Open-Source High-Performance Computing for Applications in Engineering: DEM, SPH and Multi-Agent Vehicle Simulations with Project Chrono

RUOCHUN ZHANG, University of Wisconsin-Madison, USA
WEI HU, University of Wisconsin-Madison, USA
SIMONE BENATTI, University of Wisconsin-Madison, USA
LUNING FANG, University of Wisconsin-Madison, USA
JASON ZHOU, University of Wisconsin-Madison, USA
LIJING YANG, University of Wisconsin-Madison, USA
ASHER ELMQUIST, University of Wisconsin-Madison, USA
JAY TAVES, University of Wisconsin-Madison, USA
AARON YOUNG, University of Wisconsin-Madison, USA
COLIN VANDEN HEUVEL, University of Wisconsin-Madison, USA
RADU SERBAN, University of Wisconsin-Madison, USA
DAN NEGRUT, University of Wisconsin-Madison, USA

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1 INTRODUCTION

This poster touches on three HPC-related research thrusts based on Project Chrono [4]. Chrono::GPU and Chrono::FSI leverage GPU computing to accelerate large-scale granular dynamic simulations (based on DEM and SPH respectively), while SynChrono exploits MPI to support real time multi-agent autonomous vehicle simulations.

Authors' addresses: Ruochun Zhang, University of Wisconsin-Madison, Madison, USA, rzhang294@wisc.edu; Wei Hu, University of Wisconsin-Madison, Madison, USA, whu59@wisc.edu; Simone Benatti, University of Wisconsin-Madison, Madison, USA, benatti@wisc.edu; Luning Fang, University of Wisconsin-Madison, Madison, USA, lfang9@wisc.edu; Jason Zhou, University of Wisconsin-Madison, Madison, USA, zzhou292@wisc.edu; Lijing Yang, University of Wisconsin-Madison, Madison, USA, lyang296@wisc.edu; Asher Elmquist, University of Wisconsin-Madison, Madison, USA, amelmquist@wisc.edu; Jay Taves, University of Wisconsin-Madison, Madison, USA, jtaves@wisc.edu; Aaron Young, University of Wisconsin-Madison, Madison, USA, aryoung5@wisc.edu; Colin Vanden Heuvel, University of Wisconsin-Madison, Madison, USA, colin.vandenheuvel@wisc.edu; Radu Serban, University of Wisconsin-Madison, Madison, USA, serban@wisc.edu; Dan Negrut, University of Wisconsin-Madison, Madison, USA, negrut@wisc.edu.

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2 CHRONO::GPU – DEM GRANULAR DYNAMICS

Discrete Element Method (DEM) implemented in Chrono::GPU embraces the assumption that rigid bodies are allowed to have small deformation, δ_n, at the point of contact. The deformation induces contact forces and the evolution of each particle is tracked essentially applying Newton's second law to millions of particles, see Fig. 1, where $\boldsymbol{F_n}$ and $\boldsymbol{F_t}$ are the normal contact force and sliding friction force respectively. $\boldsymbol{M_r}$ and $\boldsymbol{M_{sp}}$ are the rolling and spinning frictions. $\boldsymbol{F_c}$ is the cohesive force.

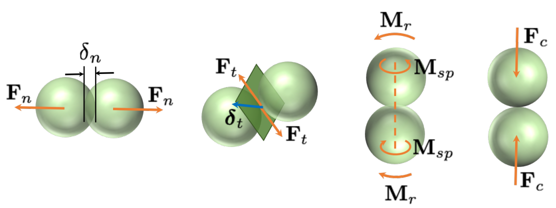

Fig. 1. Contact forces among particles.

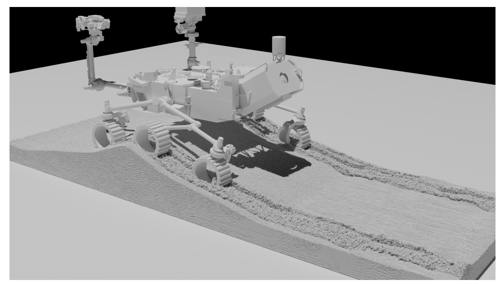

Fig. 2. Curiosity on DEM granular terrain.

Granular material is modeled as a collection of a large amount of such particles. Rover simulations on granular terrain with Chrono::GPU are given several examples in this work. One can be seen in Fig. 2. At a time when the scientific community runs simulations with approximately 10^3 to 10^5 elements, to the best of our knowledge, the largest granular dynamics simulation of practical relevance to date contained 2.4 billion elements. Among several HPC clusters, this large simulation was run on 16,384 CPUs (131,072 cores) of Japan's K-supercomputer [1–3], the 2012 fastest supercomputer in the world and now the 18th in the ranking of the world's supercomputers [5]. Thus, rather than anchoring the solution to multi million-dollar supercomputers, which are the privilege of select few, we seek to enable one to perform complex multi-body and fluid-solid interaction simulations on affordable hardware; i.e, in the range of \$2,000 – \$50,000.

3 CHRONO::FSI – SPH-BASED MULTIPHYSICS

Smoothed Particle Hydrodynamics (SPH) is a mesh-free Lagrangian method implemented in Chrono::FSI. SPH approximates a function based on a spatial average of adjacent sampling points, illustrated Fig. 3. Using SPH to solve partial differential equations associated with the "fluid" (granular) domain, rover simulations on SPH-based granular terrain are made possible, see Fig. 4 for an example.

4 SYNCHRONO – MULTI-AGENT AV SIMULATION

The purpose of SynChrono is to provide a scalable, multi-agent platform for physics-based Autonomous Vehicle (AV) simulation [6]. SynChrono uses the Message Passing Interface (MPI) standard to simulate both on-road and of-road traffic scenarios. Relying on an MPI framework (compared to running on a single rank, Fig. 5), we can explore AV traffic scenarios that combine tens of vehicles, some autonomous and some with human-in-the-loop, see Fig. 6.

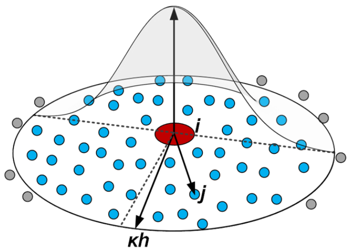

Fig. 3. SPH markers and approximated function.

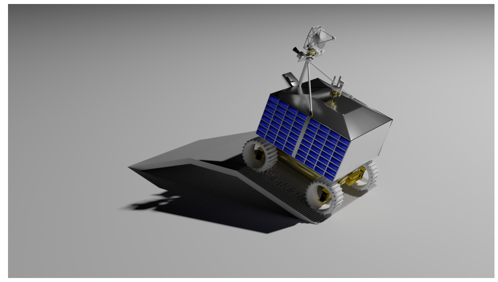

Fig. 4. VIPER on SPH granular terrain.

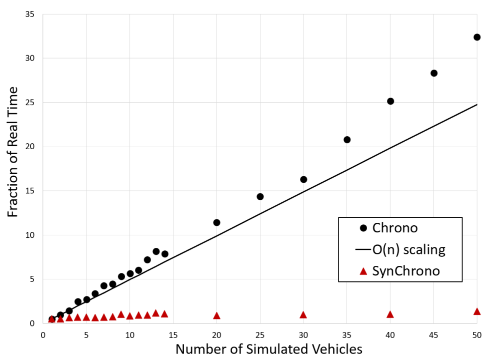

Fig. 5. The scalability of SynChrono.

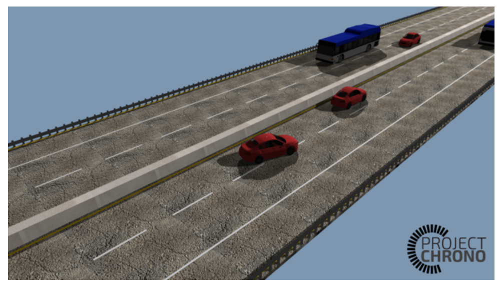

Fig. 6. A highway scenario with multiple vehicles.

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