Toward Real-Time, Stable, and Physically Accurate Simulation: Vertex Block Descent and Beyond

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Physics-based simulation demands three essential properties: stability, physical accuracy, and computational efficiency. Despite decades of progress, existing methods struggle to deliver all three simultaneously. Convergent solvers faithfully solve the underlying physics but suffer from instability and poor parallel performance due to global system dependencies. GPU-friendly approaches like Extended Position Based Dynamics (XPBD) achieve parallelism by simplifying the governing equations—at the cost of convergence to true physical behavior. Stability, meanwhile, remains elusive for all methods under strict computational budgets.

This presentation introduces Vertex Block Descent (VBD), a novel solver for the variational form of implicit Euler integration that achieves all three properties. By reformulating the problem as vertex-level Gauss-Seidel iterations that reduce global variational energy through purely local position updates, VBD enables massive parallelism while guaranteeing numerical convergence and unconditional stability.

Beyond the core solver, my work addresses the longstanding challenge of collision handling. I propose a formal universal collision formulation called Offset Geometric Contact (OGC), which guarantees intersection-free results and provides a universal collision formulation for codimensional objects—cloth, strands, and shells—achieving over 100× speedup compared to previous work. This is complemented by a novel penetration-free enforcement technique that is solver-agnostic and material-agnostic, enabling interactive simulation of extreme contact scenarios with millions of simultaneous contacts.

Finally, I will also present a high-resolution deformation capture system for acquiring real-world data on non-rigid objects, enabling data-driven simulation and opening new avenues for inverse physics problems.

Together, these contributions advance physics-based simulation by orders of magnitude in performance while providing unconditional stability and penetration-free guarantees under extreme conditions.