Chrono: a parallel multi-physics library for rigid-body, flexible-body, and fluid dynamics

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Abstract

We present the high performance computing capabilities of the Chrono simulation tool [1, 2], a multi-physics, multi-discipline computational framework for the modeling, simulation, and visualization of multibody dynamics and fluid-solid interaction applications.

Chrono has a modular structure, built on top of five foundation elements (see Figure 1) that provide support for (1) modeling; (2) numerical solution; (3) proximity computation and contact detection; (4) domain decomposition and inter-domain communication; and (5) pre- and post-processing.

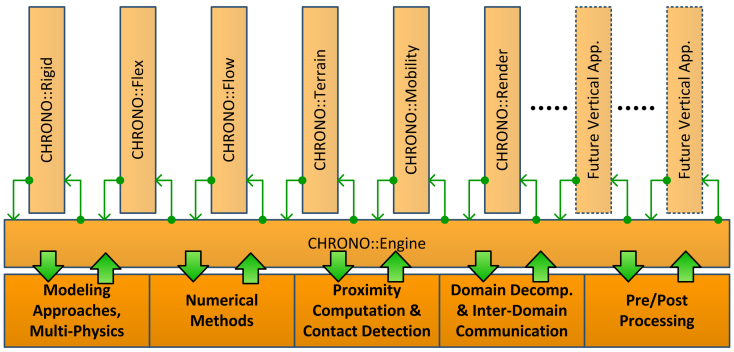

Figure 1: Structure of the Chrono framework. Chrono::Engine, the middle API layer, is built on top of five foundation components and supports various vertical applications.

The modeling component provides support for the automatic generation of the very large and complex sets of equations for different classes of applications. This is achieved in a fashion transparent to the user who need only provide high-level model and solution parameters. Examples include the equations of motion for granular flow simulations, using either a Differential Variational Inequality (DVI) or a Discrete Element Method (DEM) approach, the dynamic equations in an Absolute Nodal Coordinate Formulation (ANCF) for flexible multibody dynamics, the Smooth Particle Hydrodynamics (SPH) discretization of the Navier-Stokes equations for fluid-solid interaction problems, etc.

The numerical solution component provides the parallel algorithmic support required to solve the set of equations governing the dynamics of interest. Depending on the underlying physics, various parallel solvers are employed for: optimization problems arising in the DVI approach for handling frictional contact; solving nonlinear problems arising in the context of implicit numerical integration; SPH-based methods for fluid-solid interaction problems, etc.

For discrete problems, the proximity computation and contact detection component handles contact detection tasks; for continuum problems handled in a meshless framework it produces the list of neighboring nodes that overlap the compact support associated with each node of the discretization.

The domain decomposition and inter-domain communication component manages the splitting of large problems into subdomains and provides support for the required inter-process communication. This enables the MPI simulation of granular flow problems with millions of particles interacting through frictional contact, conducted on hundreds of distributed nodes.

The pre/post-processing component supports the process of setting up a model using the Chrono API and provides support for efficient visualization of simulation results from problems involving millions of states resolved at frequencies of hundreds of Hertz.

Chrono leverages heterogeneous parallel computing architectures, including GPU and multi-core CPU processors, as well as MPI distributed architectures, to accelerate the simulation of very large systems. Examples of such systems include those encountered in granular dynamics where the number of interacting elements can be in the millions and fluid-solid interaction simulations involving millions of fluid markers and tens of thousands of solid (rigid or flexible) bodies. Chrono handles seamlessly systems that include both complex mechanisms composed of rigid bodies connected through mechanical joints and collections of millions of discrete elements interacting through contact, impact, and friction.

Several vertical applications are either built into or in the process of being included into the Chrono framework. A sample set of simulations conducted with the Chrono tools are illustrated in Figure 2.

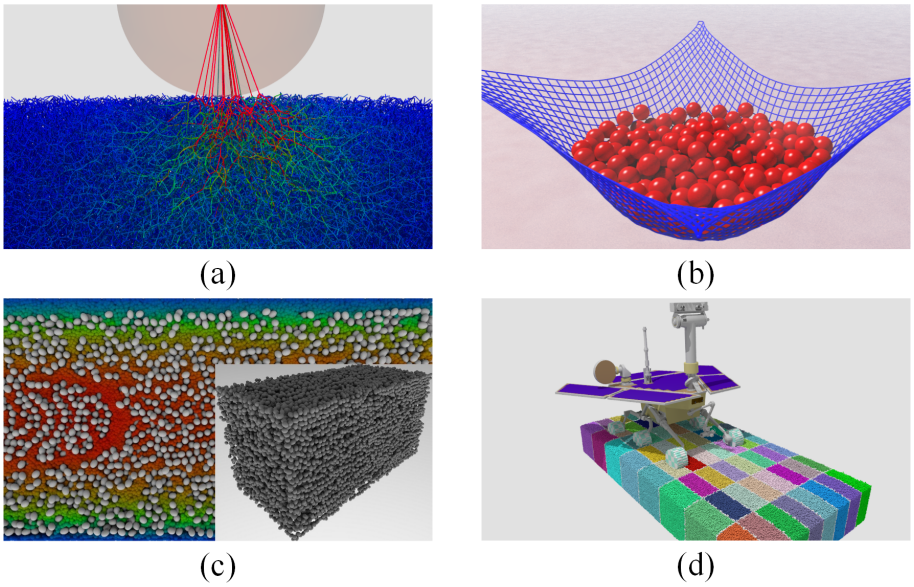

Figure 2: Examples of Chrono simulations: (a) cross-section view of 3D normal contact forces in granular material (modeled using 0.6 million rigid bodies) during impact by a spherical object; (b) flexible net simulation using $101,025$ flexible beam elements constrained through $640,146$ constraint equations; (c) SPH simulation of a dense suspension of $23,000$ ellipsoids in 3D square channel flow; (d) snapshot from a 64-core MPI simulation of a rover driving over granular terrain (modeled using 2 million bodies).

Chrono is available open source, under a BSD license [3]. Completely platform-independent, Chrono::Engine libraries are available for Windows, Linux and Mac OSX, in both 32-bit and 64-bit versions.

References

[1] Mazhar, H; Heyn, T; Pazouki, A; Melanz, D; Seidl, A; Bartholomew, A; Tasora, A; Negrut, D.: Chrono: a parallel multi-physics library for rigid-body, flexible-body, and fluid dynamics. Mech. Sci., Vol. 4, No. 1, pp. 49–64, 2013.

[2] ProjectChrono, 2013. http://www.projectchrono.org/chronoengine

[3] Chrono, 2013. https://github.com/projectchrono/chrono