Tsunami-driven debris effects on structures using a multi-GPU MPM tool.

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Tsunamis and storm surges pose a significant threat to coastal communities and infrastructure around the world. The damage from such events is often not only the result of the flowing water itself, but also of transported fields of debris. Such debris fields are composed of objects the inundation flow mobilizes while moving through a stricken region, ranging from vehicles, to watercraft, to houses. Our work addresses this by experimentally and numerically studying flow-driven ensembles of debris impacting structures, quantifying impact forces and damming effects of these highly nonlinear, chaotic systems. Among many possible numerical methods, the Material Point Method (MPM) emerges as most effective for modeling dynamic interaction of multi-phase, multi-material deformable bodies. However, the method presents limitations on practical levels of resolution that can be achieved at scale due to computational and memory costs. Graphics Processing Unit (GPU) based MPM implementations offer a solution.

GPUs accelerate MPM programs on the order of 100x, but limited memory and bandwidth have historically restricted simulation size. Recent hardware and software advances now permit fast Multi-GPU MPM for engineering projects with many material points (100,000,000+) and grid-cells (1,000,000,000+). Further, hardware trends suggest rising GPU viability, with doubling of (i) video memory, (ii) bandwidth, (iii) computational cores, and (iv) increased accessibility in the next four years.

We present our expansion of an optimized, open-source Multi-GPU MPM code (Claymore, https://github.com/penn-graphics-research/claymore), bringing it from computer graphics to engineering, where certain quantities (e.g., stress, strain, state-variables, forces) must be held to high standards. We explore the pros and cons of innovative MPM modifications proposed mainly by computer graphic researchers (e.g. APIC, MLS-MPM, ASFLIP) which may improve conservation of angular momentum, halve simulation time, avoid shape-function gradient calculations, and reduce sticky-contact in MPM with extraordinary simplicity. Such methods range from rigorous innovations to unstable short-cuts, the latter of which may still present value if handled carefully. We provide an engineering review of computer graphics methods and present validation case examples so others may discern their applicability to their own projects

This Multi-GPU MPM tool is used to model hundreds of real-world wave flume experiments, performed in 12m (UW WASIRF) and 120m (OSU LWF) long facilities. Stochastic debris-field transportation, jammed debris formations, and precise loadings are captured and extrapolated for probabilistic structural design against tsunamis. Validation and verification examples are included for the tool.