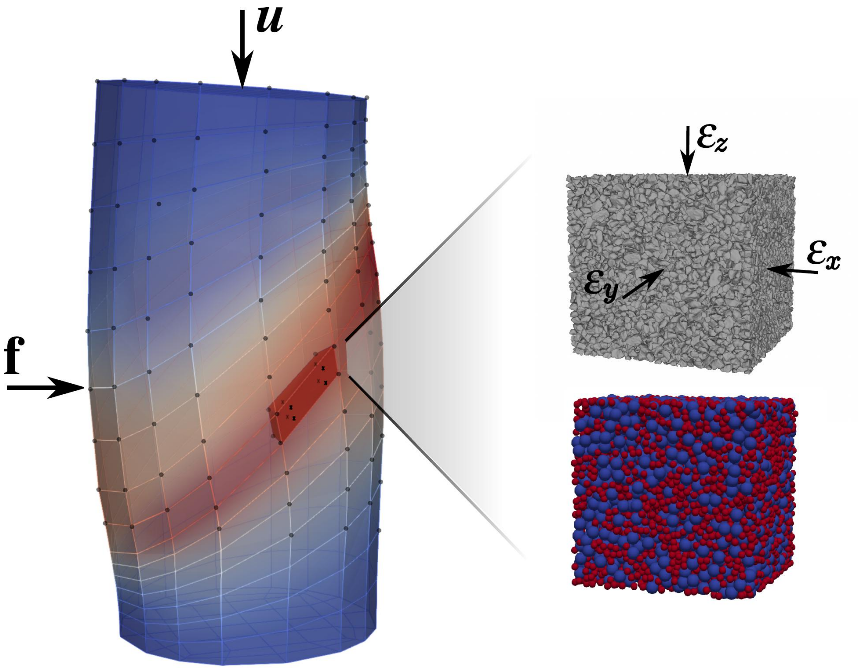
EPFL



CIVIL-408 Multiscale Modeling in Mechanics

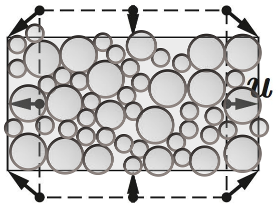
Prof. Kostas Karapiperis

Exercises - Week 7

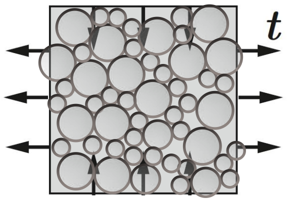
K.Karapiperis

RVE boundary conditions

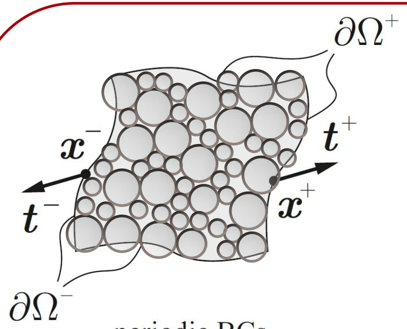
Different types of boundary conditions



affine displacement BCs



uniform traction BCs



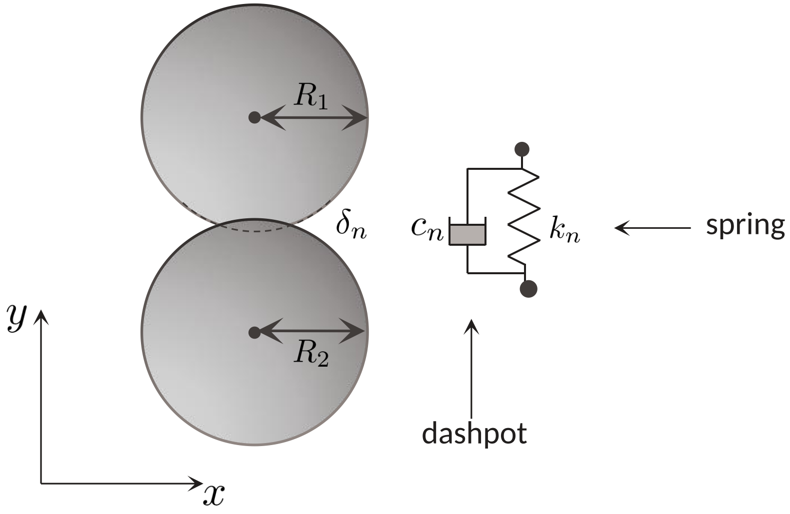
periodic BCs

Linearized kin.: $\boldsymbol{u} = \boldsymbol{\varepsilon}_0 \boldsymbol{x}$ | $\boldsymbol{t} = \boldsymbol{\sigma}_0 \boldsymbol{n}$ | $\boldsymbol{u}^+ = \boldsymbol{u}^- + \boldsymbol{\varepsilon}_0(\boldsymbol{x}^+ - \boldsymbol{x}^-)$, $\boldsymbol{t}^+ = -\boldsymbol{t}^-$

RVE averages: $\langle \boldsymbol{\varepsilon} \rangle = \boldsymbol{\varepsilon}_0$ | $\langle \boldsymbol{\sigma} \rangle = \boldsymbol{\sigma}_0$ | $\langle \boldsymbol{\varepsilon} \rangle = \boldsymbol{\varepsilon}_0$

Review of DEM

Particle interaction



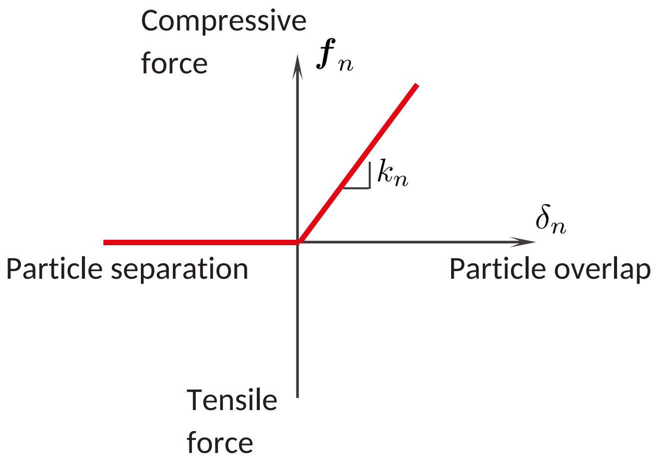
Overlap:

$$\delta_n = R_1 + R_2 - \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

Contact normal:

$$\boldsymbol{n} = \frac{\boldsymbol{x}_1 - \boldsymbol{x}_2}{||\boldsymbol{x}_1 - \boldsymbol{x}_2||}$$

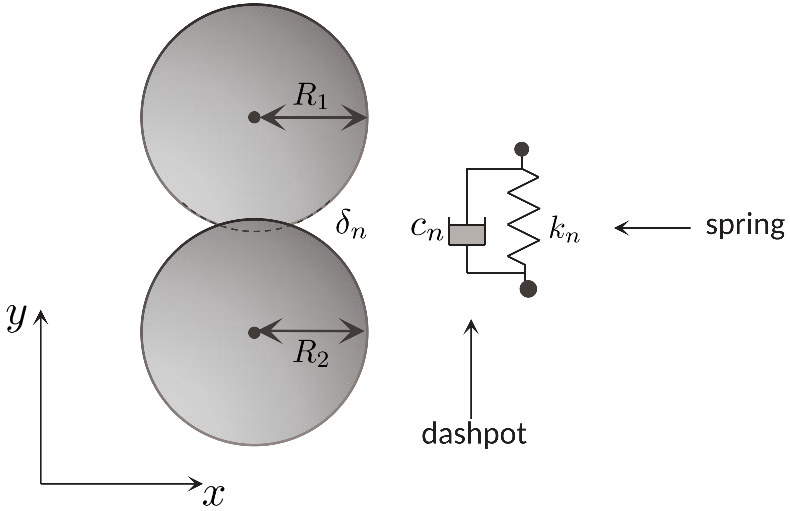
Hookean contact stiffness



$$f_n = k_n \delta_n$$
$$k_n = \text{const}$$

Review of DEM

Particle interaction



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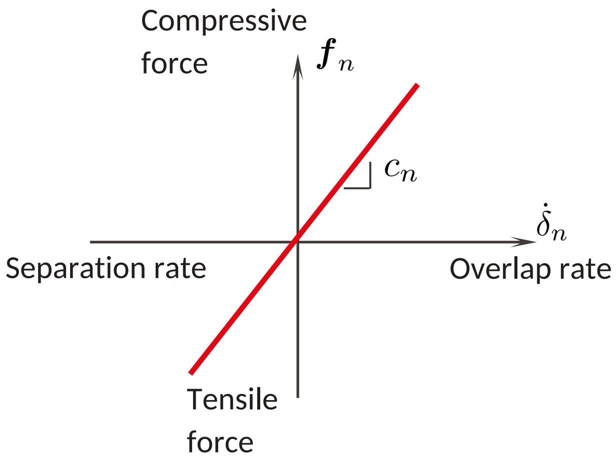
Contact normal:

$$\boldsymbol{n} = \frac{\boldsymbol{x}_1 - \boldsymbol{x}_2}{||\boldsymbol{x}_1 - \boldsymbol{x}_2||}$$

Viscous energy dissipation due to **restitution**



$$f_n = k_n \delta_n + c_n \dot{\delta}_n$$

$$c_n = -2 \frac{\ln e}{\sqrt{\pi^2 + \ln e^2}} \sqrt{m^* k_n}$$

$$m^* = \frac{m_1 m_2}{m_1 + m_2}$$

Quiz

The **critical time step** in DEM is mainly determined by:

a) the mass and stiffness of the particles

b) the simulation domain size

c) the number of particles

d) the density of the packing only

The **Verlet radius**:

a) determines the size of the RVE

b) defines the area around each particle where contact is checked

c) is the maximum particle radius in the system

Quiz

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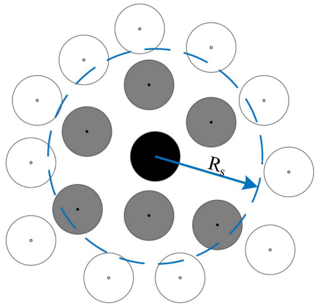
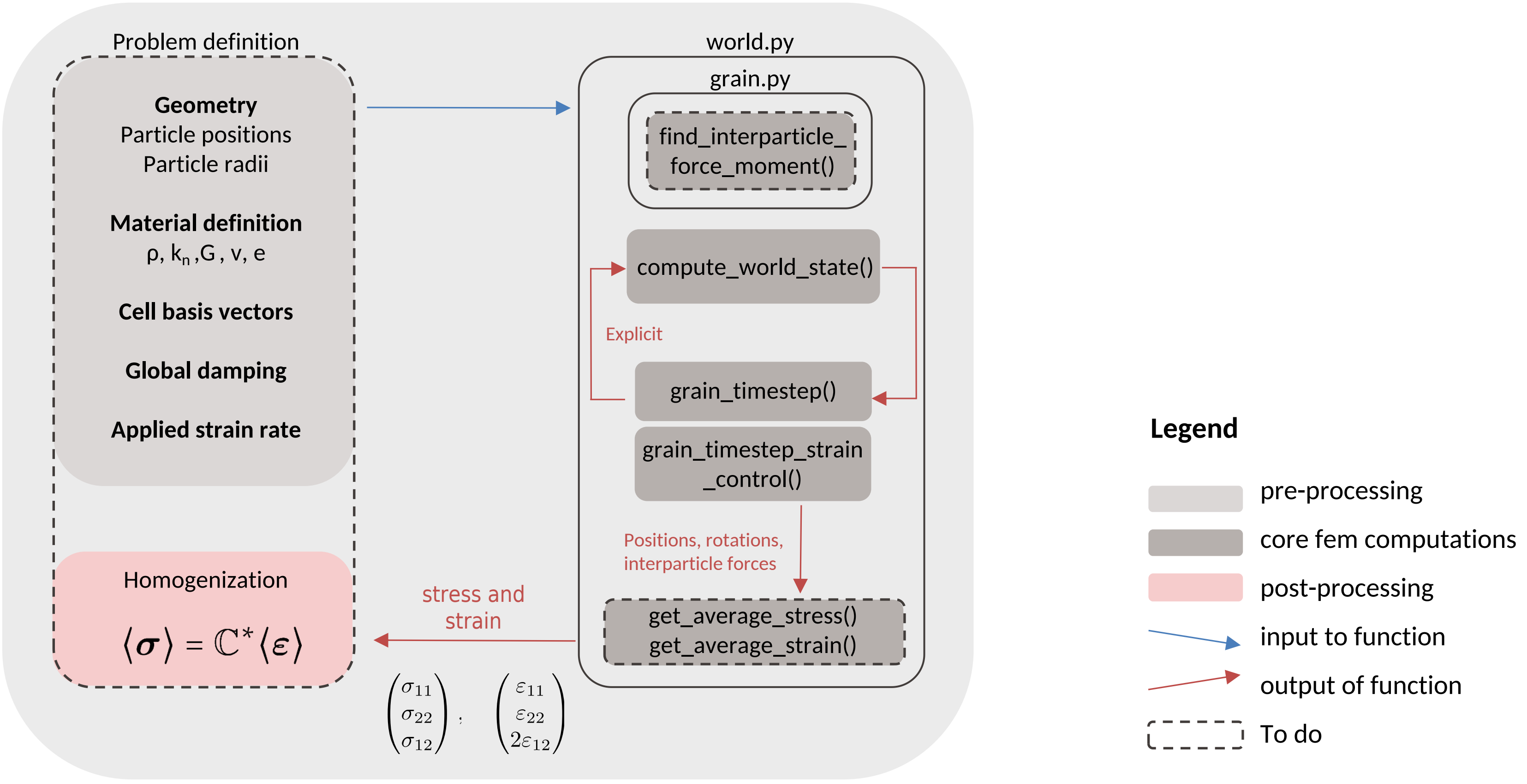


Python implementation

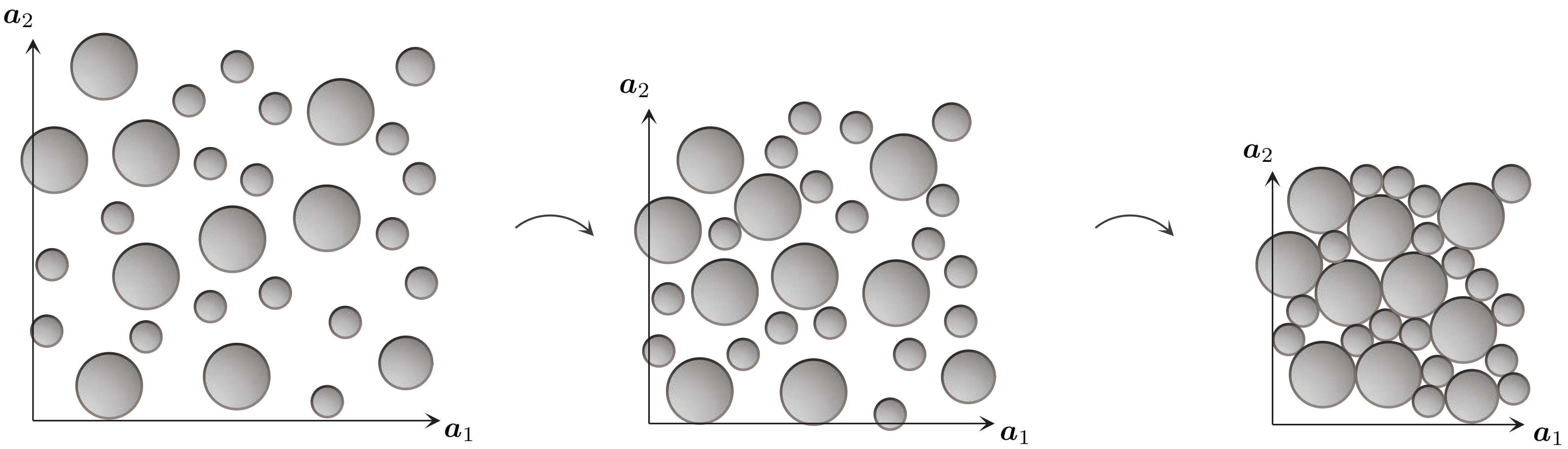
homogenized_stiffness_*.py



Exercise - Particle packing

We will compress the system from a gas state, and let it relax while imposing periodic boundary conditions.

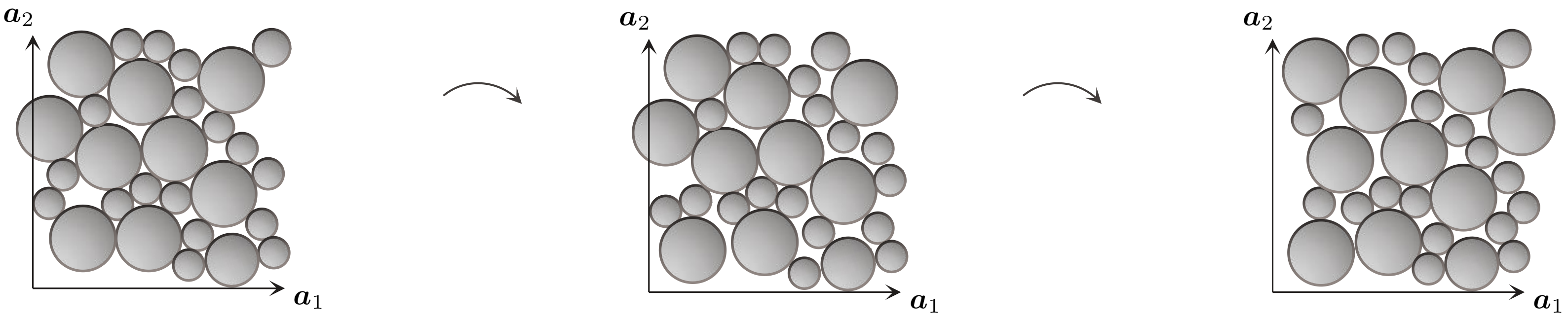
Phase 1: Compression



Exercise - Particle packing

We will compress the system from a gas state, and let it relax while imposing periodic boundary conditions.

Phase 2: Relaxation



Q: Why do we consider a **polydisperse** system?

Exercise - Particle packing

Particles:

N = 225

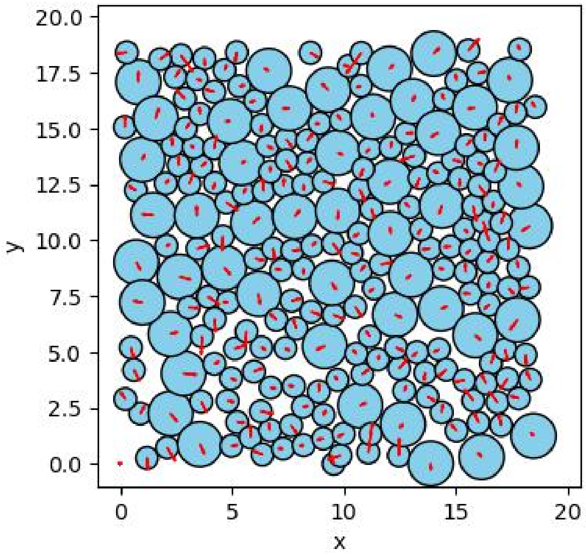
Size-bidisperse

Objective:

- Create packing of given packing fraction $\phi = \frac{\sum_p V_p}{V}$

using:

- Periodic BCs $\boldsymbol{a}' = \boldsymbol{F}\boldsymbol{a} = (\boldsymbol{I} + \dot{\boldsymbol{\varepsilon}}\, dt)\, \boldsymbol{a}$



Python notebook

Let’s move to the Python notebook