THM short-course: **Day 2**

FlowEngine - Yade's pore finite volume scheme

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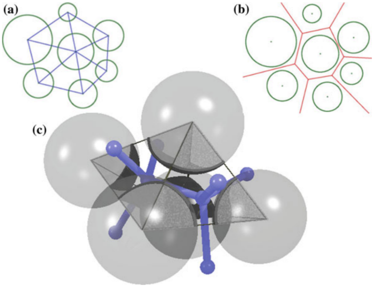
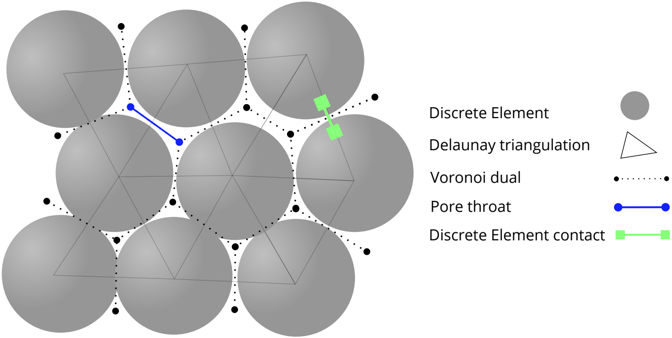


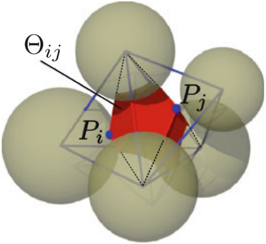
Fundamentals

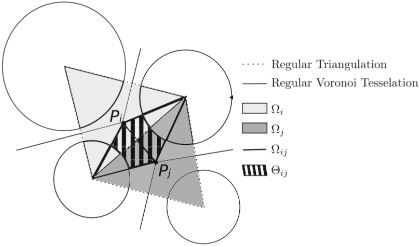
The triangulation



Caulk 2022

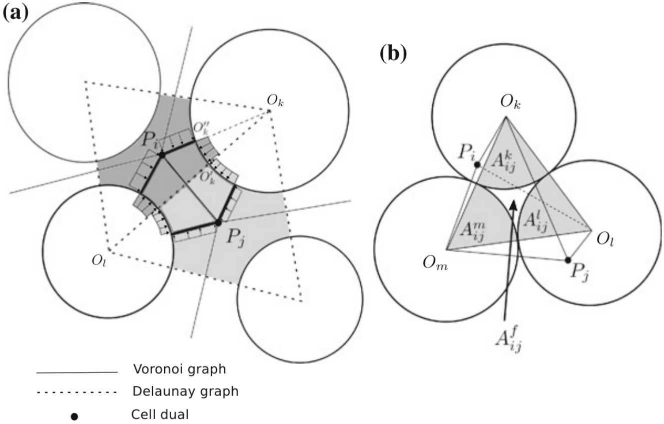
Geometric breakdown





Chareyre 2012

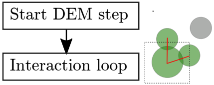
Geometric breakdown



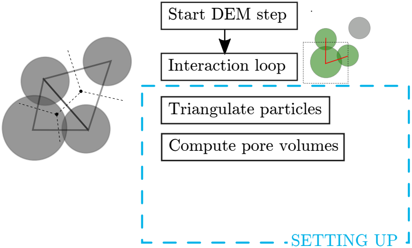
Chareyre 2012

Algorithmic considerations

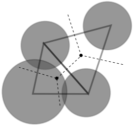
Broad overview



Broad overview

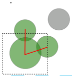


Broad overview



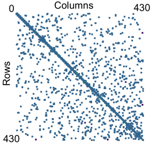
Start DEM step

Interaction loop



- Triangulate particles
- Compute pore volumes
- Build conductivity matrix [$\mathbf{G}$]
- Analyze [$\mathbf{G}$]
- Factorize [$\mathbf{G}$]

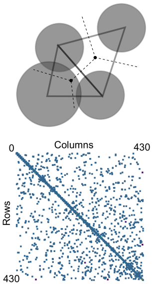
SETTING UP

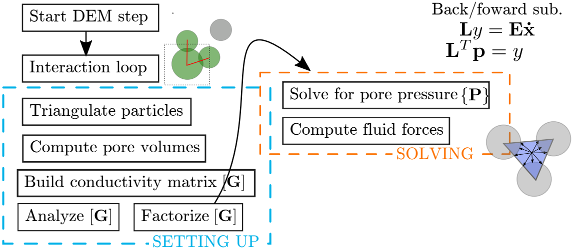


$$\mathbf{G}\mathbf{p} = \mathbf{E}\dot{\mathbf{x}} + \mathbf{Q} \quad \text{Linear system}$$

$$\mathbf{G} = \mathbf{L}\mathbf{L}^T \quad \text{Cholesky decomposition}$$

Broad overview





$$\mathbf{G}\mathbf{p} = \mathbf{E}\dot{\mathbf{x}} + \mathbf{Q}$$ Linear system

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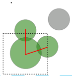
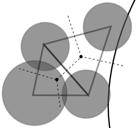
Broad overview

Start DEM step

Interaction loop





SETTING UP

- Triangulate particles
- Compute pore volumes
- Build conductivity matrix [**G**]
- Analyze [**G**]
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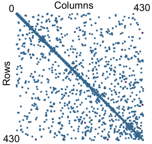

$$\mathbf{G}\mathbf{p} = \mathbf{E}\dot{\mathbf{x}} + \mathbf{Q}$$ Linear system

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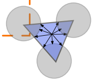
SOLVING

- Solve for pore pressure $\{\mathbf{P}\}$
- Compute fluid forces

Back/foward sub.

$$\mathbf{L}y = \mathbf{E}\dot{\mathbf{x}}$$
$$\mathbf{L}^T\mathbf{p} = y$$



Law of motion

$$\ddot{\mathbf{x}} = \frac{f}{m}$$ Newton's 2nd law

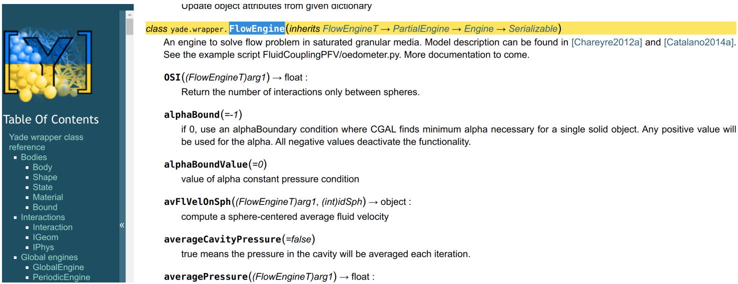
Translating to Yade

FlowEngine - instantiation

Users add FlowEngine() to their O.engines list to initiate the fluid coupling.

```
O.engines = [
        ForceResetter(),
        InsertionSortCollider([Bo1_Sphere_Aabb()]),
        InteractionLoop(
        [Ig2_Sphere_Sphere_ScGeom()],
        [Ip2_FrictMat_FrictMat_FrictPhys()],
        [Law2_ScGeom_FrictPhys_CundallStrack()]
        ),
        FlowEngine(label="flow"),  # Add FlowEngine here
        NewtonIntegrator()
]
```

The broad functionality of `FlowEngine()` can be explored in the trusty `Class Reference`



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Update object attributes from given dictionary

class `yade.wrapper.`**`FlowEngine`**(*inherits FlowEngineT → PartialEngine → Engine → Serializable*)

An engine to solve flow problem in saturated granular media. Model description can be found in [Chareyre2012a] and [Catalano2014a]. See the example script FluidCouplingPFV/oedometer.py. More documentation to come.

`OSI`(*(FlowEngineT)arg1*) → float :

Return the number of interactions only between spheres.

`alphaBound`(*=-1*)

if 0, use an alphaBoundary condition where CGAL finds minimum alpha necessary for a single solid object. Any positive value will be used for the alpha. All negative values deactivate the functionality.

`alphaBoundValue`(*=0*)

value of alpha constant pressure condition

`avFlVelOnSph`(*(FlowEngineT)arg1, (int)idSph*) → object :

compute a sphere-centered average fluid velocity

`averageCavityPressure`(*=false*)

true means the pressure in the cavity will be averaged each iteration.

`averagePressure`(*(FlowEngineT)arg1*) → float :

https://yade-dem.org/doc/yade.wrapper.html#yade.wrapper.FlowEngine

Setting BCs

Users need to set their boundary conditions and flow parameters before the first step of the *coupled* simulation. Considering a typical cuboid shape:

```
# boundaries xmin, xmax, ymin, ymax, zmin, zmax
flow.bndCondIsPressure = [0, 0, 1, 1, 0, 0]
flow.bndCondValue = [0, 0, 100, 50, 0, 0]
flow.boundaryUseMaxMin = [0, 0, 0, 0, 0, 0]
```

Controlling the mesh

Users should be aware that particle deformations will only be reflected in the triangulation is a `flow.meshUpdateInterval` is set:

```
flow.meshUpdateInterval = 200  # remesh every 200 iterations
flow.defTolerance = 0.3  # optional deformation detection
```

Extracting quantities

Quantities of interest, such as pressure, boundary flux, etc. using a plethora of `getters`:

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`getCellFlux`(*(FlowEngineT)arg1*, *(int)cond*) → float :
Get influx in cell associated to an imposed P (indexed using 'cond').

`getCellFluxFromId`(*(FlowEngineT)arg1*, *(int)id*) → float :
Get influx in cell.

`getCellInvVoidVolume`(*(FlowEngineT)arg1*, *(int)id*) → float :
get the inverse of the cell volume for cell 'id' after pore volumes have been initialized and FlowEngine:iniVoidVolumes = True, or compressibility scheme active with FlowEngine::fluidBulkModulus.

`getCellPImposed`(*(FlowEngineT)arg1*, *(int)id*) → bool :
get the status of cell 'id' wrt imposed pressure.

`getCellPressure`(*(FlowEngineT)arg1*, *(int)id*) → float :
get pressure by cell 'id'. Note: getting pressure at position (x,y,z) might be more usefull, see :yref`FlowEngine::getPorePressure`:

`getCellTImposed`(*(FlowEngineT)arg1*, *(int)id*) → bool :
get the status of cell 'id' wrt imposed temperature.

`getCellTemperature`(*(FlowEngineT)arg1*, *(int)id*) → float :
get pressure in cell 'id'.

`getCellVelocity`(*(FlowEngineT)arg1*, *(Vector3)pos*) → object :
Get relative cell velocity at position pos[0] pos [1] pos[2].

`getCellVolume`(*(FlowEngineT)arg1*, *(Vector3)pos*) → float :
Get volume of cell at position pos[0] pos [1] pos[2].

`getConductivity`(*(FlowEngineT)arg1*, *(int)cellId*, *(int)throat*) → float :
get conductivity from cell and throat, with throat between 0 and 3 (same ordering as incident cells)

`getConstrictions`(*(FlowEngineT)arg1*[, *(bool)all=True*]) → list :
Get the list of constriction radii (inscribed circle) for all finite facets (if all==True) or all facets not incident to a virtual bounding sphere (if all==False). When all facets are returned, negative radii denote facet incident to one or more fictious spheres.

Extracting quantities

getters are typically called inside a PyRunner with the plot.addPlotData():

```
def getPFVquantities():
        plot.addData(
                p = flow.getPorePressure((0.5,0.5,0.5))  #
                ↪  pore pressure at coordinate
                k = flow.getConductivity(10,2)  # get
                ↪  conductivity at cell 10, pore 2
        )

O.engines = O.engines + [PyRunner(iterPeriod=200,
↪  command='getPFVquantities()', label='pfvgetter')]
```

Exporting the mesh

The triangulation can be exported to VTK for Paraview post-processing using `flow.saveVtk()`:

```
O.engines = O.engines + [PyRunner(iterPeriod=200,
↪  command='flow.saveVtk()', label='savevtk')]
```

https://yade-dem.org/doc/yade.wrapper.html#yade.wrapper.FlowEngine.saveVtk

Exporting the mesh

Opening the VTK files in Paraview leverages deep post-processing tools: