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LMGC90

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Résumé —
LMGC90 is an open source platform dedicated to the modelling of large collections of interacting objects (2D/3D). It aims at modelling objects of any shape with various mechanical behaviour and to take into account non-smoothed interaction laws as complex as necessary. Furthermore multiple physics couplings (thermal effects, fluids, etc.) may be taken into account.
Mots clés — contact, non-smooth dynamics, multiple physics, DEM, FEM, FOSS

1 Main Features

LMGC90 [11] is an open source research software which developments are mainly coordinated by the LMGC. It aims at modelling large collection of objects of any shape with various mechanical behaviour and to take into account interaction laws as complex as necessary.

1.1 Bulk behaviour of objects

Objects are either rigid bodies or deformable bodies modeled using the finite element method. In the latter case, the different hypothesis used may be :
- small perturbation
- small perturbation around a floating frame
- large transformations

A large panel of behaviour law is available thanks to the use of MatLib [2] library, like elastic, hyperelastic, viscous... in fact any constitutive model expressed with the *Generalized Standard Materials* formalism.
Some multiple physics coupling are available for thermomechanics, poromechanics (with a single fluid or a biphasic one).
Instead of using the build-in FEM functionalities, it is possible to use an external finite element software/library like *Pelicans* [3] or *Code_Aster* [9].
In the same way, external software simulating Multi-Body-System can provide dynamical systems, as illustrated by the coupling with Robotran software [4].
Finally there is an ongoing collaboration with the development team of *migflow* [5] for fluid-grains coupling simulations.

1.2 Shape of objects

LMGC90 relies on making a clear distinction between the bulk model (which nodes hold **D**egrees **o**f **F**reedom) and the potential locus of contact (where contact nodes are located).
The description of a geometric locus used for contact detection is called a *contactor*. There are two families of contactor primitives within LMGC90 depending on the type of body it belongs to :
- rigid body (or MBS) : points, disks, spheres, polygons, cylinders, polyhedron, etc.
- deformable body : points, lines, triangle/quadrangle surfaces.

A rigid object, discretized by a single node (with DoF), can hold a single contactor or a compound of several contactors allowing to design complex non-convex shapes.
The contact detection is performed for most combination of primitives and provides a list of binary interactions. There are several possibilities to perform this step which depend on the primitives to detect,

especially regarding polyhedron.

1.3 Interaction laws

A large set of interaction law is available either between rigid or deformable bodies. The most fundamental one is frictional contact (with or without restitution). There are several cohesive laws (capillarity, damage, brittle), and adhoc laws to model wire, rod, etc.
The most recent ones allows to take into account pressure or thermal effects inside a crack or effects of chemical reaction for concrete leaching.

1.4 Analysis

Analysis are mainly driven by the **N**on **S**mooth **C**ontact **D**ynamics method [1].
This strategy uses a given time-step, and behaves like a predictor/corrector scheme. A time integration scheme is used to predict body motion and compute a configuration detection. Then after detecting the active interactions, an implicit contact solver is used to determine the reactions used to correct the bodies' velocity and re-compute a new configuration. Available contact solvers are : Non Linear Gauss Seidel (NLGS) or Jacobi which allow to mix any kind of contact laws in the same simulation.
Using the *Siconos-Numerics* library [6] it is possible to access additional contact solvers (Alart-Curnier, global solvers, etc).
Usually θ-scheme is used for the time integrator, but an explicit time integrator or a quasi-static time evolution are also available.
Applications with a large number of interacting bodies are reachable thanks to multi-threading with the *OpenMP* library.

2 User features

2.1 Pre-processing

A build-in scriptable pre-processor written in Python helps to define : geometries, material properties, boundary conditions and interactions laws etc.
Specific features are available, for example :

- granular materials : like deposit of dense packing of particles in container,
- masonry structure : to define rule of automatic wall generation,
- finite element : to define group from geometric predicates.

There are also features to read meshes produced by *gmsh* [7]. Any software with a Python API can easily be used.

2.2 Scripted analysis

All stages of a simulation are finely driven by a Python script. Moreover the Python interface provides accessors to LMGC90's database, which offers the possibility to manage complex and customized simulations.
In the meantime, advanced developments benefit from a Fortran 90 modular software design which preserves performance.

2.3 Visualization and Post-processing

By default *VTK* files are generated which can be visualize using *Paraview* [10] (or any alternatives supporting vtk files like Mayavi or Visit).
Furthermore, thanks to the Python accessors, any kind of user defined post-processing workflow and plotting can be implemented.

3 Open platform for research

LMGC90 is dedicated to academic research and advanced R&D of industrial actors.
Therefore is provides a rich Python API easily allowing fine tuning of the simulation and weak coupling with other Python modules. Furthermore, there are a lot of ways to plug-in additional libraries within the Fortran core, albeit more technical.
It is an open platform under CeCiLL license (equivalent to the GPL one) and any contribution is welcome.
There is a large set of examples, tutorials (as jupyter notebooks) and documentations.
There is a user mailing list to address common issues, where developers are more than willing to help new users. Finally, once a year, there is an on-line course to help to take the first steps with the software.

LMGC90's wiki contains all available information concerning installation or formation.

4 Some Fields of Application

4.1 Granular materials

A typical and historical use of LMGC90 is the study of the rheology of granular materials and the structural effect emerging from such materials.
Most recent use study the stability of strongly non-convex rigid bodies or the accretion process of asteroids [8].

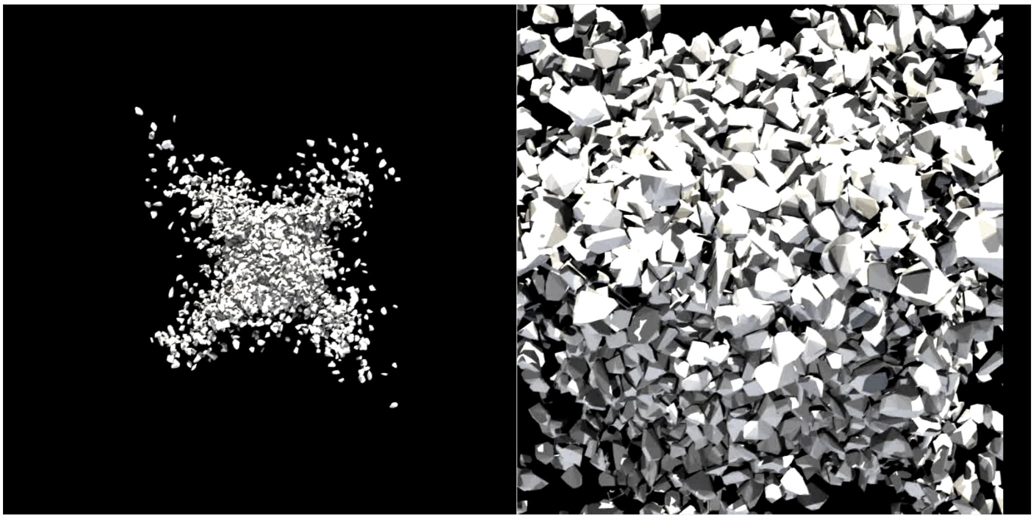
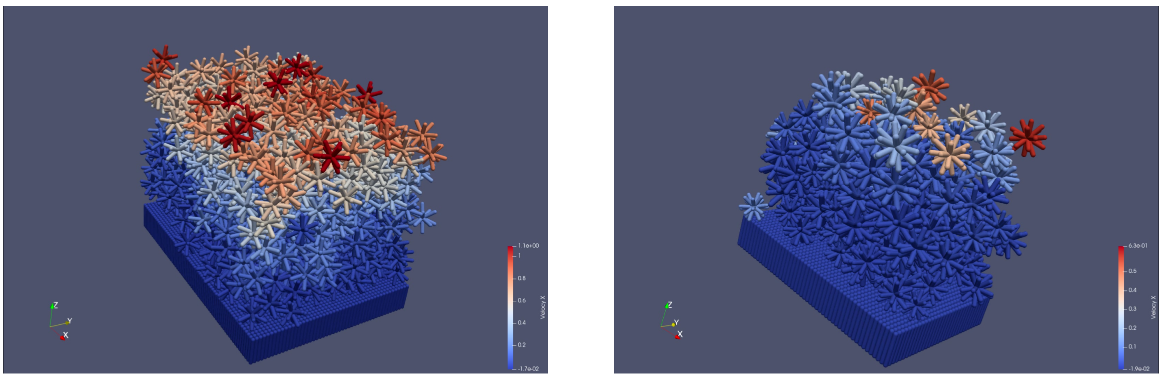


FIGURE 1 – Asteroid formation by accretion under self-gravity



(a) 12 branches

(b) 20 branches

FIGURE 2 – Stability of non-convex particles on inclined plane

4.2 Masonry structure

Another biggest use of the software is for assessing the stability and the safety of masonry structures under static or dynamical load.
As such it has been used to study the state of the cathedral Notre-Dame de Paris, to identify the effect of the fire on the stability of the different arks within the structure.

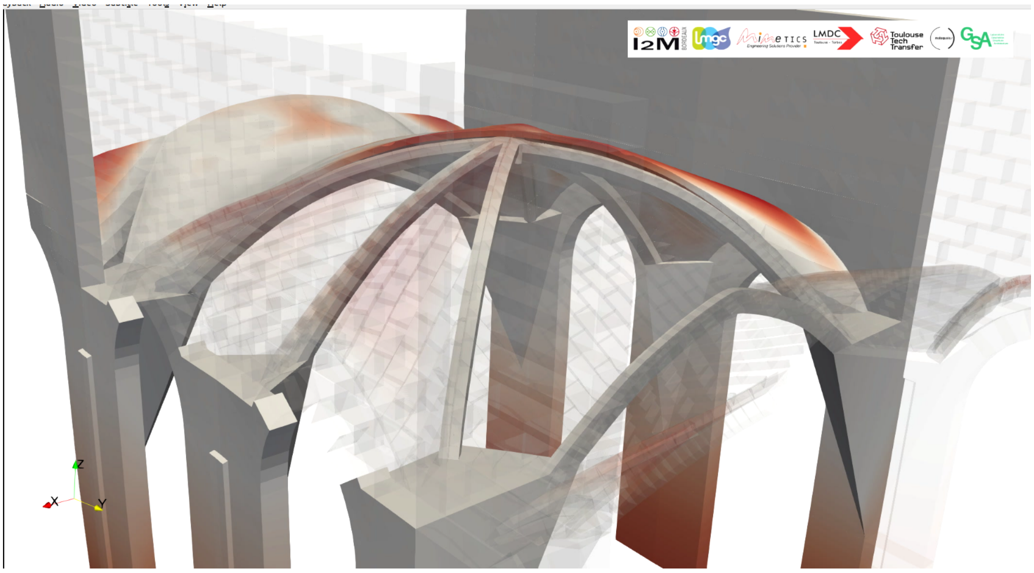


FIGURE 3 – Fire effects on the stability of vault of Notre-Dame

4.3 Fracture of heterogeneous media

Using a Friction Cohesive Model, fracture can be modeled from initiation to post-failure.

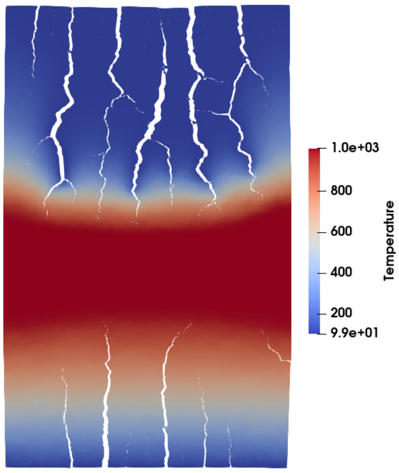


FIGURE 4 – Solidification of lava (62278 elements)

4.4 Coupling with Multi-Body-System

Coupling with software such as Robotran allows to correctly simulate the behavior of complex system in interaction with a large number of particles.

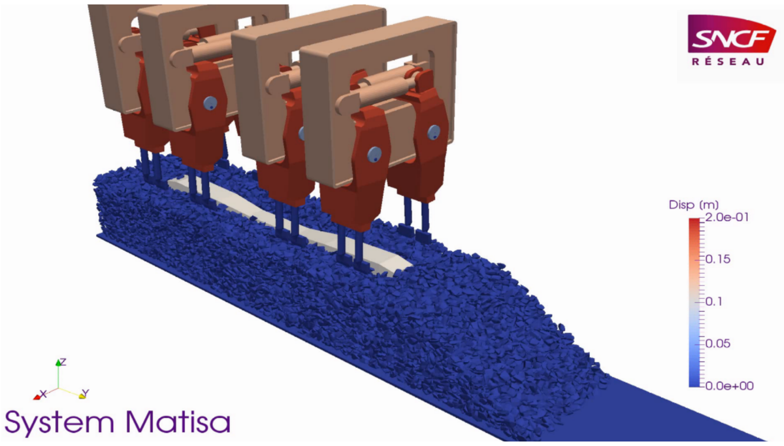


FIGURE 5 – Ballast packing

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