations of MPM, specifically in Taichi Lang (Python-esque scripts) and ClaymoreUW (C++ CUDA configured by JSON), into both local and remote workflows is detailed. Capabilities unlocked by connecting popular UQ engines (e.g., Dakota, SimCenterUQ), robust structural analysis software (e.g., OpenSees), generative AI (e.g., BRAILS, Point-e), surrogate modeling techniques (e.g. GNS, Gaussian Processes, Probabilistic Learning on Manifolds), and cutting-edge community resources for computation and storage (e.g. TACC, DesignSafe DataDepot) with the high-performance multi-physics of MPM are demonstrated. Emphasis is placed on intended exa-scale applications for the social sciences and regional policy-making. All workflows are reproducible in the NHERI SimCenter's open-source, graphical desktop applications for Mac, Windows, and Linux (e.g., HydroUQ).