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# The Contact Dynamics (CD) Method, as a Discrete Element Method for the simulation of granular asteroids

Paul Sanchez (1), Mathieu Renouf (2), Emilien Azéma(2), Rémy Mozul (2)

(1) Colorado Center for Astrodynamics Research, University of Colorado Boulder, 431 UCB, Boulder, Colorado, USA,

(2) LMGC, Université Montpellier, CNRS, Montpellier, France.

## Abstract

Discrete Element Method aim to model the collective behavior of a media composed of distinct interacting particles, and constitute a significant support to experimentation in the sense that they give us access to informations that are difficult to obtain experimentally. Discrete element methods can be classified into two main families: 1) Non Smooth approaches based on non-regular mechanics that take into account shocks without grain interpenetration; and 2) Smooth approaches allowing grains interpenetration. Here, we aim to introduce the Non-smooth Contact Dynamics method, its implementation in LMGC90, as a class of Non Smooth approach, to the Planetary Sciences community. We apply the CD method to model the accretion of spherical and polyhedral particles, and we discuss on the numerical efficiency of the CD method for modeling granular asteroids.

## 1. Introduction

Discrete Element Methods (DEM) aim to model the collective behavior of a media composed of distinct interacting particles. These methods are commonly used for modeling granular media (such as sand, rocks...), condensed media (such as gels, suspensions), fractured media, etc. Assuming that most of the Near Earth Objects (NEOs) are gravitational aggregates, likened to a pile of rubble, due to their collisional evolution and potentially bound together by cohesive and gravitational forces, the field of application of DEM is beginning to expand to the so-called “granular asteroids” [1, 2].

The common denominator of discrete element methods is to consider the degrees of freedom associated with the elements (grains), considered as rigid objects, and to integrate the equations of motion for these degrees of freedom. In practice, DEM are based on two families of numerical methods: 1) “Smooth” (regular) approaches, assimilating grain interpenetration

to possible deformation at the contact and 2) “Non-Smooth” (non-regular) approaches, based on non-regular mechanics, which take into account shocks without grain interpenetration.

The aim of this work, is to present a class of Non-Smooth approaches, the Contact Dynamics (CD) Method, originally developed by J.-J. Moreau and M. Jean [4] in Montpellier (France), and to expand the field of applicability of CD to granular asteroids modeling.

## 2 The Contact Dynamics method

In CD, particles are assumed to be perfectly rigid and to interact through mutual exclusion and Coulomb friction. The frictional contact interactions are described as complementarity relations, without regularization, between the relative velocities of the particles and the corresponding forces at the contact points. As a direct consequence, the characteristic time of the system is determined by the dynamics of the particles and larger time step than in regular method can be used.

Particles motion is no longer regular, but includes speed jumps reflecting multiple collisions and collective friction between particles. Because of these discontinuities, the equations of motion are written in an integrated form and an implicit integration scheme, based on Gauss-Seidel algorithm, is used to solve the contacts.

A major advantage of the CD method is precisely the lack of a force law as in a regularized method. This is in particular crucial in the modeling of non-spherical particles (typically polyhedral), where particles can have face-to-face or face-to-side contacts [5, 6, 7]. In these cases, in CD, only three, respectively two, geometrical contact points are sufficient to represent these geometrical constraints, while in a regularized method a specific force law is required.

We use the LMGC90 code which is a multipurpose software developed in Montpellier that implements the

CD methodology and is capable of modeling a collection of deformable or undeformable particles of various shapes (spherical, polyhedral, polygonal, non-convex) through different algorithms.

### 3. Accretion of regolith particles

We apply the CD method, together with a direct application of self-gravity, to simulate the aggregation process of spheres and polyhedral particles arranged in a cubic grid ; see 1. The case of sphere allow us to compare with simulations performed with the well known *SSDEM*, a class of smooth method already introduced to Planetary Sciences community, in particular, by P. Sanchez [2]. The results obtained with CD prove to be in good agreement with those obtained with *SSDEM* simulations.

### 4. Perspectives

In this abstract, we have presented in few words the general concepts of the Contact Dynamics (CD) Method, a class of Non-smooth Discrete Element Method. The CD method has been extensively applied to investigate granular materials, as well as other mechanical systems composed of rigid bodies with frictional and cohesive interactions. The applicability of CD method in a Planetary Sciences context open new perspectives in the modeling of *realistic* self-gravitating systems by incorporating a wide range of particle and asteroid sizes and shapes, and various sources of cohesion (which are generally coupled with particle size) for different dynamical scenarios.

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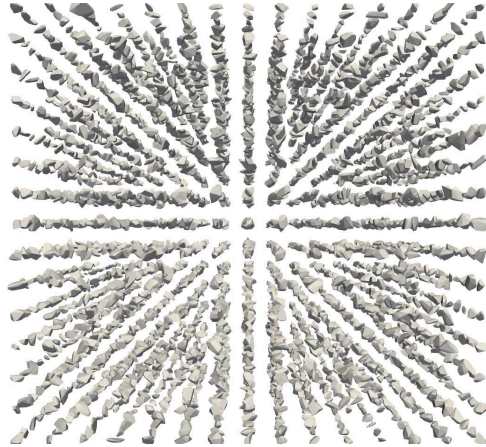


Figure 1: Accretion of 3375 self-gravitating polyhedral particles by means of the CD Method.