Modeling particle's shape in granular materials with a Level Set-Discrete Element Method

Jérôme DURIEZ

RECOVER, Irstea
(Aix-en-Provence, France)

Granular materials @ Irstea

Rockfill for rockfill dams

Serre-Ponçon rockfill dam, 123 m
https://www.edf.fr/edf/accueil-magazine/serre-poncon-cumule-les-superlatifs

The Rock Manual, CIRIA

Granular materials @ Irstea

Soils for earthfill dams

Moreau dam under construction, half-2016

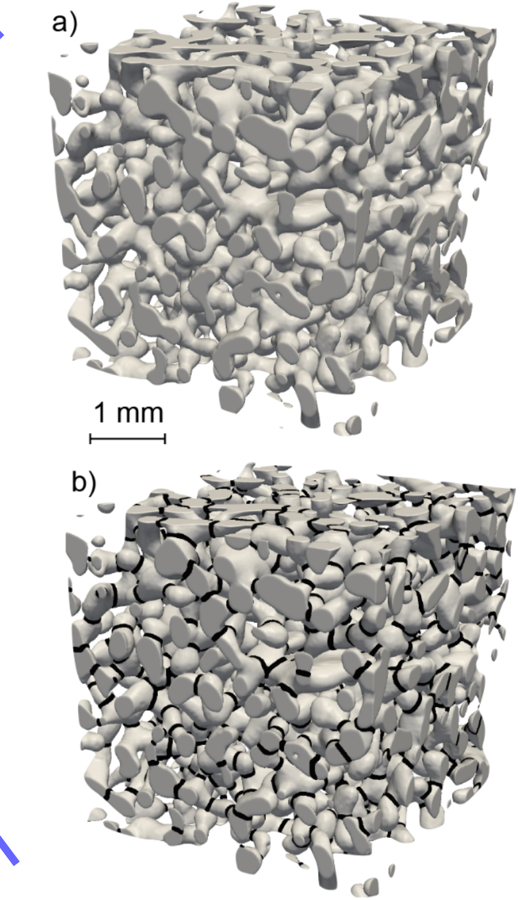
Photo G^{2}DR/Irstea

www.elyskiphire.co.uk

Granular materials @ Irstea

Snow for snow avalanches

Hervé Bellot/Irstea



Hagenmuller et al.,
The Cryosphere, 2015

Granular materials @ Irstea

Bedload/Sediments for solid transport

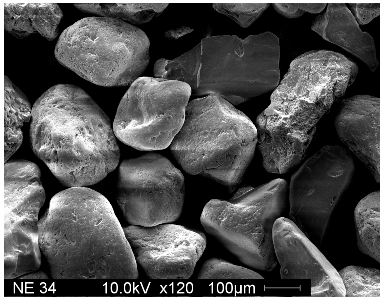
Maurice Meunier/Irstea

Mickael Lagouy/Irstea

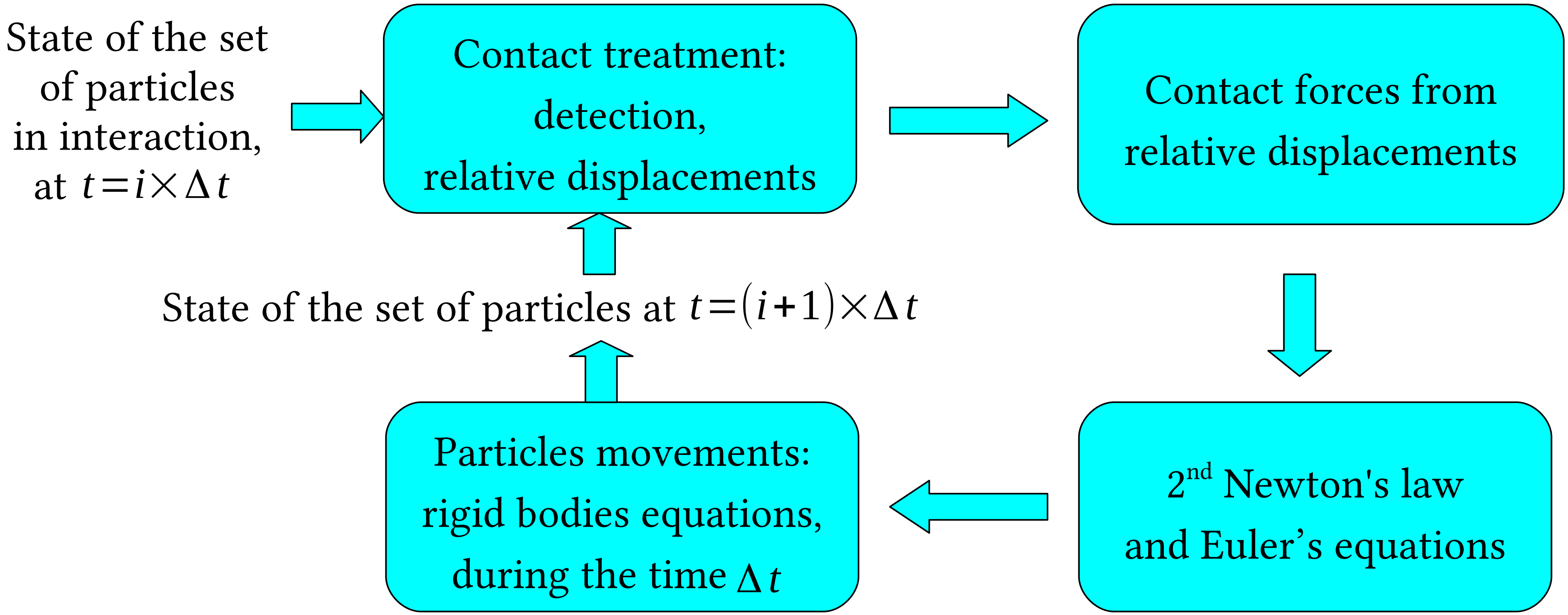
Hence the Discrete Element Method (DEM)

Numerical simulation of a granular material

www.elyskiphire.co.uk



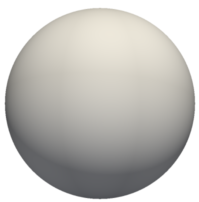
Laboratoire Navier

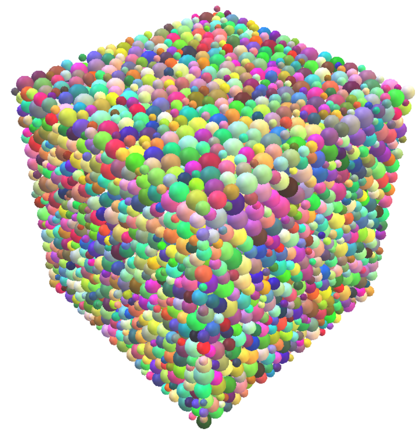


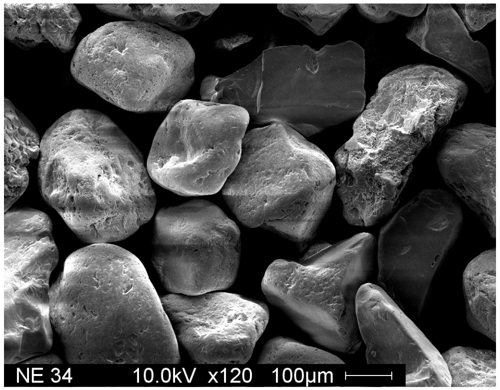
Discrete Elements

Classical shapes for Discrete Elements

- Spheres

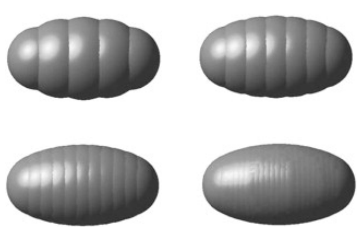




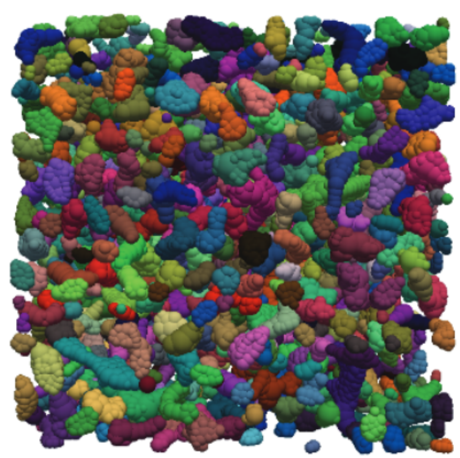


Sand
Laboratoire Navier

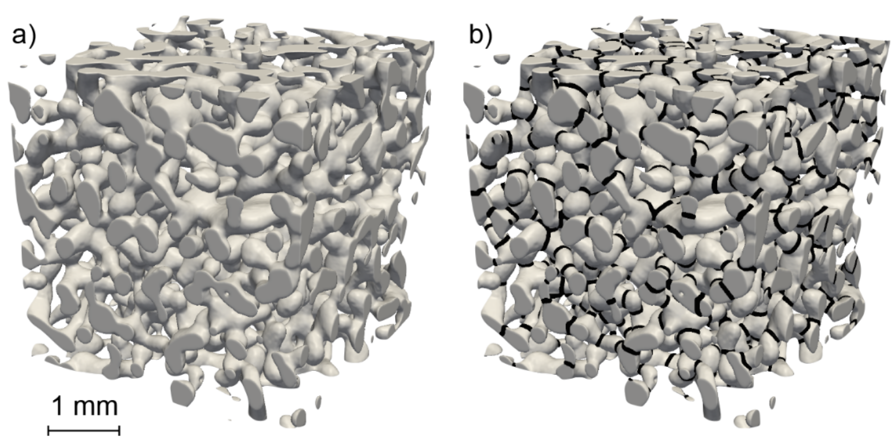
- Rigid aggregates (Clumps) of spheres



Höhner et al., *Powder Technology*, 2011



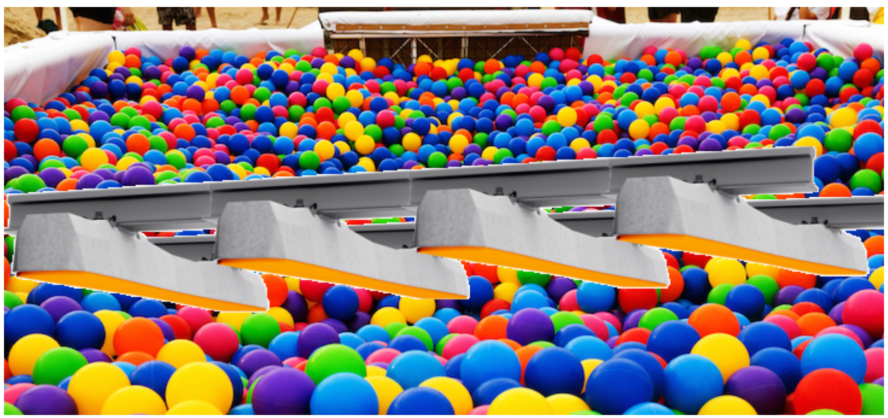
Mede et al., *Powders & Grains 2017*



Snow
Hagenmuller et al., *The Cryosphere*, 2015

Role of shape

Wanna go for a 300 km/h TGV ride ?



www.getzner.com ; londonist.com
(adapted)

OR ?

Public Domain, https://commons.wikimedia.org/

A new shape descriptor: LS-DEM

Level Set – Discrete Element Method (LS-DEM) for a better shape description ?

Contents lists available at ScienceDirect

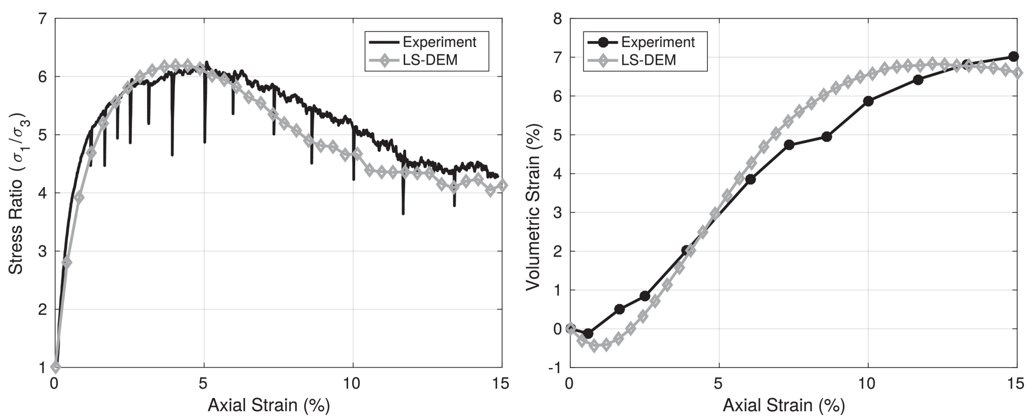
Journal of the Mechanics and Physics of Solids

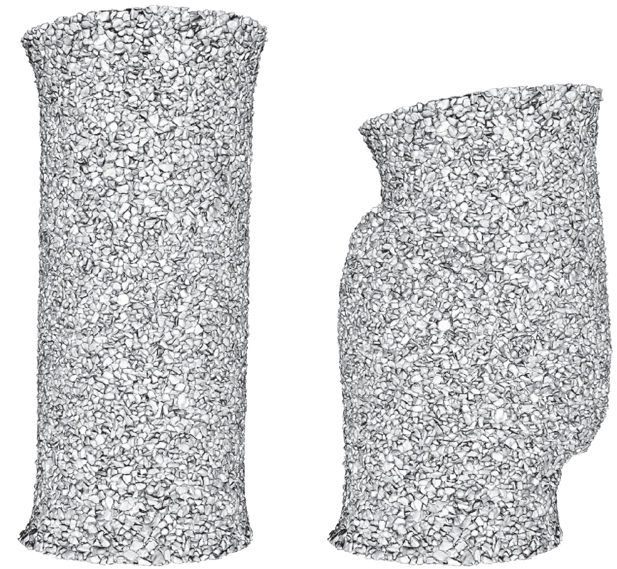
journal homepage: www.elsevier.com/locate/jmps

All you need is shape: Predicting shear banding in sand with LS-DEM

Reid Kawamoto[a], Edward Andò[b], Gioacchino Viggiani[b], José E. Andrade[a,*]

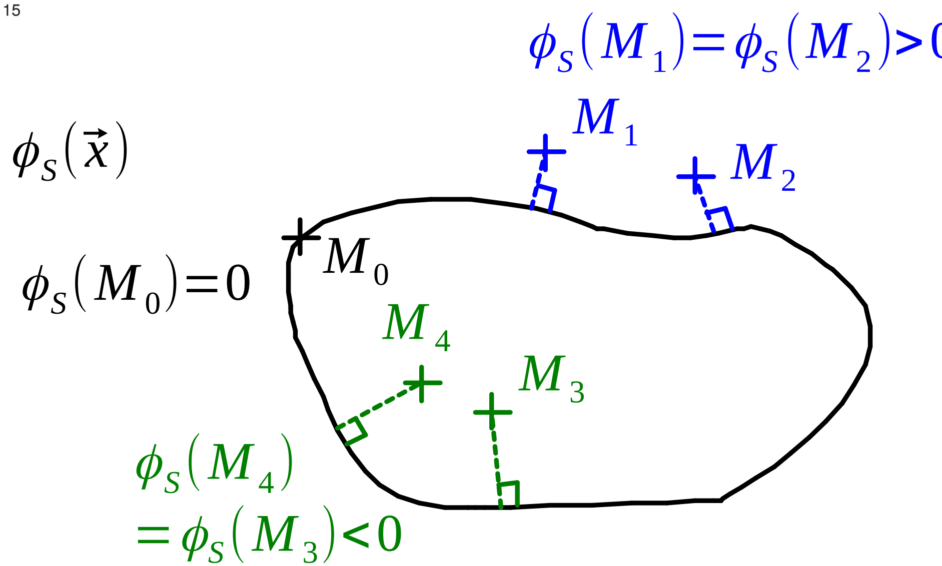
[a] Division of Engineering & Applied Science, California Institute of Technology, Pasadena, CA 91125, USA
[b] Grenoble-INP / UJF-Grenoble 1 / CNRS UMR 5521, Laboratoire 3SR, Grenoble, France





(a) (b)

- Shape description from *signed distance function* $\phi_S(\vec{x})$



Outline

- Level Set – Discrete Element Method
and its (ongoing) implementation in YADE

- Examples and Computational aspects

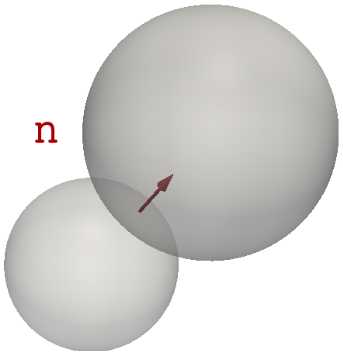
www.yade-
dem.org

YADE implementation overview

New code and old code

class LevelSet
(← Shape)

class Bo1_LevelSet
⇒ Axis-aligned bounding box
class Ig2_LevelSet_LevelSet_ScGeom
⇒ $\vec{n} ; u_n ; \Delta u_t$



State of the set of particles at $t = i \times \Delta t$

Contact treatment: detection, relative displacements

Contact forces from relative displacements

2^{nd} Newton's law and Euler’s equations

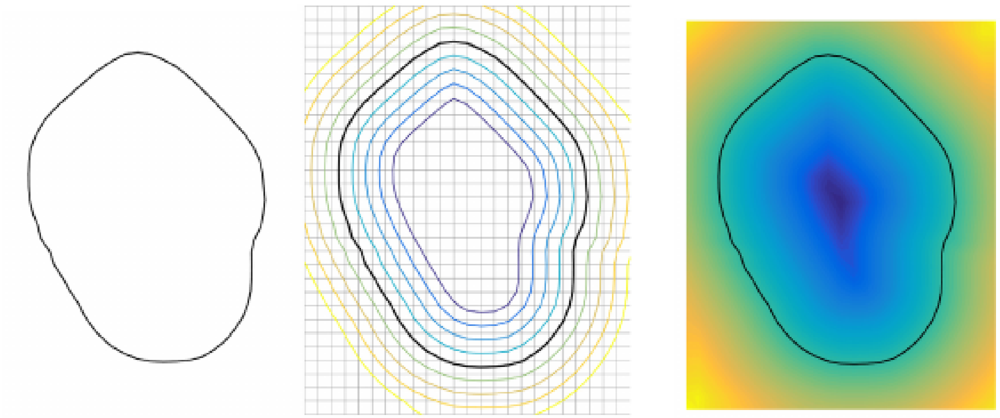
Particles movements: rigid bodies equations, during the time Δt

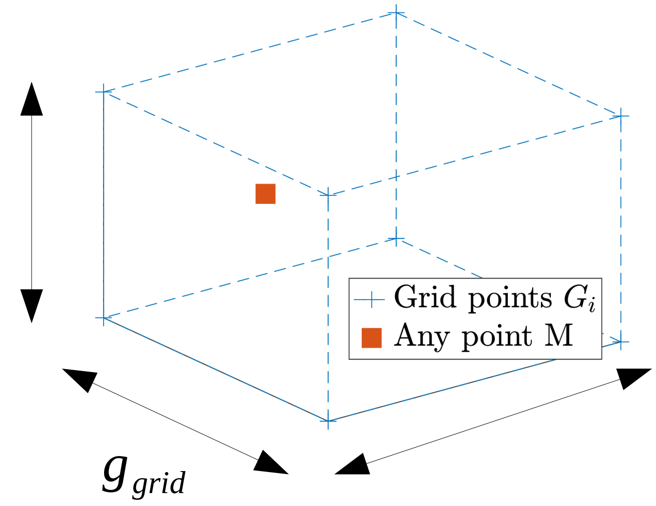
State of the set of particles at $t = (i+1) \times \Delta t$

The Level Set – Discrete Element Method

Discrete description of signed distance function ϕ_s

Storing ϕ_s values on a particle-centered grid

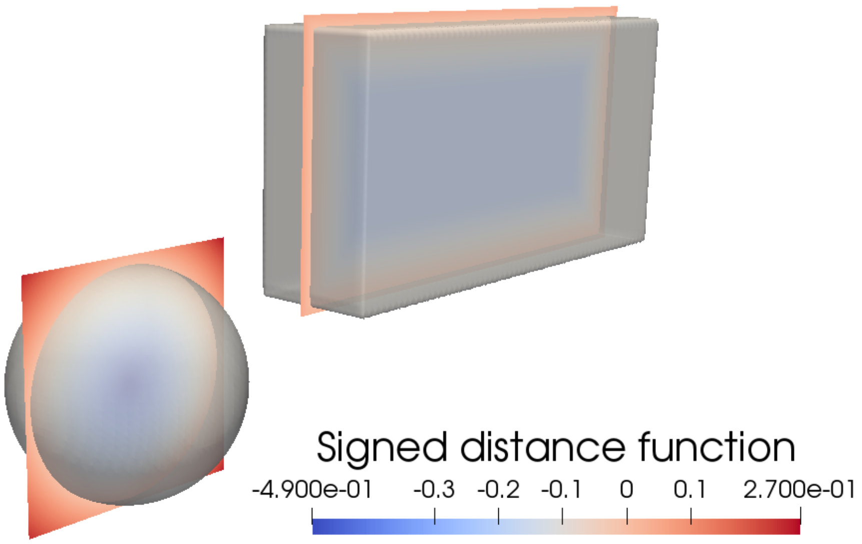




Kawamoto et al., *J. of the Mechanics and Physics of Solids*, 2016

Discrete (Voxellised) description of particles volumes

- $V_{grain} = \int_{V_{grain}} dV \approx \sum_{'inside'\,voxels} g_{grid}^{3}$
- and so on for all inertial quantities



The Level Set – Discrete Element Method

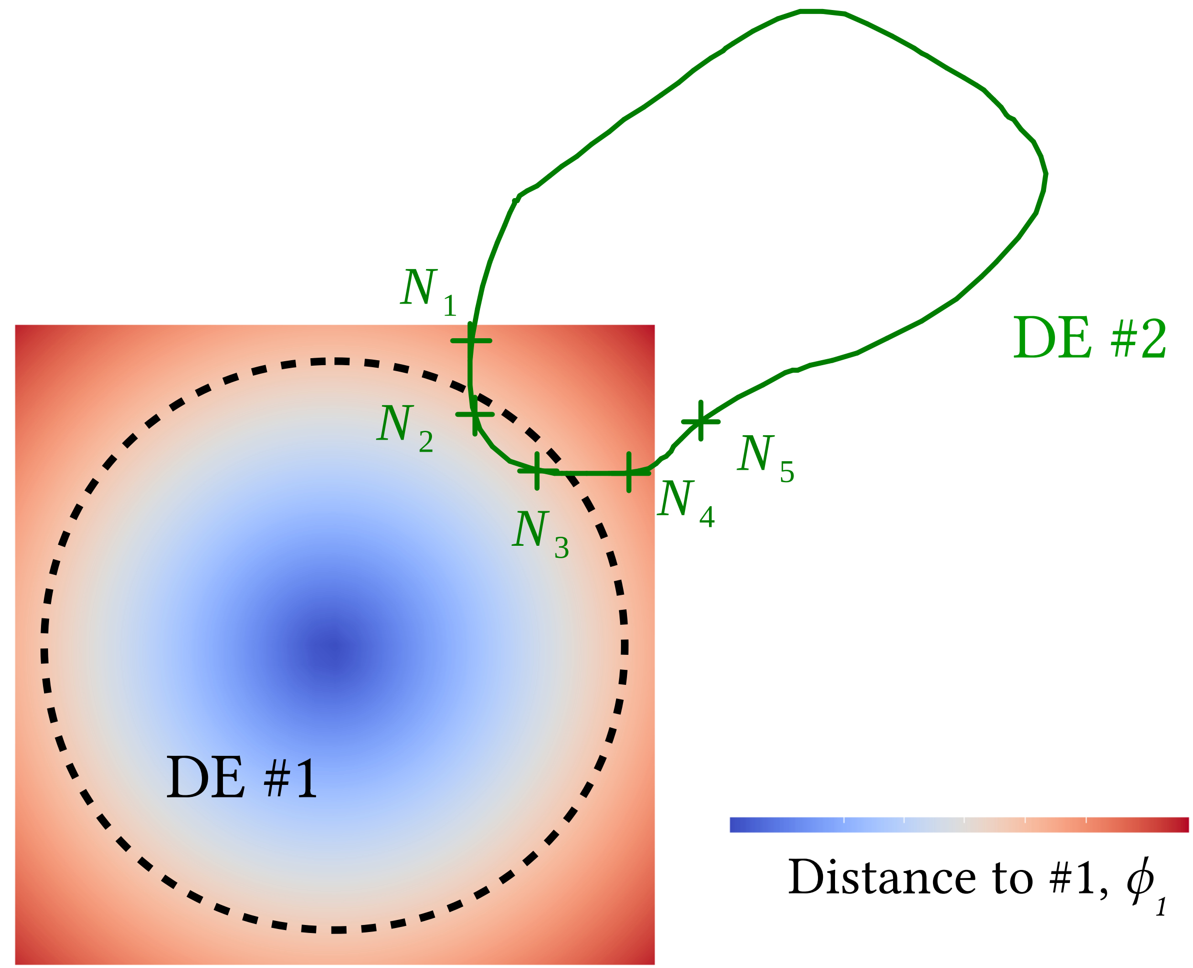
Contact treatment: "master-slave" with boundary nodes

- ϕ_1 field
- boundary nodes N_i of 2, along S_2

$$\min_{N_i} \phi_1(N_i) < 0 \ ?$$

$$\vec{n} = \nabla \phi_1$$

accounting for rigid
bodies' transformations

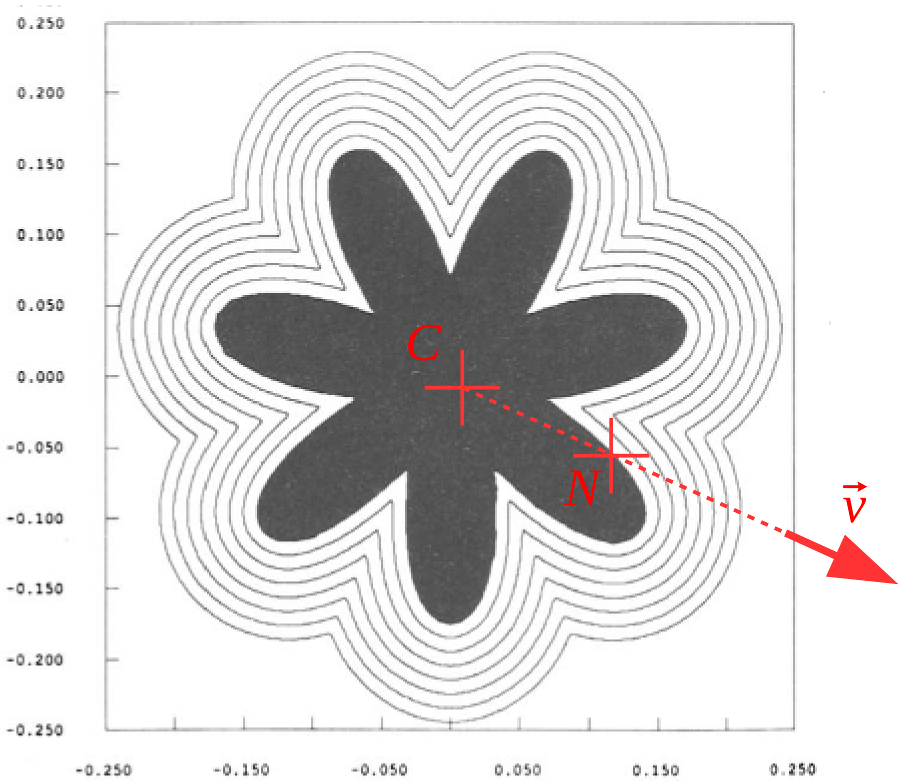


Objective ??

The Level Set – Discrete Element Method

Ray tracing of boundary nodes N_i

Once, at DE creation:

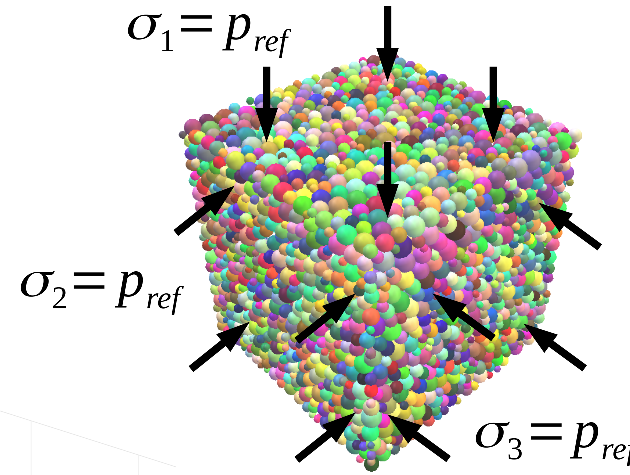


Osher & Sethian, *J. of Computational Physics*, 1988

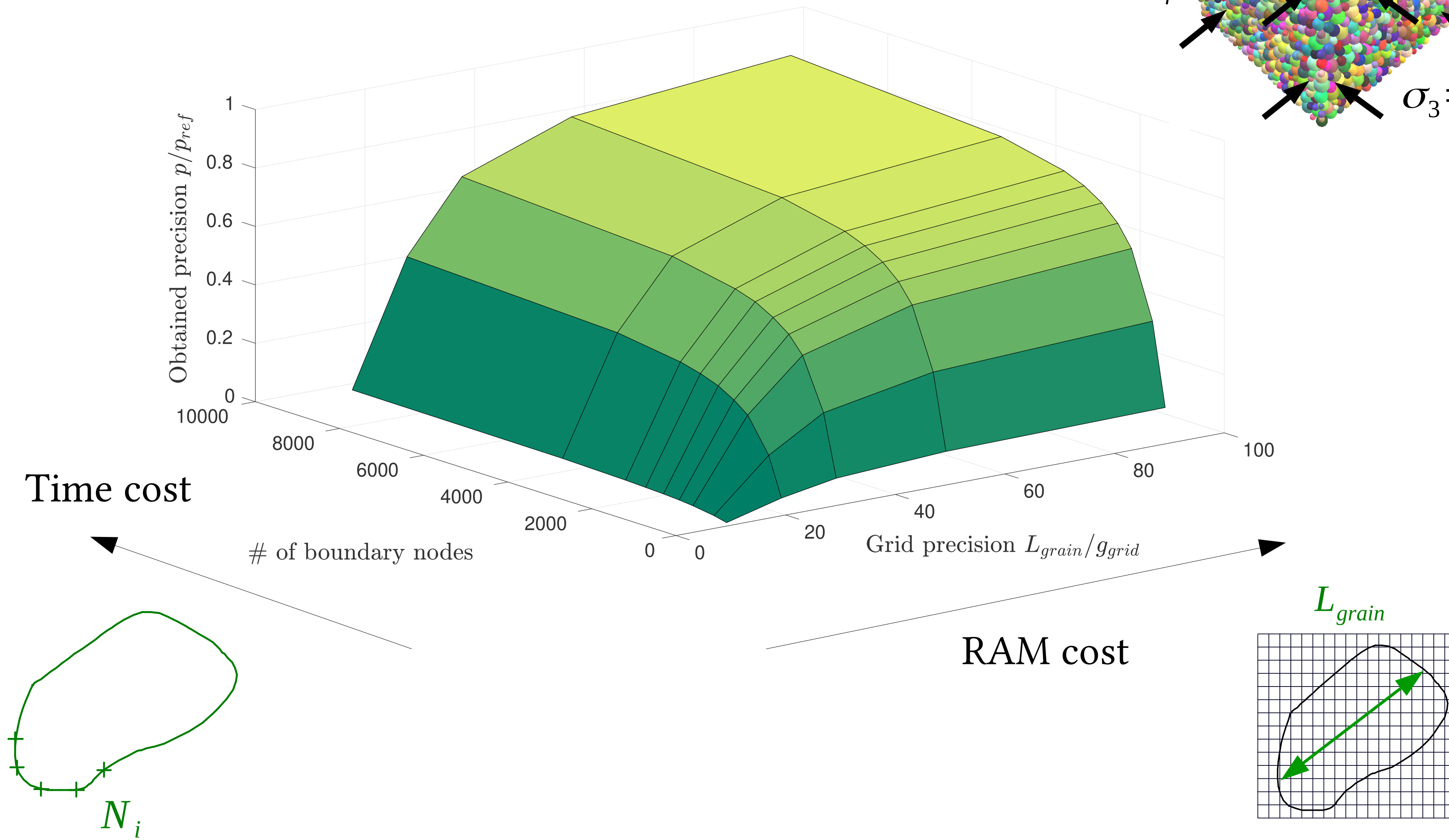
For $N = C + k\vec{v}$, $\phi_S(N) = 0 \Leftrightarrow a_3 k^3 + a_2 k^2 + a_1 k + a_0 = 0$

The Level Set – Discrete Element Method

Precision of Level Set – DEM



Isotropic configuration of 8000 spheres in a dense packing

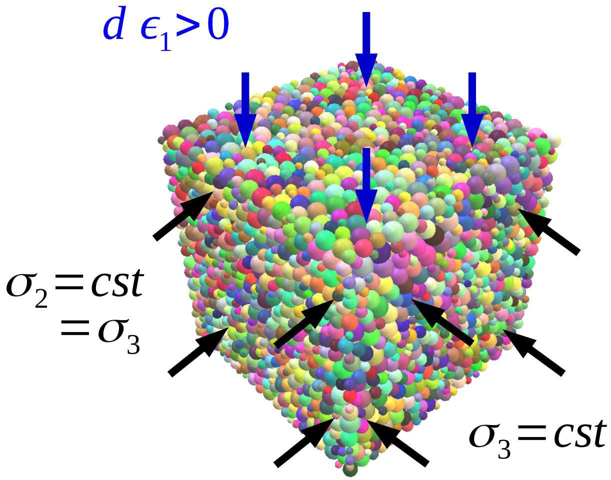


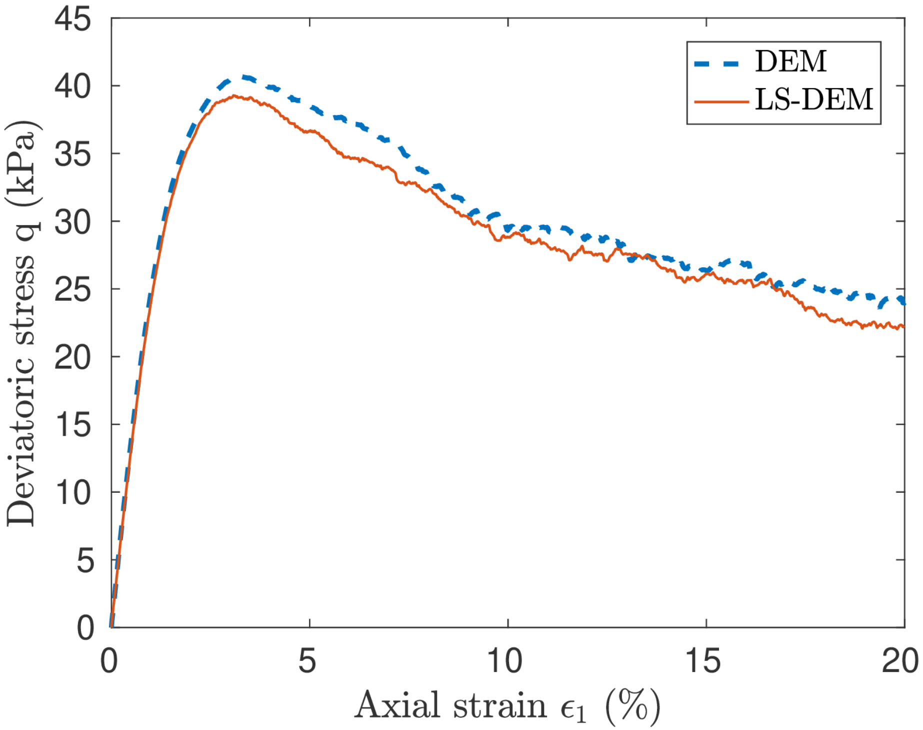
Validation example: LS–DEM vs DEM

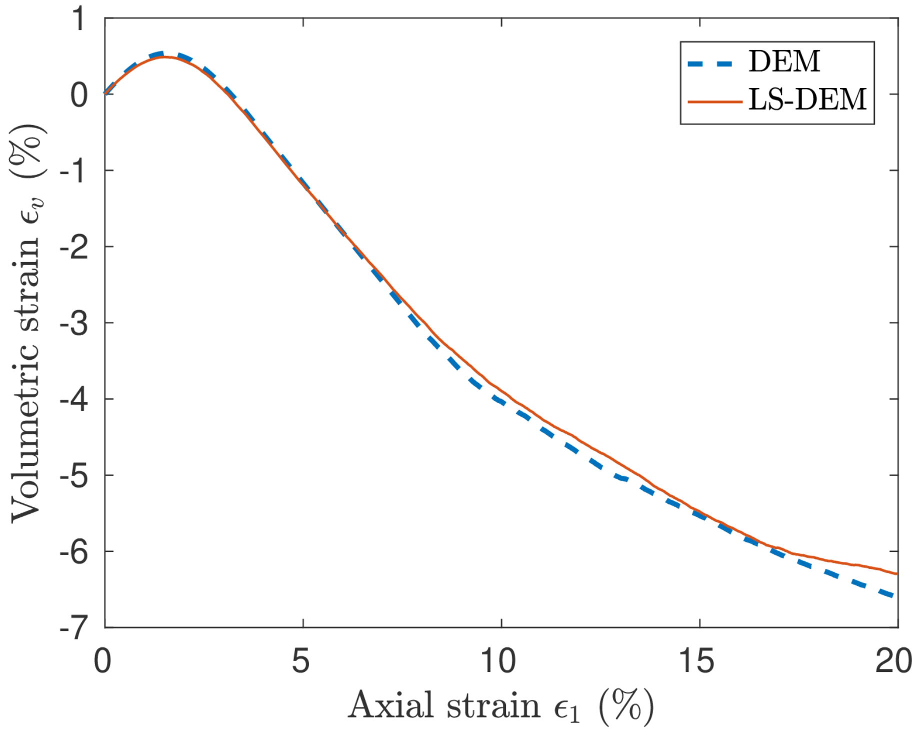
Triaxial test

Dense packing of 8000 spherical DE
- 50^2=2500 boundary nodes

- $L_{grain}/g_{grid}=90$







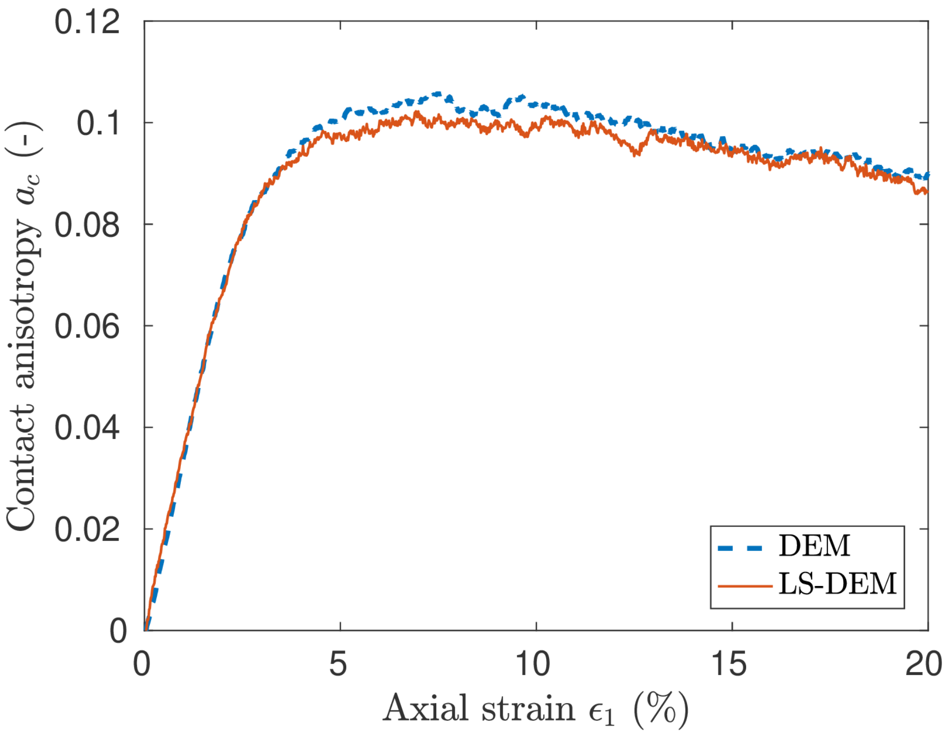
Validation example: LS–DEM vs DEM

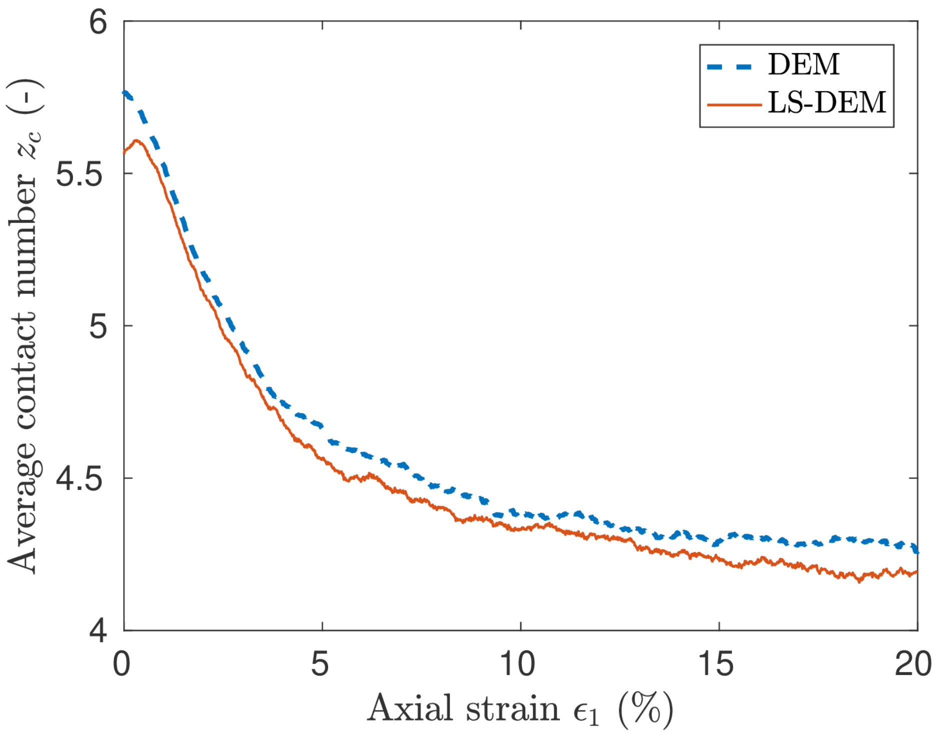
Triaxial test

Dense packing of 8000 spherical DE

- 50^2=2500 boundary nodes

- $L_{grain}/g_{grid}=90$





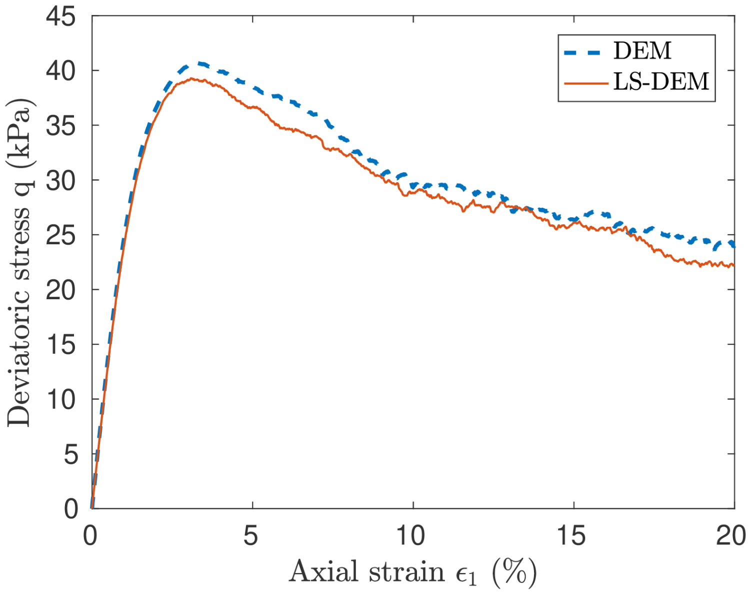
$$a_c = dev\left(\frac{1}{N_c}\sum_c \vec{n}\otimes\vec{n}\right)$$

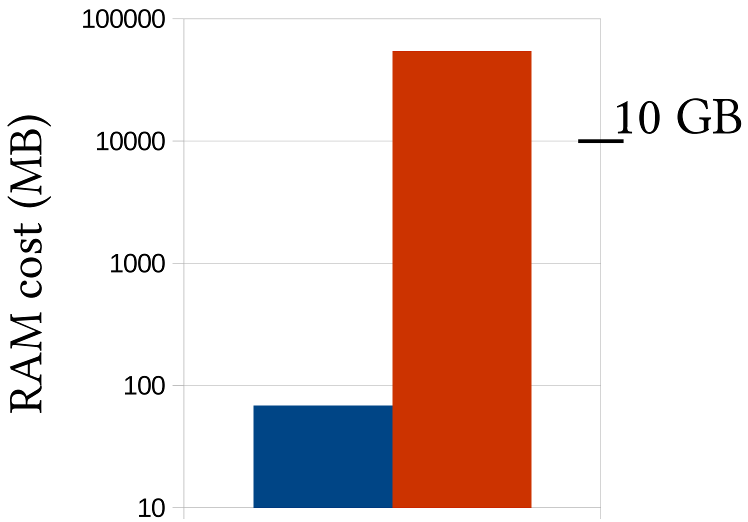
Validation example and computational cost

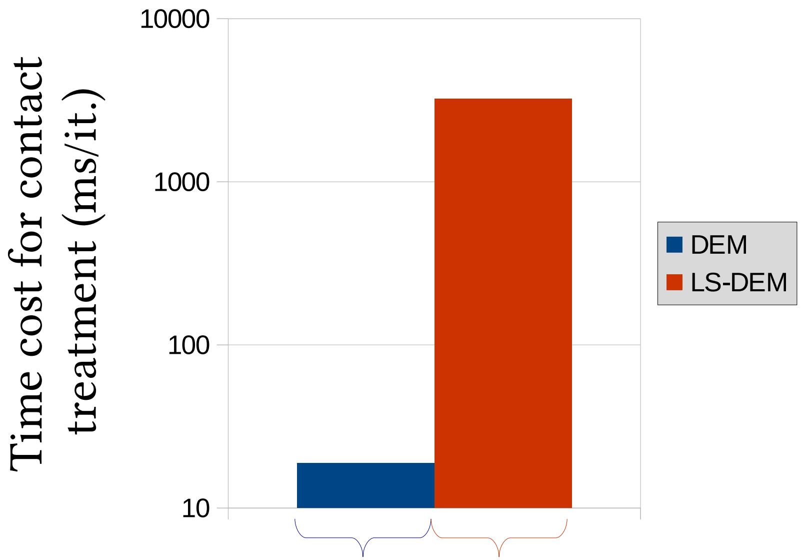
Triaxial test

Dense packing of 8000 spherical DE

- 50^2=2500 boundary nodes
- $L_{grain}/g_{grid}=90$







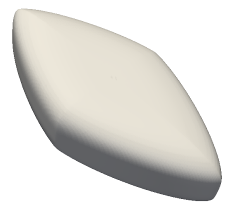
87% of *50 min* 99.9% of *1 week…*

Optimal choices ???

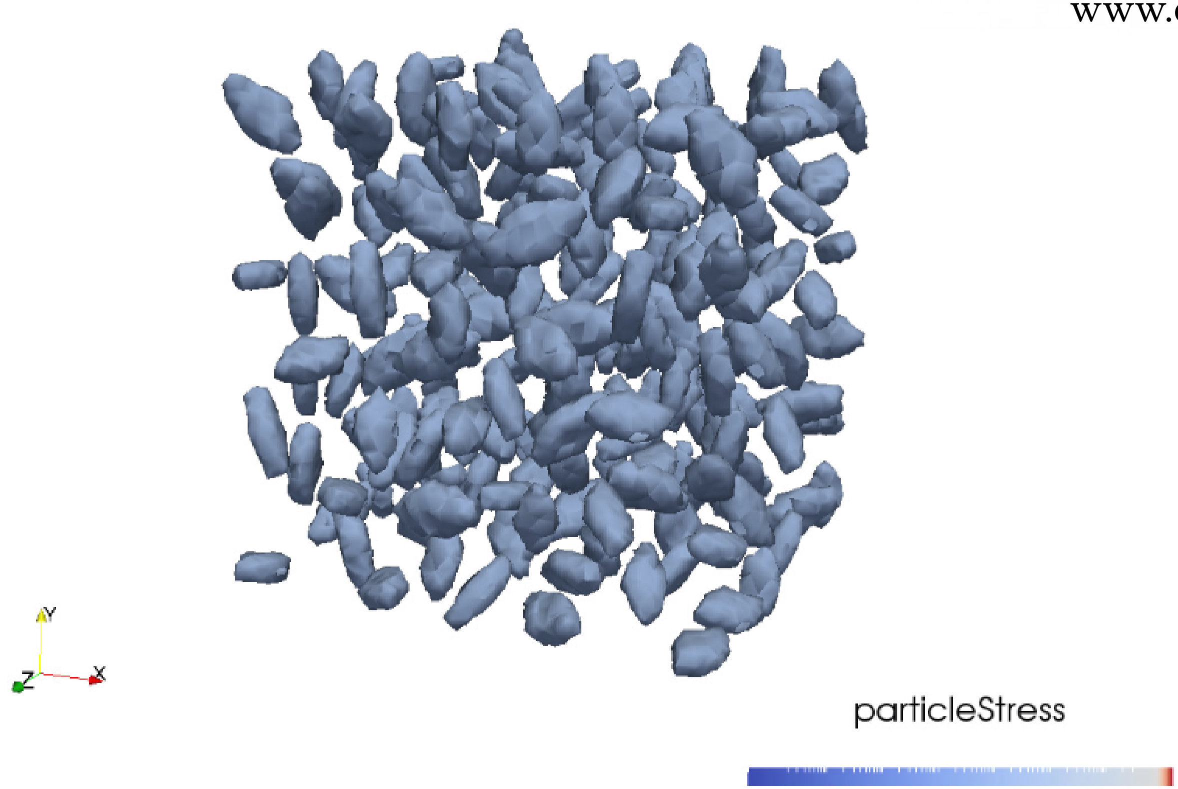
Some calissons ?

Superellipsoids (preliminaries)

$$f = \left(\left| \frac{x}{r_x} \right|^{\frac{2}{\epsilon_1}} + \left| \frac{y}{r_y} \right|^{\frac{2}{\epsilon_1}} \right)^{\frac{\epsilon_1}{\epsilon_2}} + \left| \frac{z}{r_z} \right|^{\frac{2}{\epsilon_2}} - 1$$

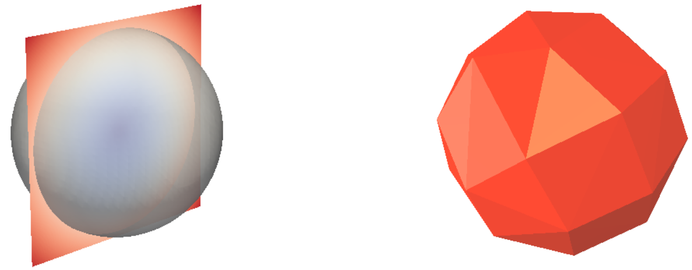


www.calisson.com



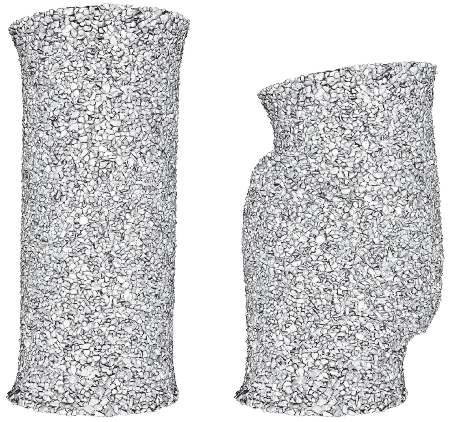
Conclusions & Perspectives

- LS—DEM and new shapes coming soon in YADE ?
- suited for any shape (no convexity required)

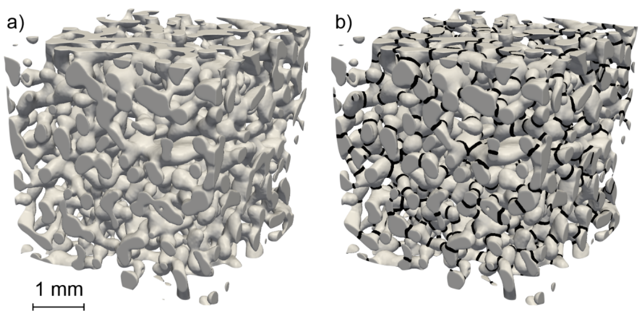


Level Set-DEM vs Convex polyedron

- apply to real shapes from
  - laser scanning on rockfill materials (2020)
  - CT scans on other materials ?



(a) (b)



Merci !

- à la Région Sud, projet LS-ENROC

RÉGION SUD
PROVENCE
ALPES
CÔTE D'AZUR

- Stéphane Bonelli (Irstea, RECOVER),
  Cédric Galusinski et Frédéric Golay (Université de Toulon, IMATH)

- et vous pour votre attention !

Merci !

- à la Région Sud, projet LS-ENROC

- Stéphane Bonelli (Irstea, RECOVER),
  Cédric Galusinski et Frédéric Golay (Université de Toulon, IMATH)

- et vous pour votre attention !

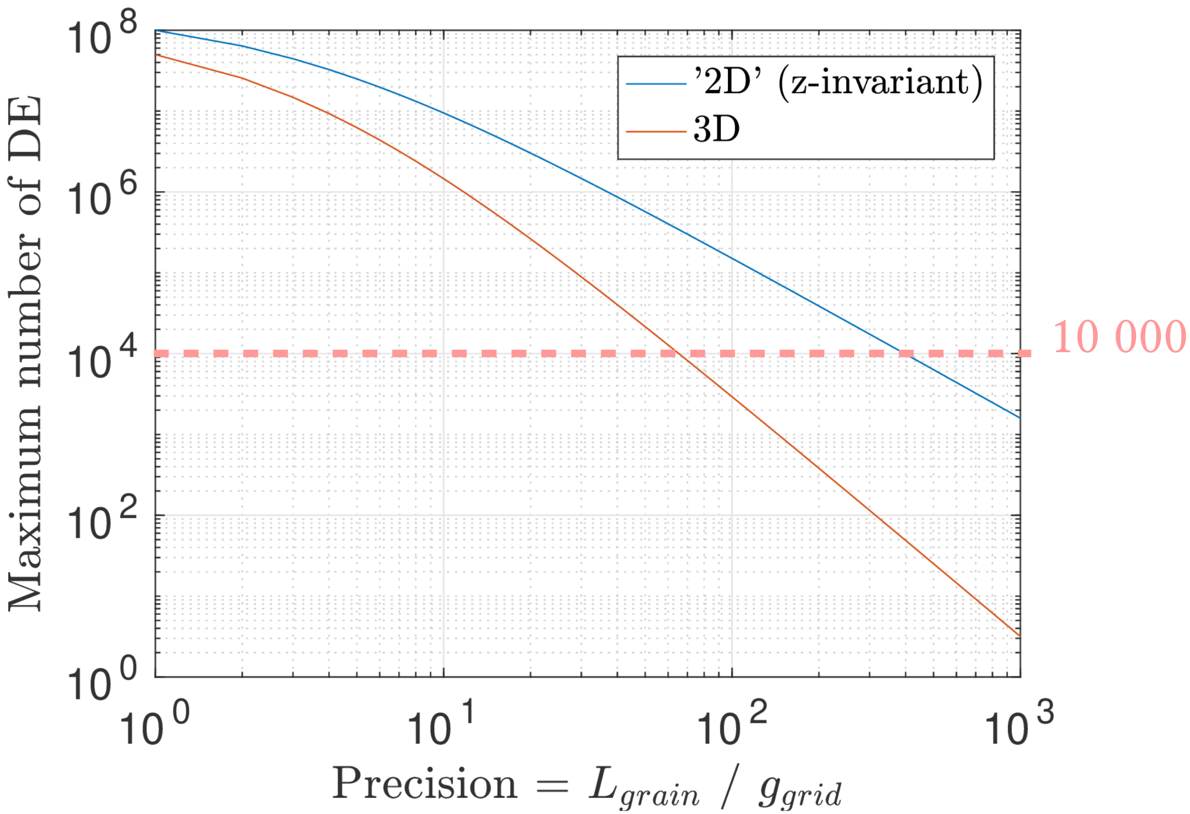
Les Inconnus, *Youpi Matin*

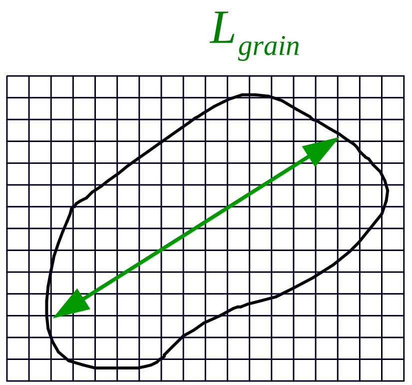
The Level Set – Discrete Element Method

Memory cost

For storing (with C++ ↔ Python exposure)
```
std::vector<std::vector<std::vector<double>>> distanceValues
```

- machine with 64 GB of RAM
- an *average* memory cost of 20 bytes / distance value

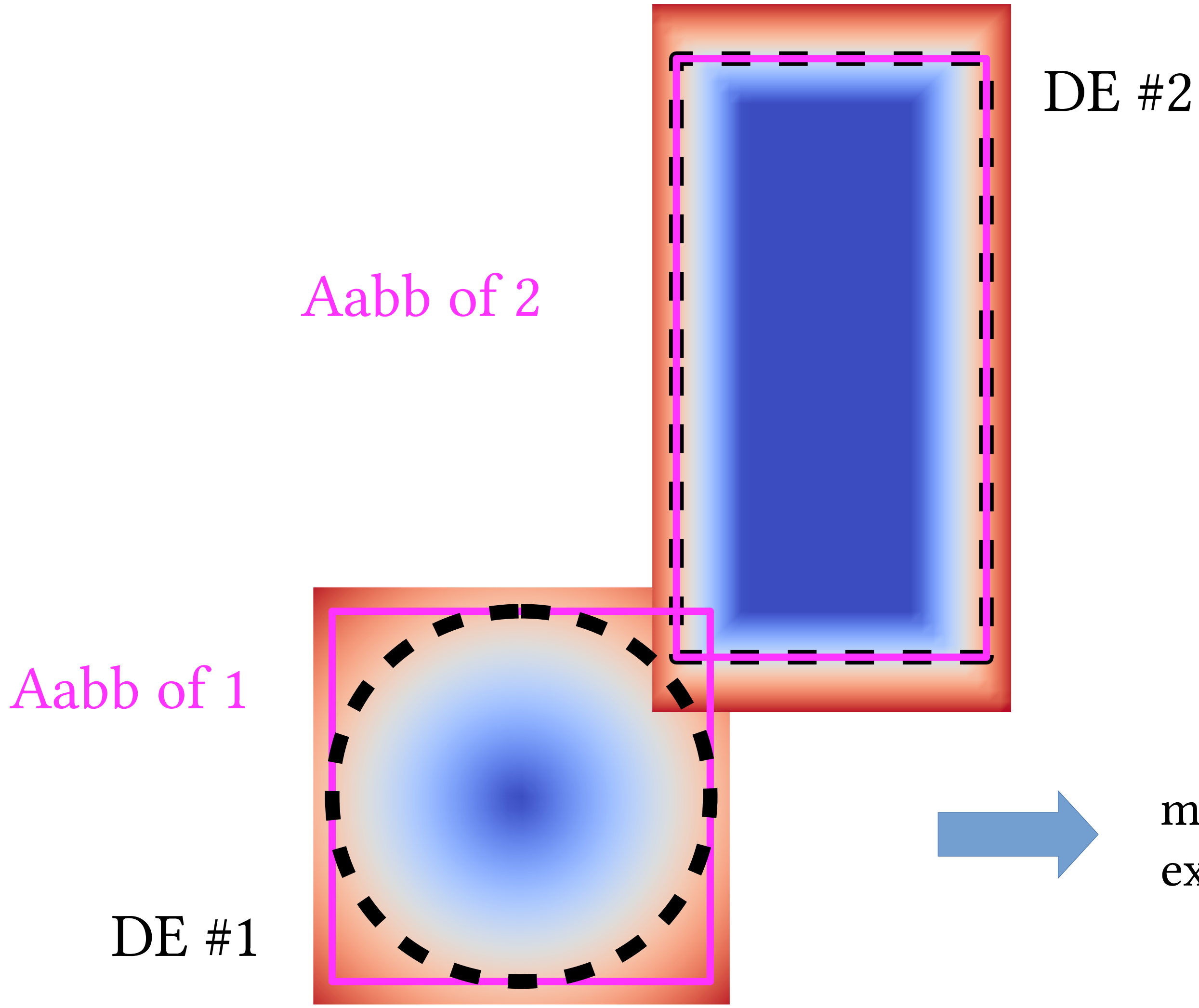




The Level Set – Discrete Element Method

Contact treatment: 1st step (approximate)

Overlap of **A**xis-**a**ligned **b**ounding **b**oxes ?

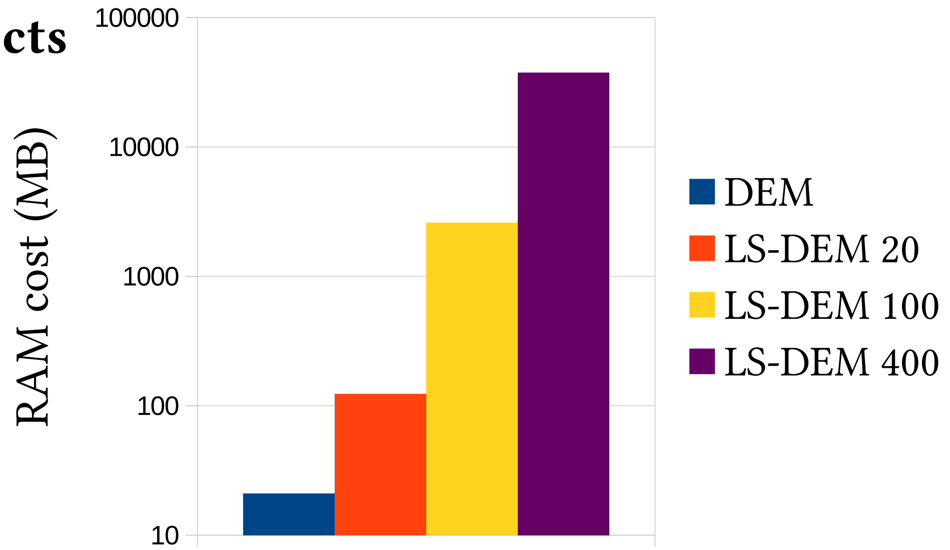


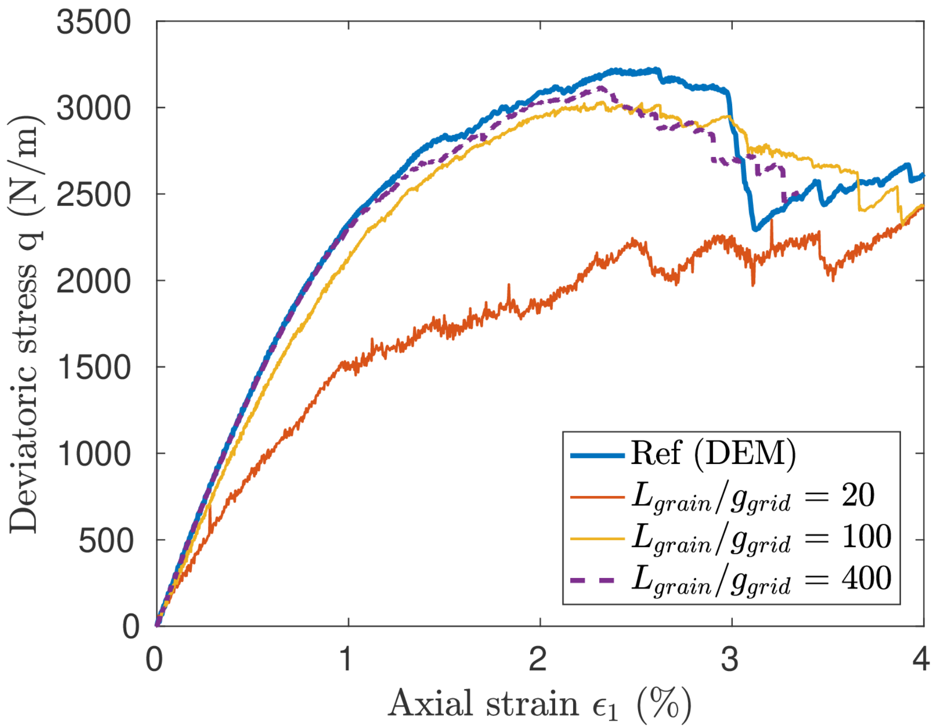
maybe contact 1-2 ?
exact treatment in 2nd step

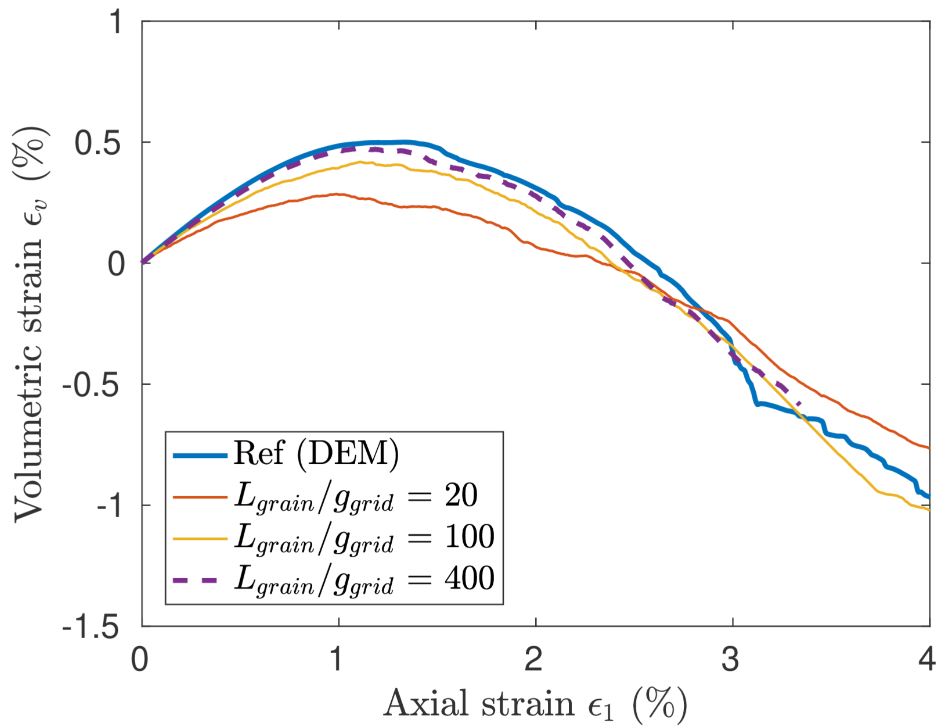
Validation of LS–DEM vs DEM

Biaxial tests (1600 disks) : computational aspects

Memory cost $\Longleftrightarrow$ grid precision







Validation of LS–DEM vs DEM

Biaxial tests (1600 disks) : computational aspects

Time cost $\Leftrightarrow$ number of boundary nodes