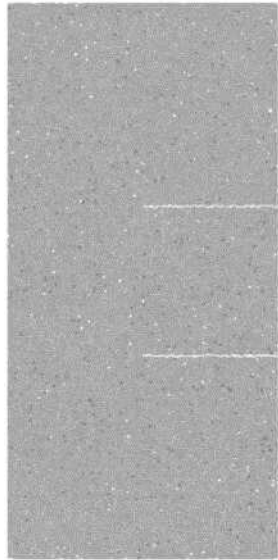
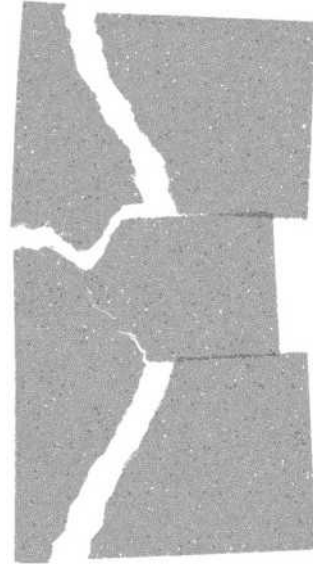


Prédiction de la durabilité des matériaux et des structures par la mécanique particulaire - Aperçu général



état initial



état final (100 μ s)

J. Girardot¹

¹ ENSAM, CNRS, Bordeaux INP, I2M, UMR 5295, F-33400 Talence

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INRAE

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Sciences et
Technologies

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INSTITUT DE
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ET D'INGÉNIERIE

Patchwork !



Grain silo – 3-rotating dryer

Patchwork !



Sand dune - Sahara

Patchwork !



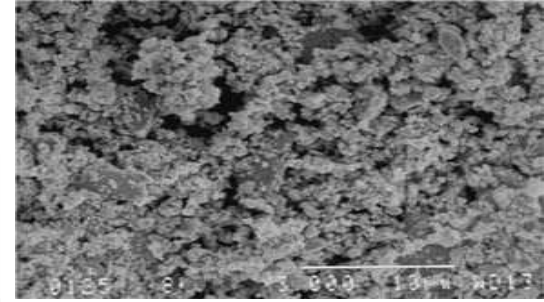
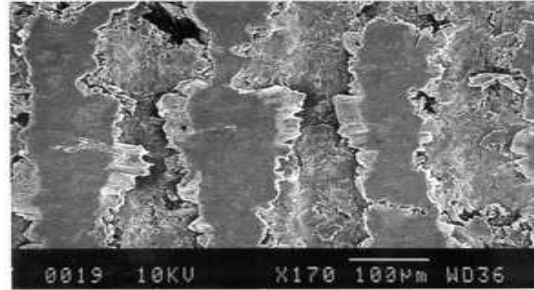
Natural Fragmentation Process (Orozco – Powders & Grains 2017)

Patchwork !



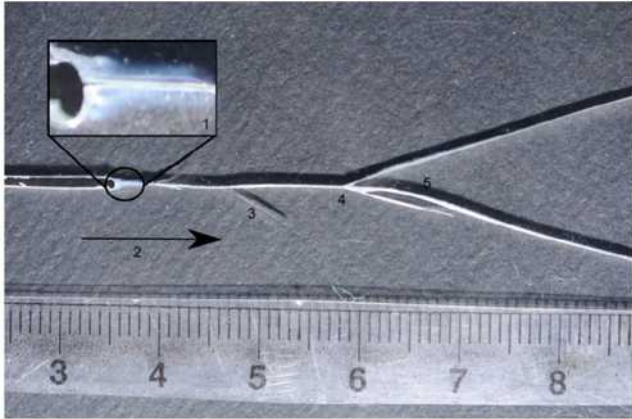
Brazilian test on a pharmaceutical compress (diameter = 11mm)

Patchwork !



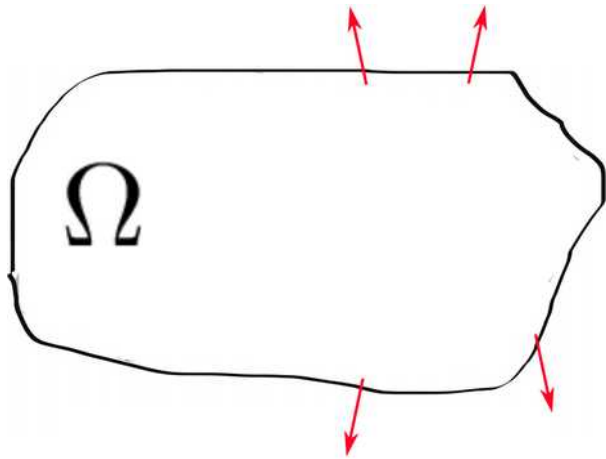
*Abraded surface – third body analysis
(Tribology lecture, I. Jordanoff)*

Patchwork !



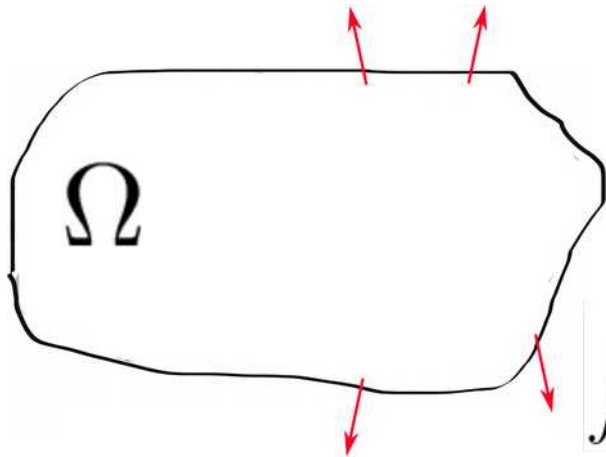
Discrete materials and/or phenomenon
→ relevance of the continuum mechanics ?

Discrete materials and/or phenomenon
→ relevance of the continuum mechanics ?



Problem =
geometry + behavior + boundary conditions + Newton 2nd law

Discrete materials and/or phenomenon
→ relevance of the continuum mechanics ?



Problem =
geometry + behavior + boundary conditions + Newton 2ndlaw

$$\int_{\Omega} F_{ext}^{\vec{v}} dV + \int_{\partial\Omega} F_{ext}^{\vec{s}} dS + \int_{\Omega} \text{div}(\vec{\sigma}) dV = \int_{\Omega} \rho \vec{a} dV$$

Discrete simulation : a general framework

Lattice method

Discrete Element Method

DEAP

NSCD

Cohesive Bond Model

Flat Joint Model

Distinct Element Method

Bonded Particle Method

SCD

Flat Bond

Molecular dynamic

Spherical-Based Model

Polygonal Based Model

Fuse Network

Coarse-grained

...?

Discrete simulation : a general framework



element i

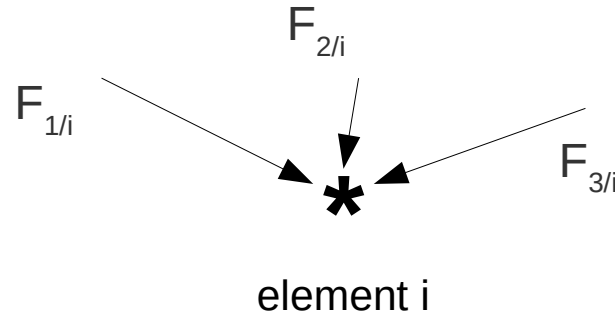
Discrete simulation : a general framework



element i

- Cartesian position
- angular position
- shape
- mass
- velocity, acceleration ...

Discrete simulation : a general framework

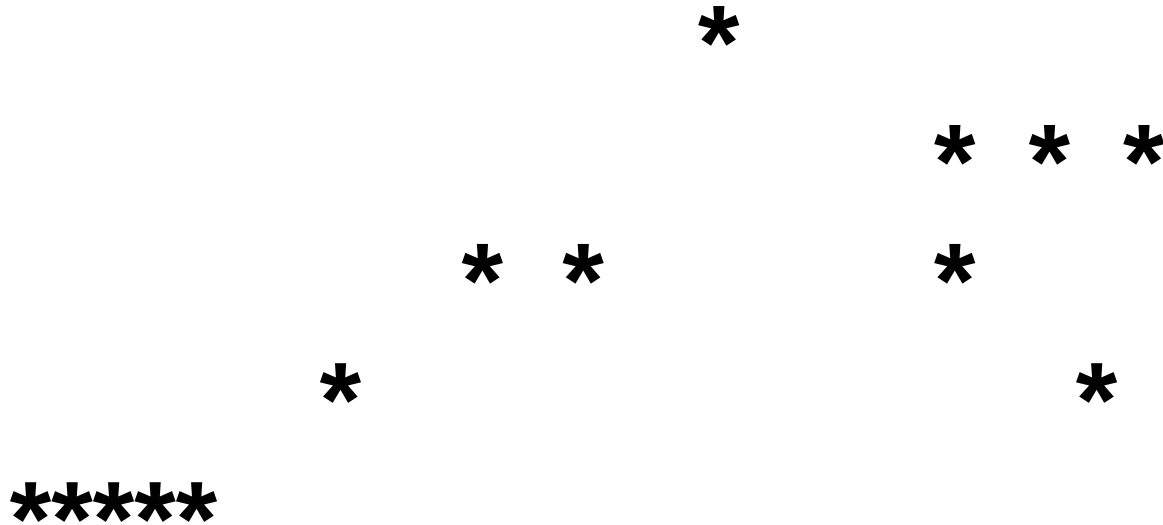


$$\sum_j^N \vec{F}_{j/i} = m_i \vec{a}_i$$

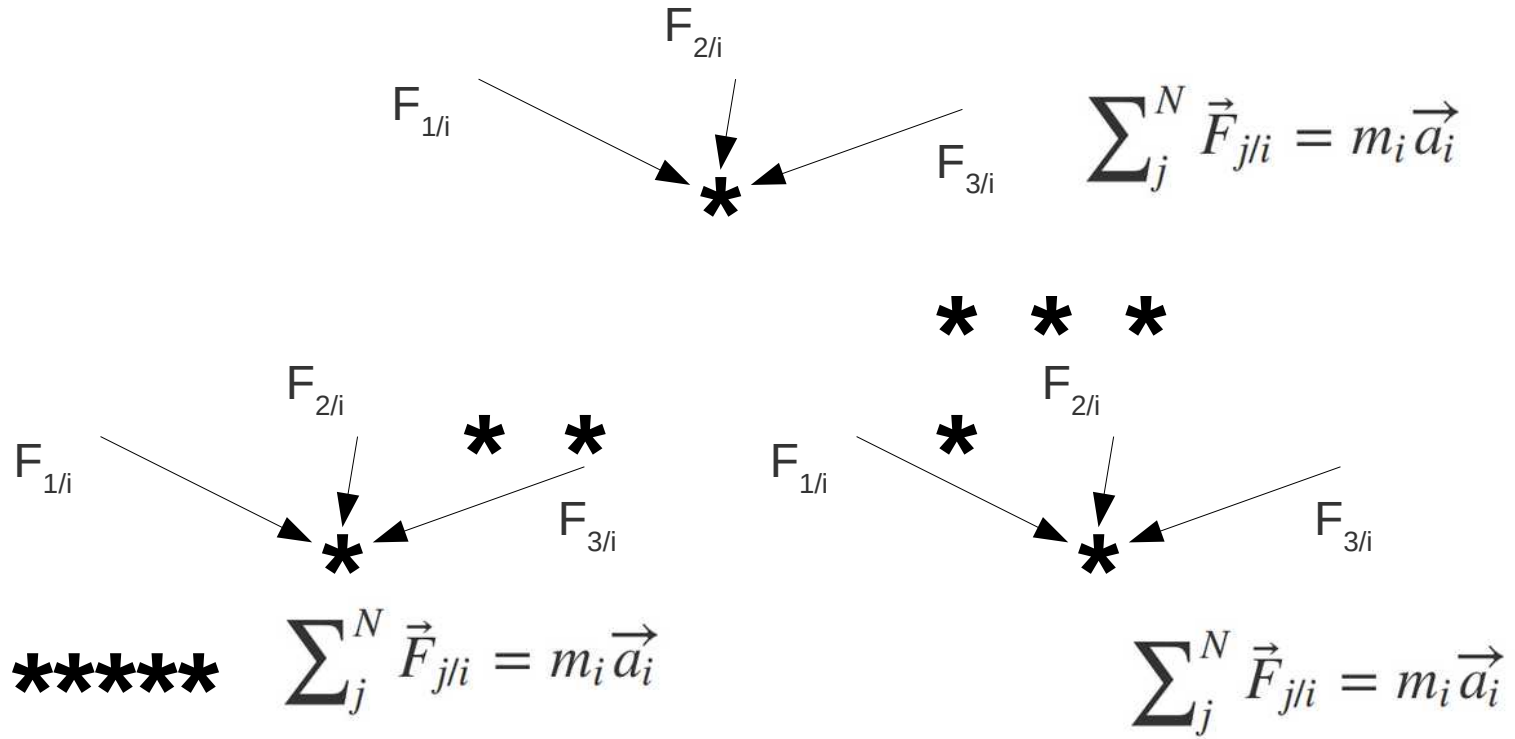
Properties

- Cartesian position
- angular position
- shape
- mass
- velocity, acceleration ...

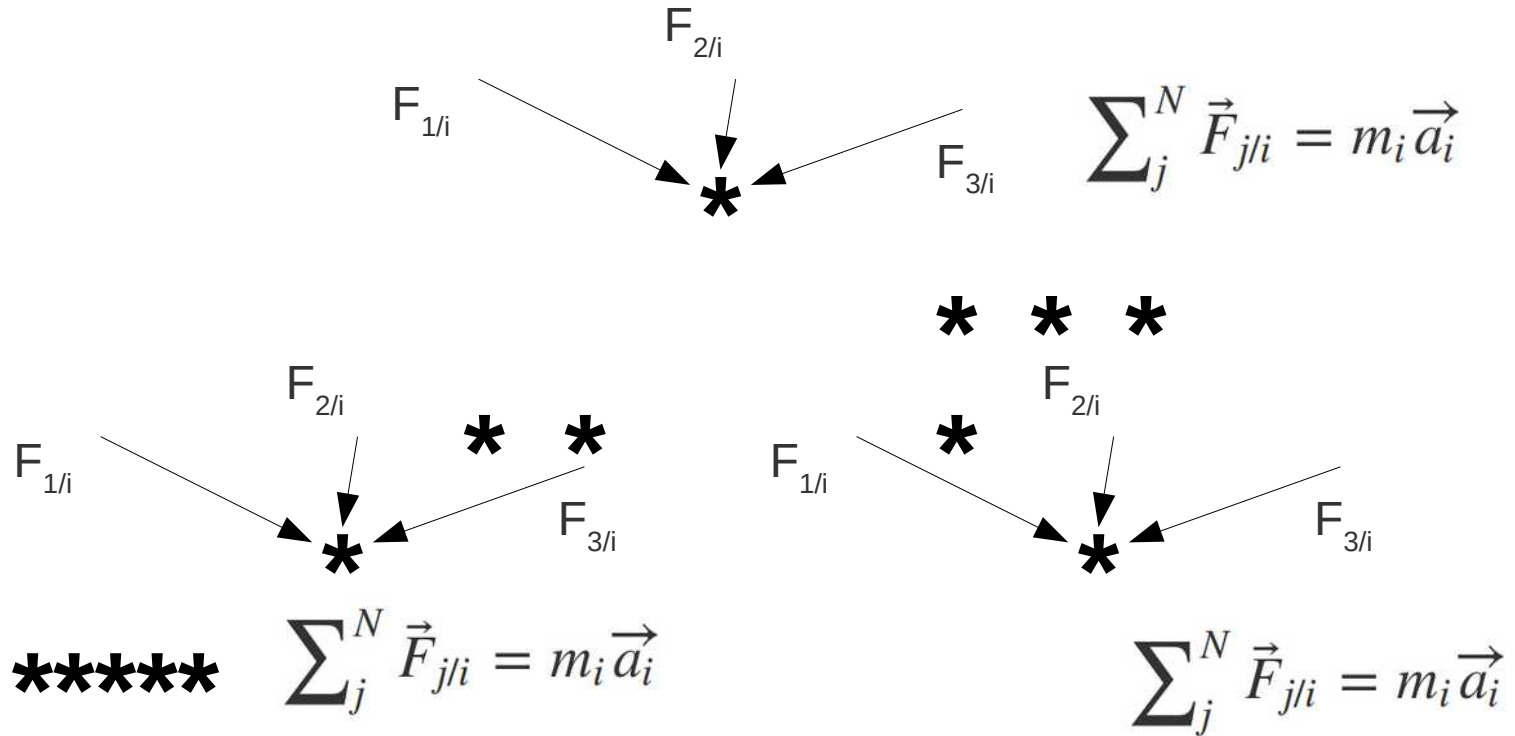
Discrete simulation : a general framework



Discrete simulation : a general framework

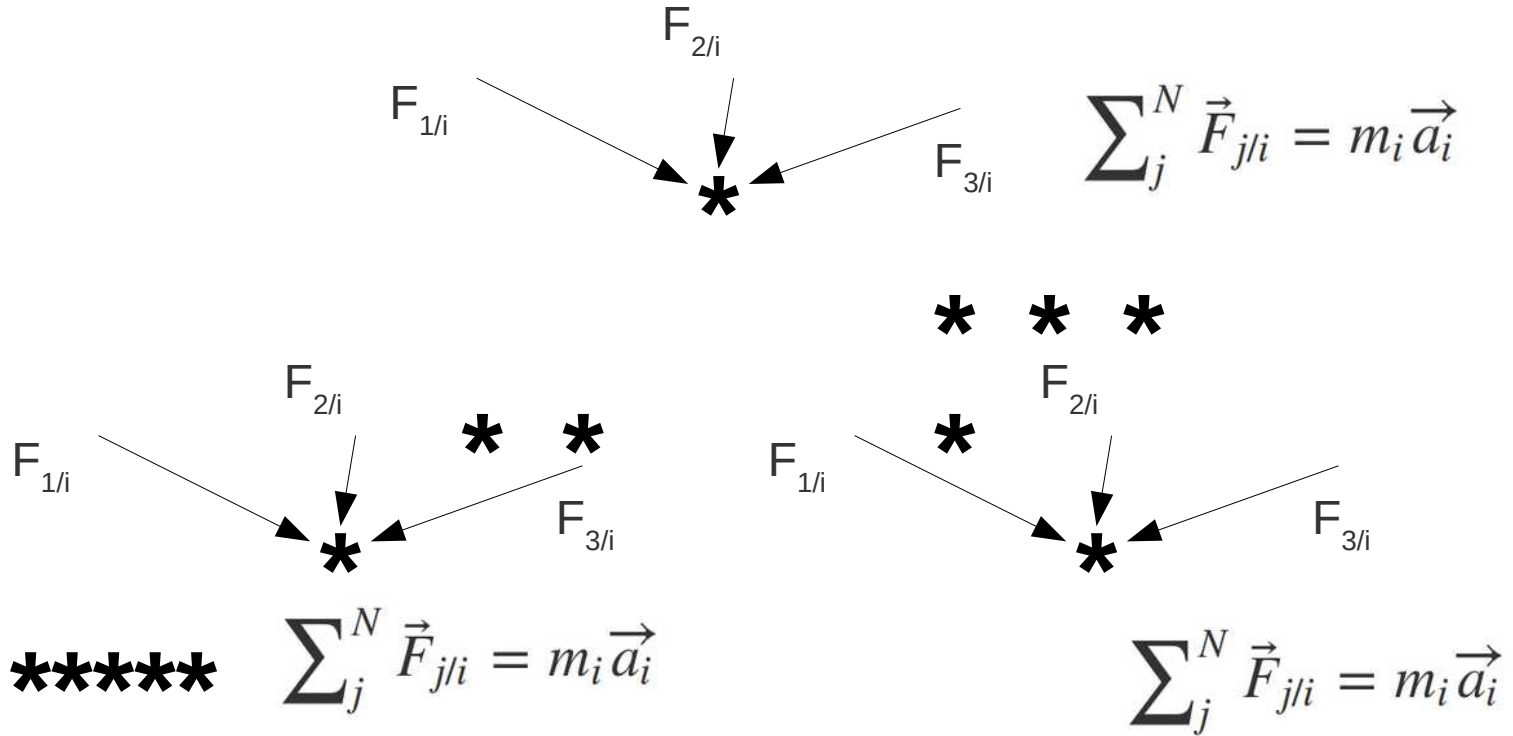


Discrete simulation : a general framework



Same definition for the rotational equilibrium → end of the general framework !!

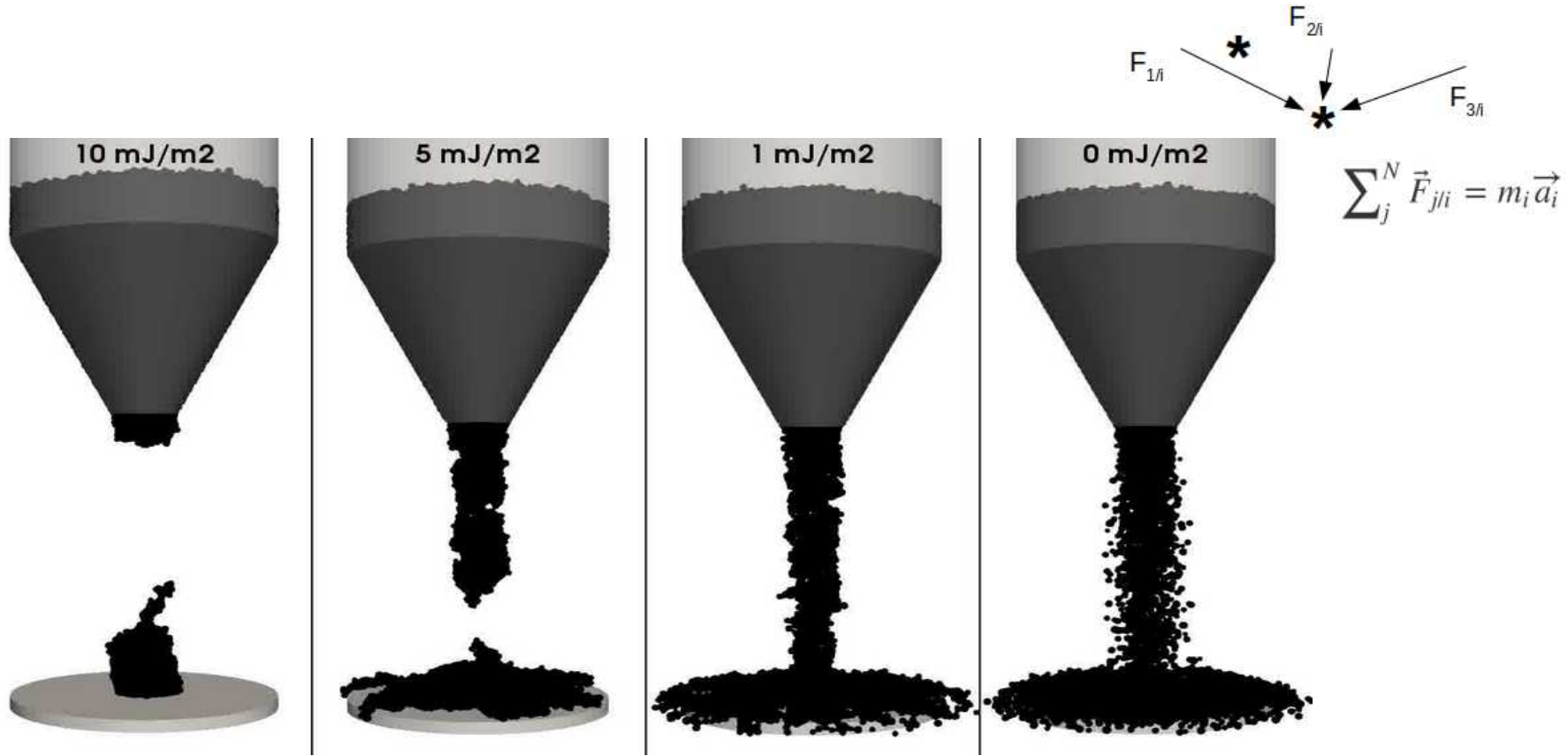
Discrete simulation : a general framework



Same definition for the rotational equilibrium → end of the general framework !!

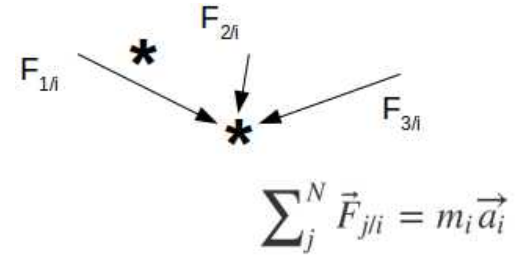
Discrete simulation : a general framework

With a smart choice of forces and momentum → **emergence** of behavior !



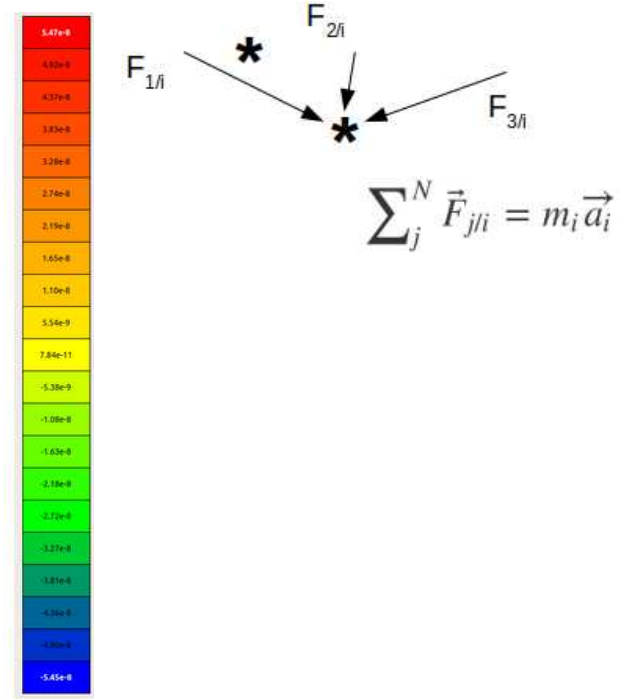
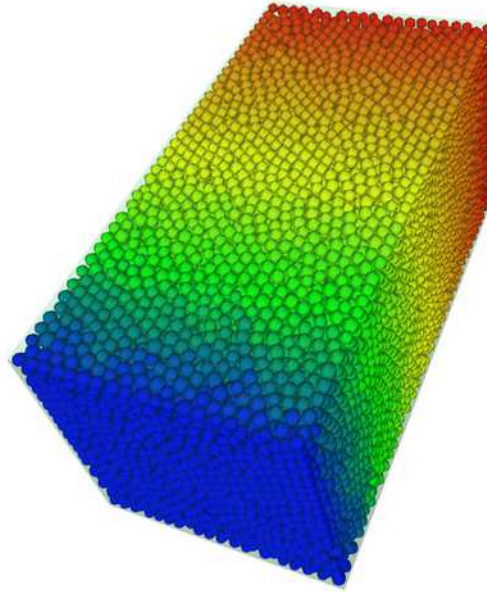
Discrete simulation : a general framework

With a smart choice of forces and momentum → **emergence** of behavior !



Discrete simulation : a general framework

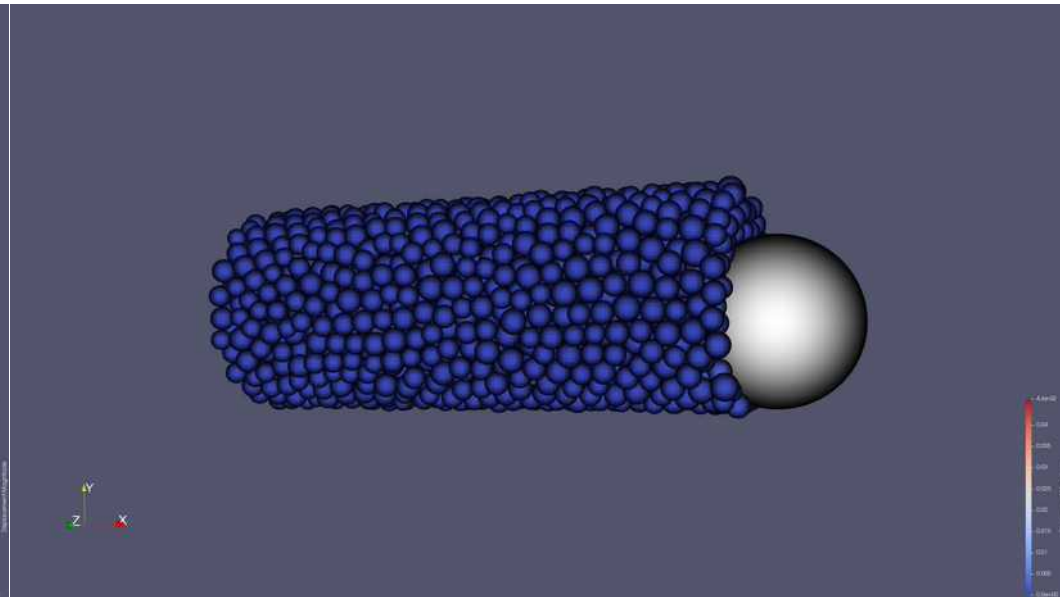
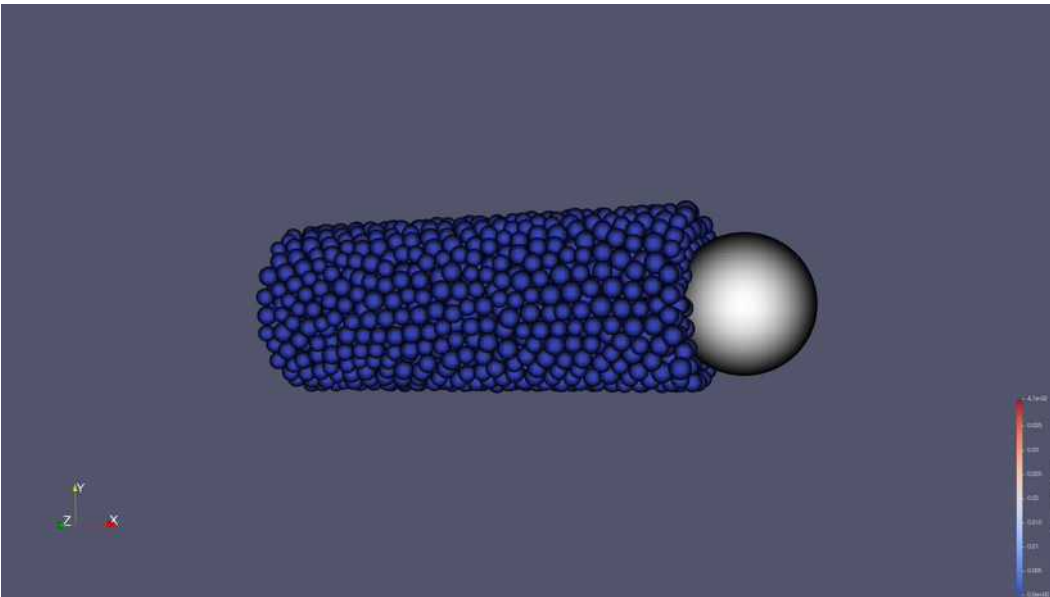
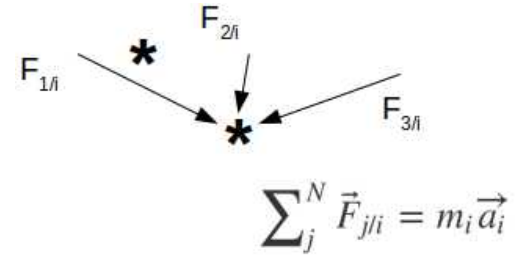
With a smart choice of forces and moments → **emergence** of behavior !



Magnitude of the vectorial property 'displacement' on each elements, uniaxial tensile test on a homogeneous, isotropic and elastic material

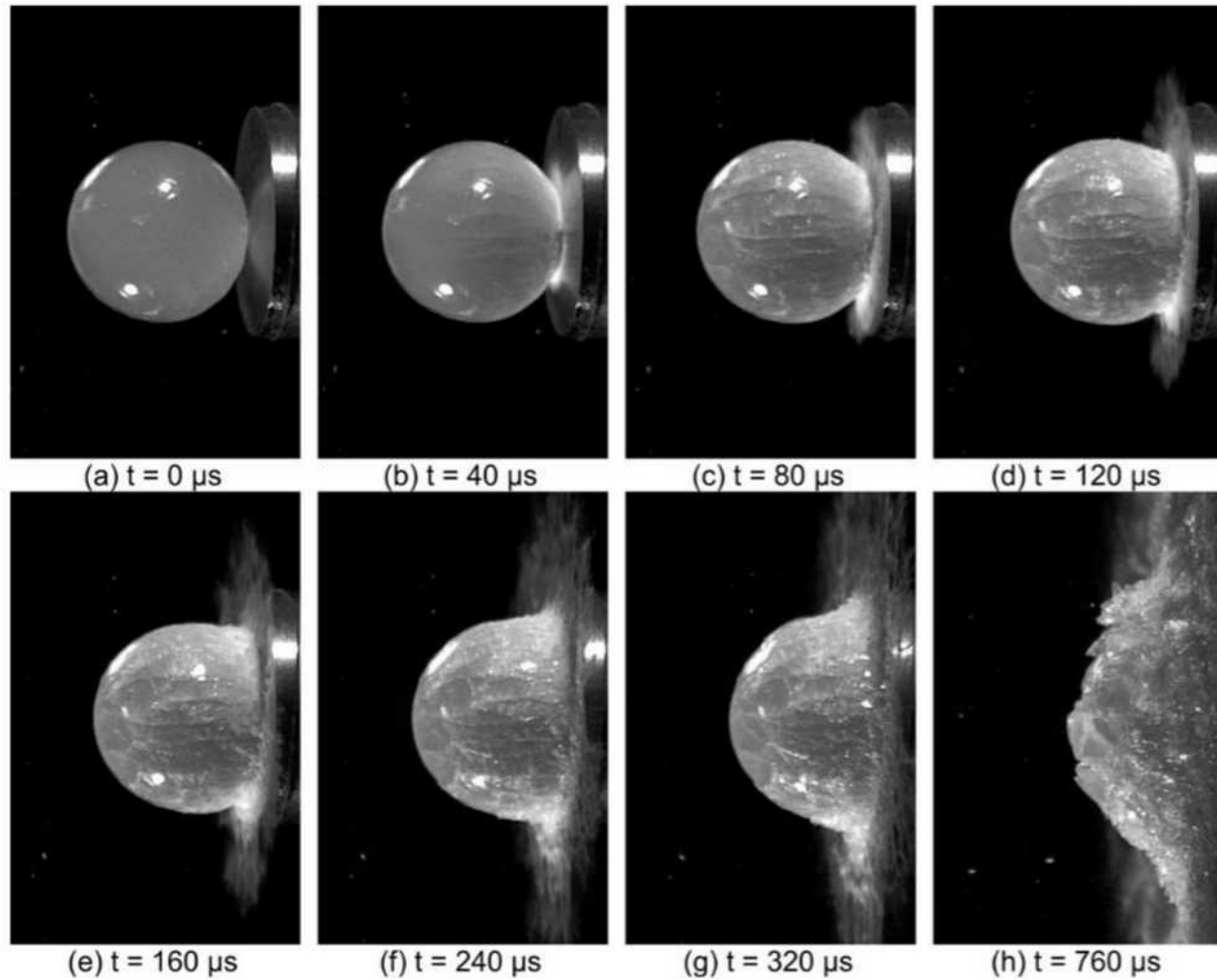
Discrete simulation : a general framework

With a smart choice of forces and moments → **emergence** of behavior !



Relevance in dynamic : some example

Example 1/28 : Hail impact simulation

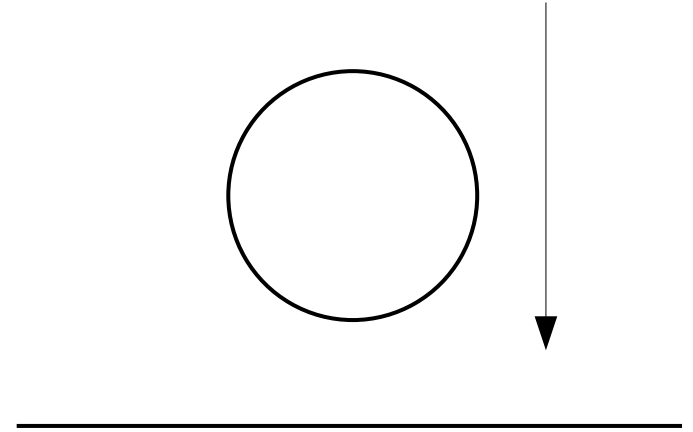


[Tippmann, 2013]

Example 1/28 : Hail impact simulation (PhD of S. Dousset, 2019)

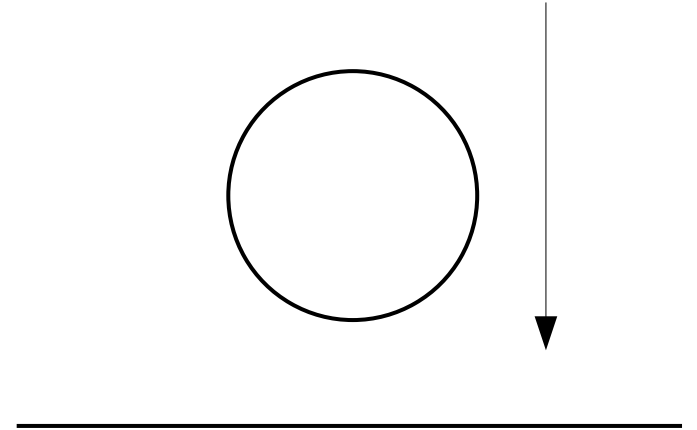
- Building of a predictive 3D model regarding the impact force for two diameters
- → using the classic continuum model with a **meshless SPH** method (based on Carney, 2006)
 - elastic, perfectly plastic behavior
 - Von Mises yield criterion with a strain rate corrector
 - fracture criterion based on a negative maximal pressure
 - post-failure mechanism :

$$\begin{cases} p & = & \min(0, p) \\ q & = & 0 \end{cases}$$

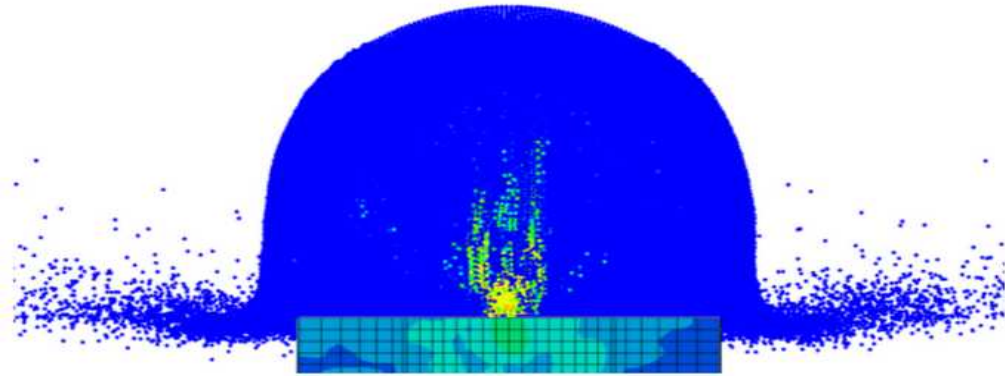


Example 1/28 : Hail impact simulation (PhD of S. Dousset, 2019)

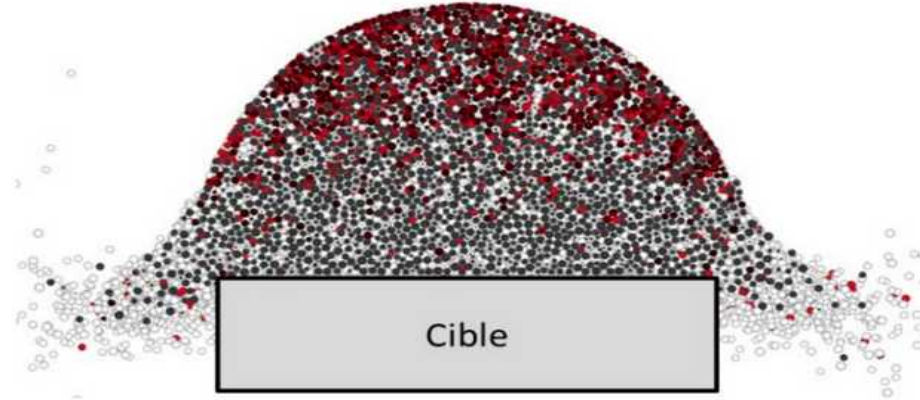
- Building of a predictive 3D model regarding the impact force for two diameters
- → using the discrete element method
 - elastic brittle material (maximum stress criteria via the virial stress)
 - granular flow with contacts after reaching the fracture criteria



Example 1/28 : Hail impact simulation (PhD of S. Dousset, 2019)



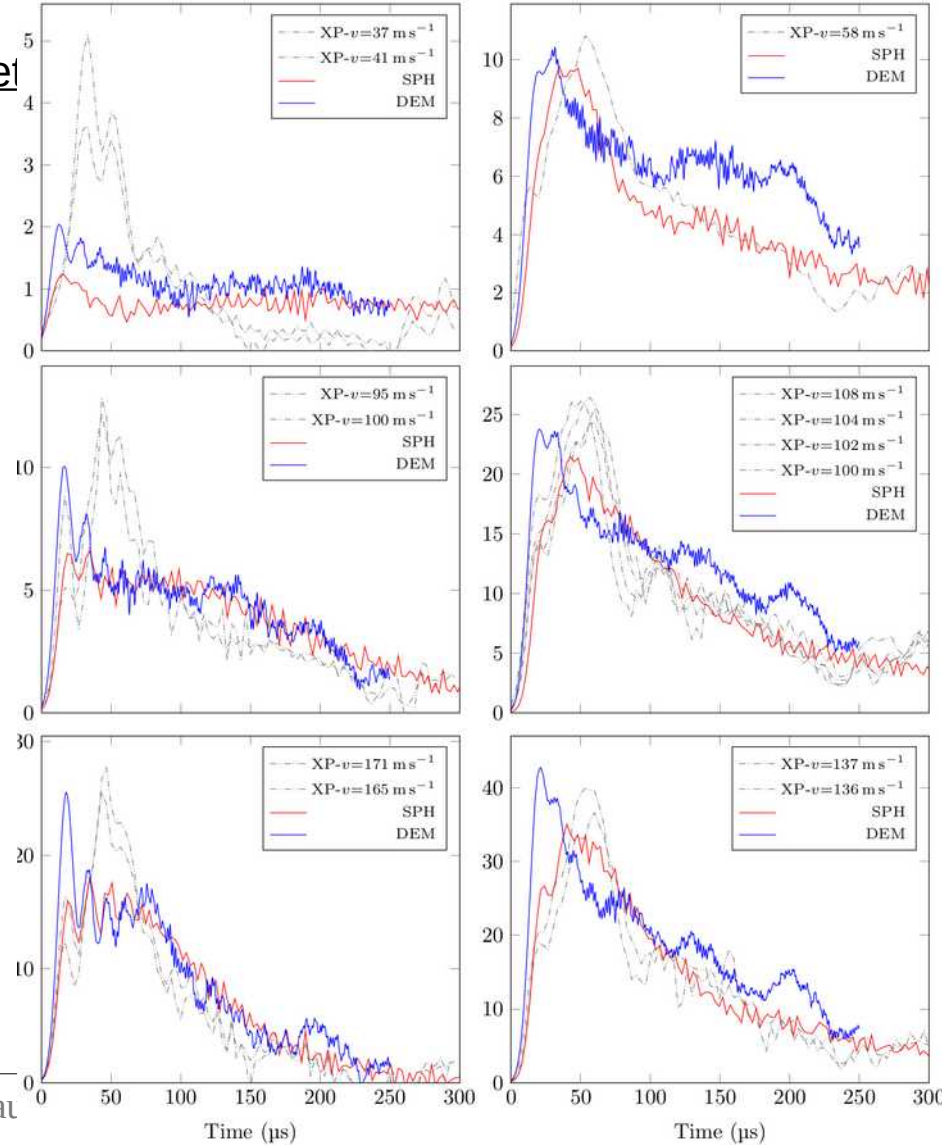
$t = 150 \mu s$



$t = 228 \mu s$

Example 1/28 : Hail impact simulation (PhD of S. Dousse)

- Same negative results for D30 at low velocity
 - continuous model needs a new calibration of p_{\max}
 - discrete model needs more physics
- Best prediction for DEM in high velocity

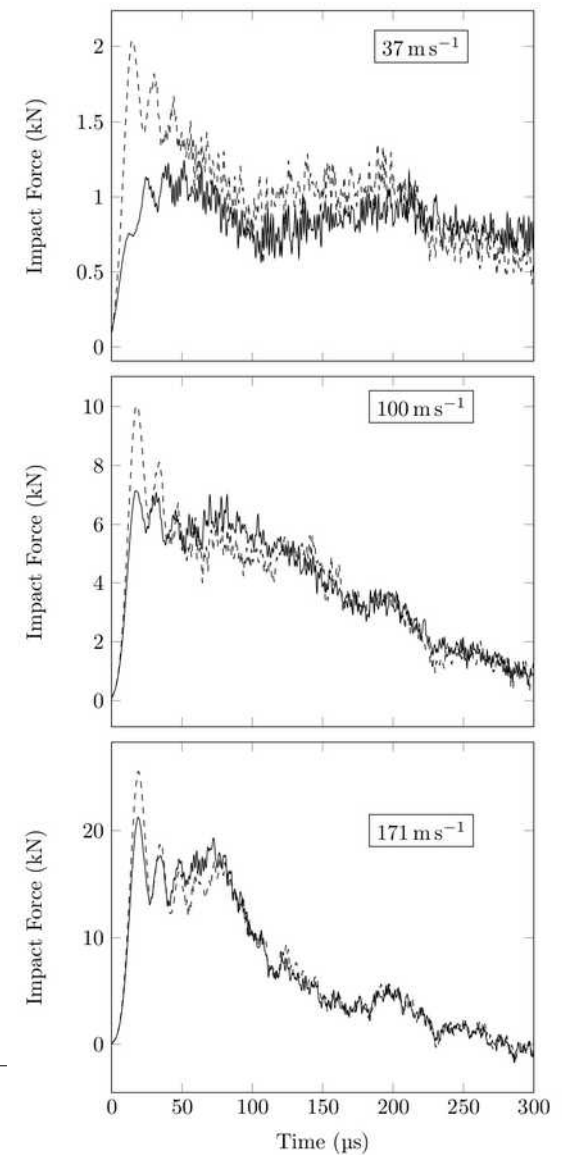


Example 1/28 : Hail impact simulation (PhD of S. Dousset, 2019)

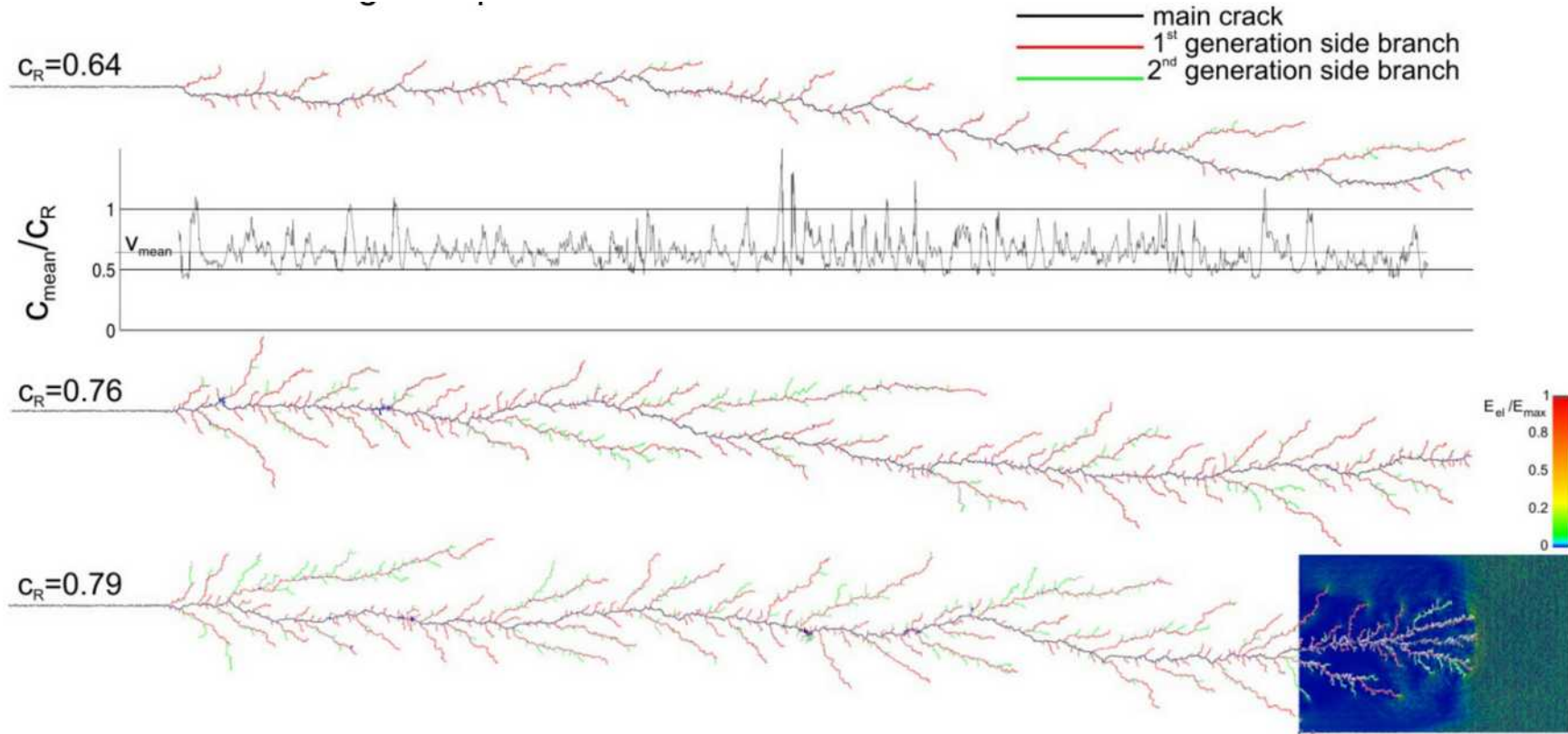
- Same negative results for D30 at low velocity
 - continuous model needs a next calibration of p_{\max}
 - discrete model needs more physics
- Best prediction for DEM in high velocity
 - Why ? Inertial impact !

Dashed : elastic-brittle
Continuous : pure granular sphere

JSMCIA 2022 - Bordeaux 2022

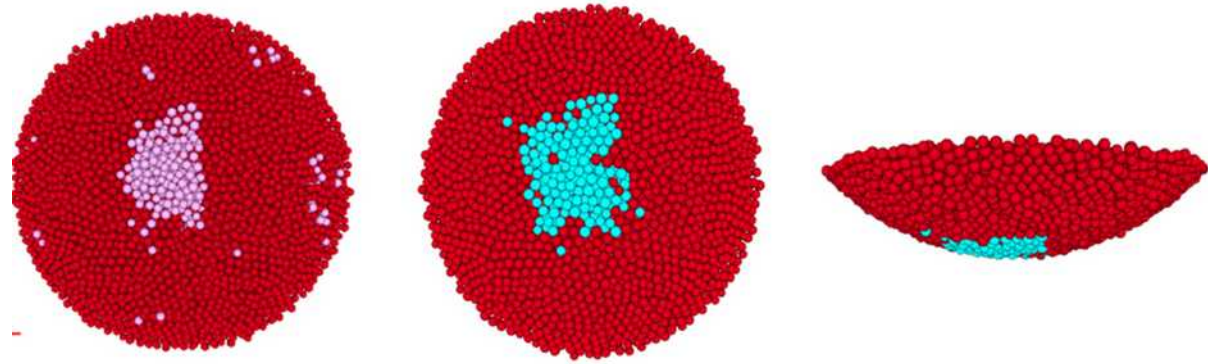
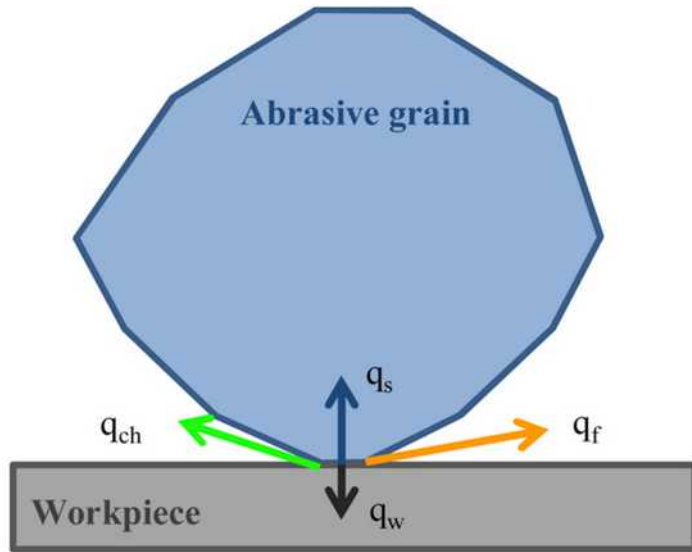


Example 2/3 : Dynamic crack propagation



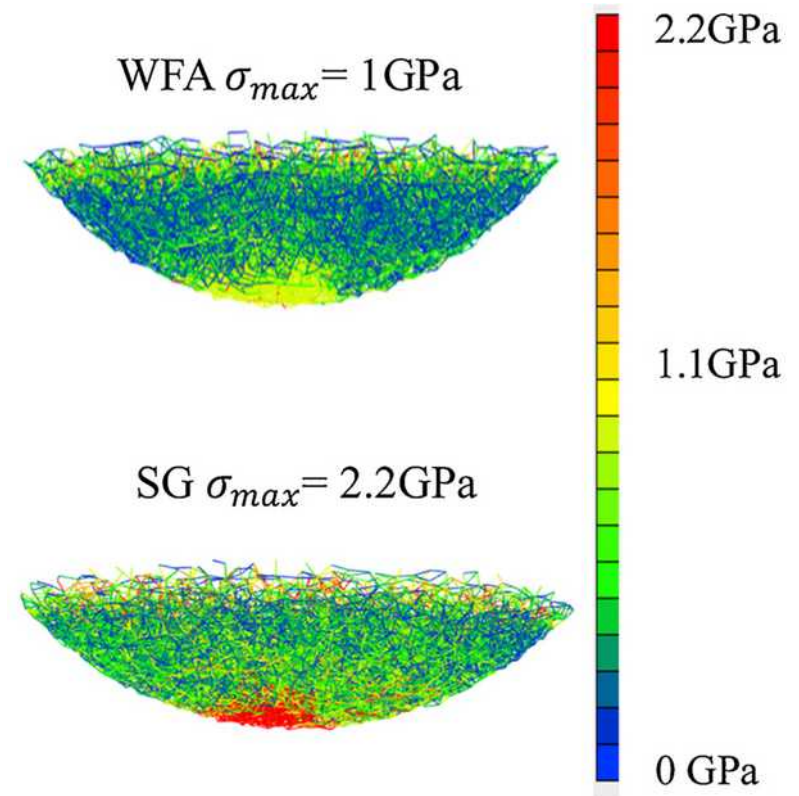
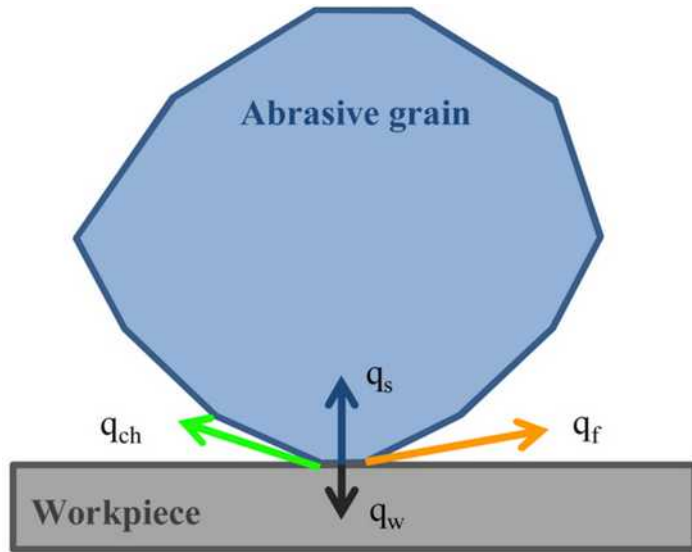
Dynamic crack propagation in heterogeneous media
[F. K. Wittel 2010]

Example 3/3 : Dynamic erosion in the grinding process



Modelling the wear of a alumina grain
under grinding condition
[PhD L. Godino, 2018]

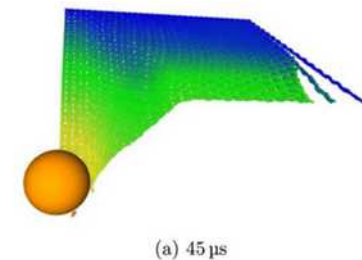
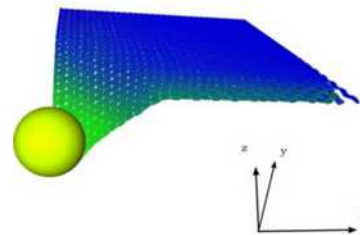
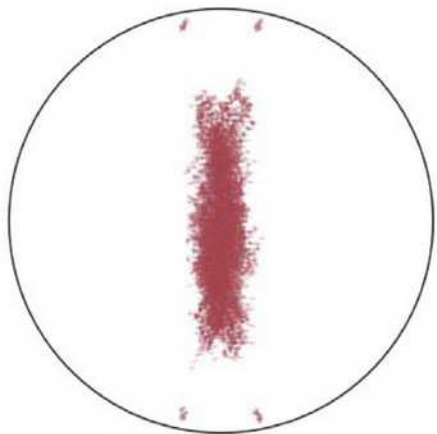
Example 3/28 : Dynamic erosion in the grinding process



Modelling the wear of a alumina grain
under grinding condition
[PhD L. Godino, 2018]

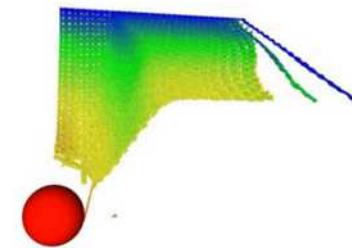
Patchwork !

Brazilian test

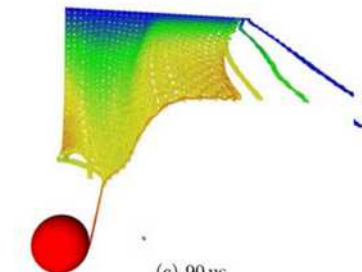


(a) 45 μs

Dry fabrics

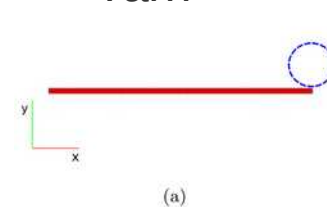


(b) 63 μs

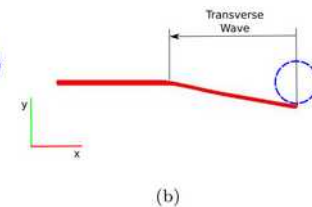


(c) 90 μs

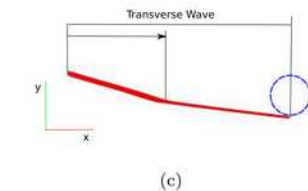
Yarn



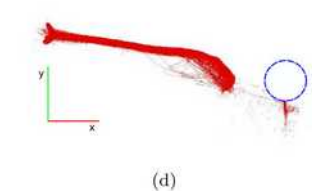
(a)



(b)

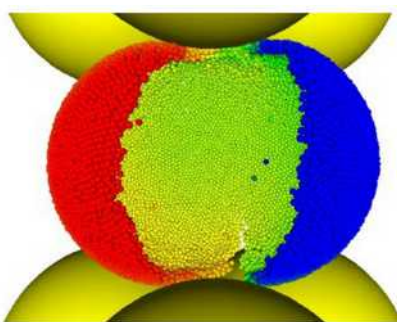
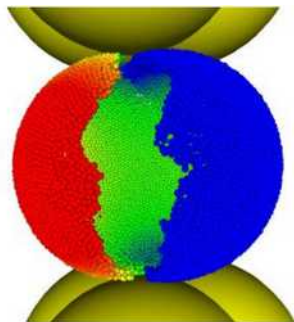
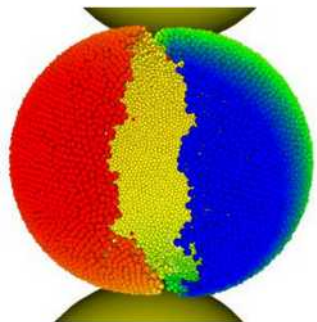


(c)



(d)

Hollow sphere



Students :

M. Sage, S. Dousset, L. Le Barbenchon, A. Coré, K. Marchais, L. Godino, P. Del Sorbo, S. Massoumi

Software :

www.granoo.org

D. André (IRCER), J. Girardot (I2M), C. Hubert (LAMIH)



A word about our numerical tools

www.granoo.org

c++/python library

Strongly Object Oriented

Very versatile

...poorly multithreaded :(

→ record : ~ 500 000 elts

...3 weeks...



Current project !

Asteroid impacts, DART mission simulation (Thesis of A. Vicaud beginning in Nov. 2022)
DGA funding

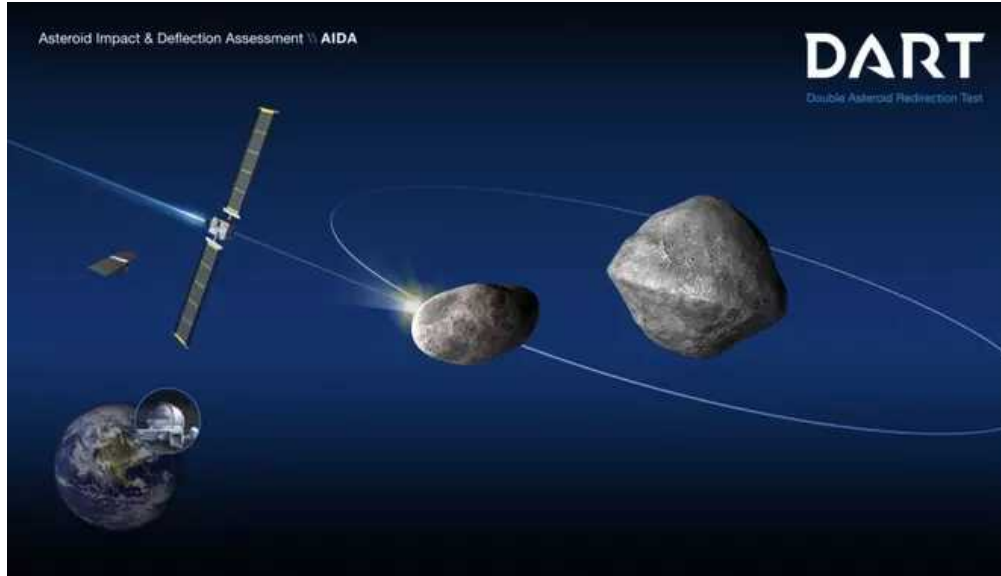
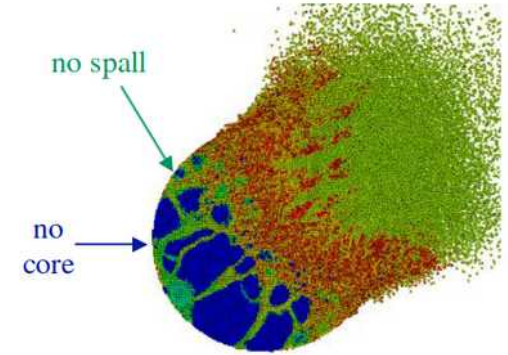


Illustration of DART Mission | Credits - NASA | garudauniverse.com

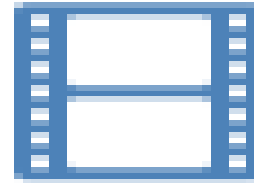


Small lab experience simulation
[Remington 2019] - SPH hydrocode

A word about our numerical tools

New project :

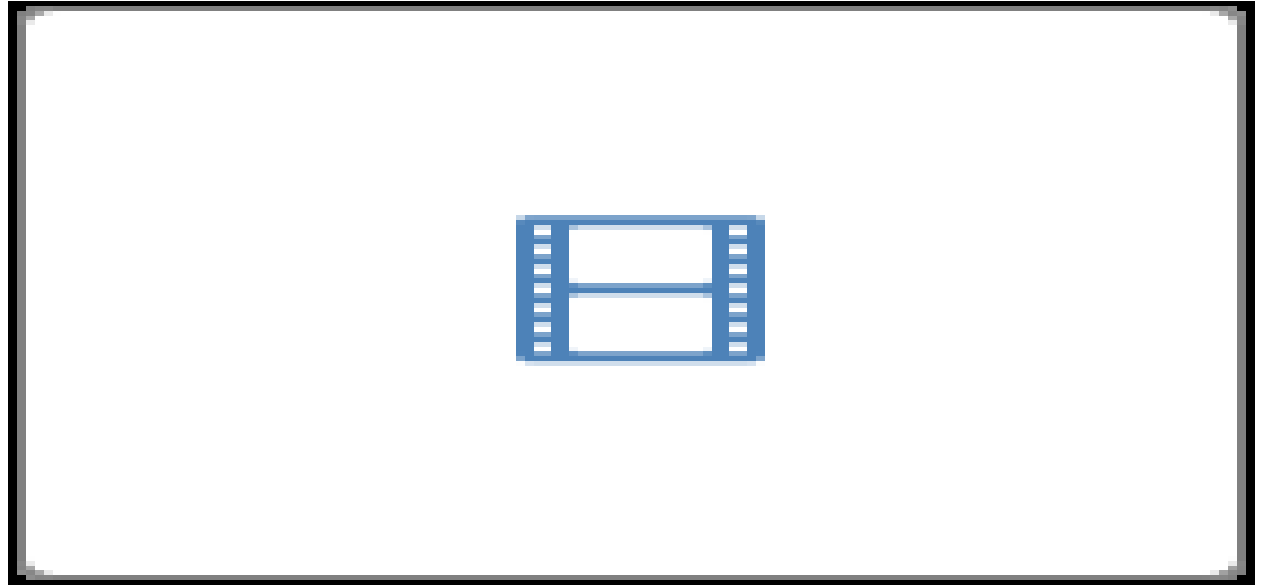
- ! Full python!
- GPU based library from nvidia
numba cuda and/or warp
(analysis in process)
- pre-test #1 :
granular column collapse test
2 millions particles
(with warp : 10 minutes)
office laptop
Visu : nvidia omniverse



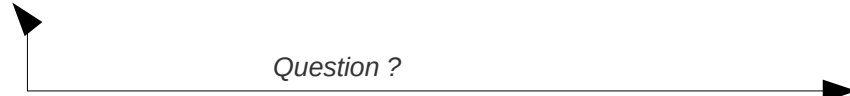
A word about our numerical tools

New project :

- ! Full python!
- GPU based library from nvidia
numba cuda and/or warp
(analysis in process)
- pre-test #2 :
 - 2 spheres collisions
 - 600000 particles
 - (with warp : 9 minutes)
 - office laptop
 - Visu : paraview



THANK YOU VERY MUCH



jeremie.girardot@ensam.eu