# Chrono DEM-Engine: an Efficient and Versatile DEM Simulator

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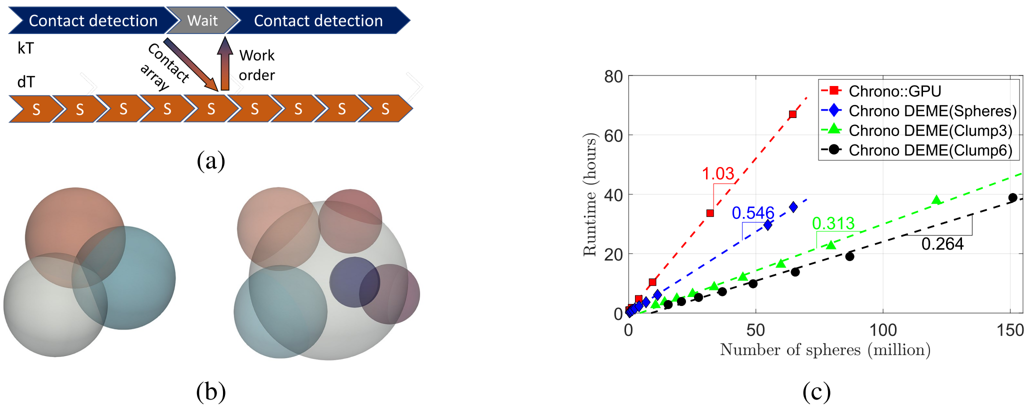
**Abstract**

This work introduces Chrono DEM-Engine [1], a physics-based simulator for granular materials such as particles, grains, and powders. The simulator, which draws on the Discrete Element Method (DEM) [2], can handle complex geometric shapes via composite geometries made of heterogeneous spheres of user-specified radii. Just like its Chrono::GPU predecessor [3], Chrono DEM-Engine is open-source. It and can leverage dual-GPU computation to accelerate the granular dynamics of system that comprise tens of millions of elements.

## 1 Overview of the key features

One salient attribute of Chrono DEM-Engine is that it implements a numerical solution strategy that decouples the kinematics computations (like contact detection) from the dynamic computations (e.g., computing contact forces and performing numerical integrations) by delegating them to two separate compute threads, denoted below by kT and dT (Fig. 1a). These two threads can, but not necessarily have to, be dispatched onto two different GPU cards that periodically synchronize. The simulator handles polydispersed granular materials with complex shapes that are generated as assemblies of spheres that combine to form so called *clumps* (Fig. 1b).




(a) (b) (c)

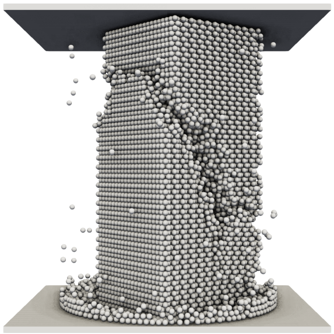
Figure 1: The asynchronized collaboration pattern for kT and dT, in which *S* indicates a time step in advancing the physics (a); shapes of the grains used in the scaling analysis (b); performance benchmark (c) (clump3 and clump6 mean the 3- and 6-sphere clumps shown previously).

## Performance

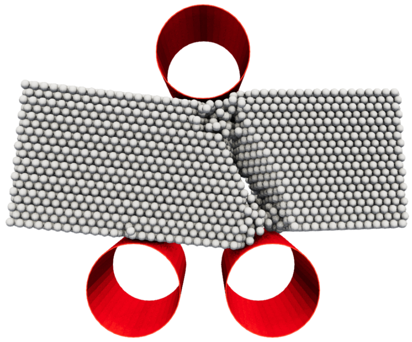
While its predecessor runs two orders of magnitude faster than two other established DEM packages [4], DEM-Engine scaling analysis indicates that the new solver further amplifies this performance by a factor of 2, as shown in Fig. 1c (blue curve). This performance gain is enabled by the efficient use of two GPUs: given the differences in computational requirements, kT and dT can operate asynchronously, exchanging contact state information only as necessary. The new solver also shows linear scalability for up to 150 million component spheres (black curve).

## Versatility

Enabled by just-in-time CUDA kernel compilation, Chrono DEM-Engine allows easy customization of the contact force models, supporting the implementation of user-defined constitutive laws, which can side, or supersed, the Hertz–Mindlin model. A bulk modeling strategy for highly cohesive materials has



(a)



(b)

Figure 2: Axial compression test of a granite block, showing the failure mechanics (a); and three-point flexural test for a concrete beam (b).

been implemented through DEM-Engine's open framework. Specifically, the adopted model is based on the theory presented in [5] that mimics the behavior of cohesive yet highly brittle elastoplastic material. The two examples in Fig 2 illustrate the response of granite- and concrete-like material to axial and three-point bending tests.

## 2 Discussion, conclusions, and future work

Our presentation will review the main simulator features and validate the code against reference solutions, including fine-grain force model evaluations and macro-scale experiments, e.g., contact wave propagation, ball drop, and hopper flow rate. Complex particle geometries will be validated through comparisons with physical data for the flow discharge of spheres, cylinders, and combinations thereof from a rectangular hopper. Lastly, the bulk modeling implementation of cohesive materials will be demonstrated for a very stiff material, such as granite. We envision Chrono DEM-Engine's use as an engineering tool for production simulations of large systems of granular material within meaningful multi-physics problems thanks to its seamless integration with Chrono [6].

## References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