Links between phenomenological and micromechanical soil behaviour

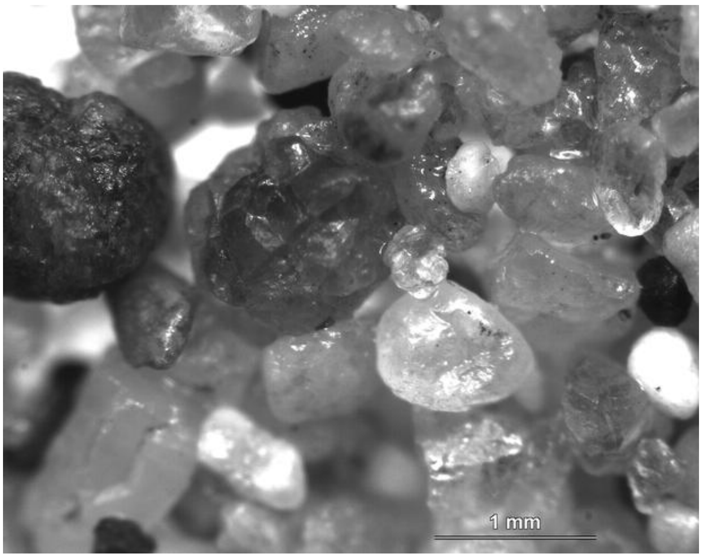
Ivo Herle[1] Max Wiebicke[1,2] Edward Andò[2] Cino Viggiani[2]

[1]Chair of soil mechanics and foundation engineering, TU Dresden
[2]Laboratoire 3SR, Grenoble

Assisi, 16th May 2016

Soil (sand)

Assembly of solid grains + voids



(Zbraslav sand)

soil behaviour:

- properties of grains (size, shape, roughness, mineral) ≡ material constants
- arrangement of grains (soil skeleton) *fabric, structure* ≡ state variables

stress-strain behaviour ⇝ mainly change of the arrangement of the grains

Phenomenological soil behaviour

Particulate material vs continuum

(Karlsruhe sand)

$\rightsquigarrow$

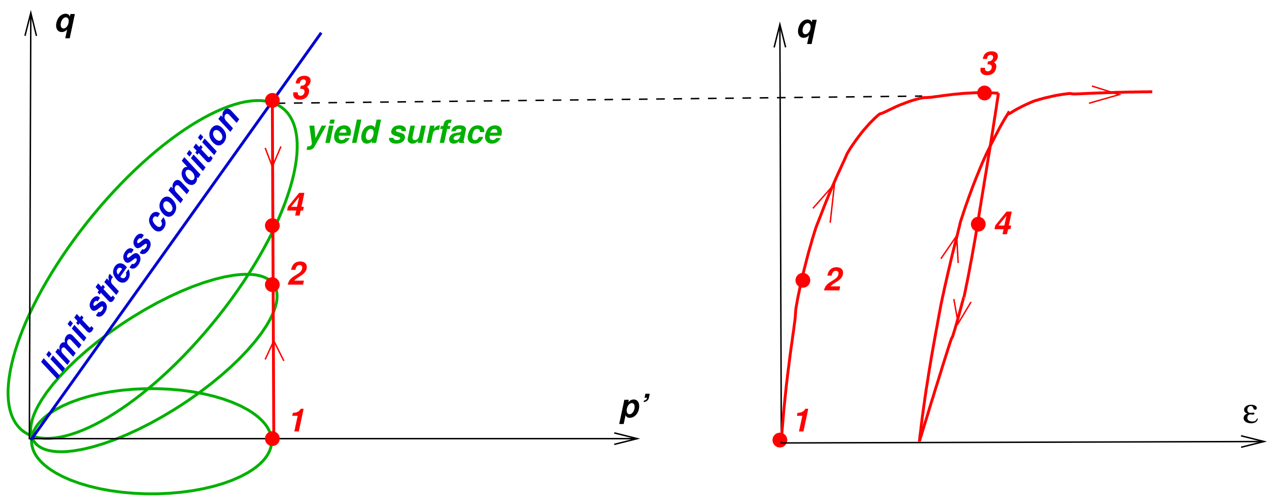
- soil $\equiv$ quasi-solid (porous) material
- frameworks of theories for solid materials (elastoplasticity, hypoplasticity)

$\rightsquigarrow$ difficult to establish links to the soil structure

Phenomenological structure characterization

Examples (hardening elastoplasticity)

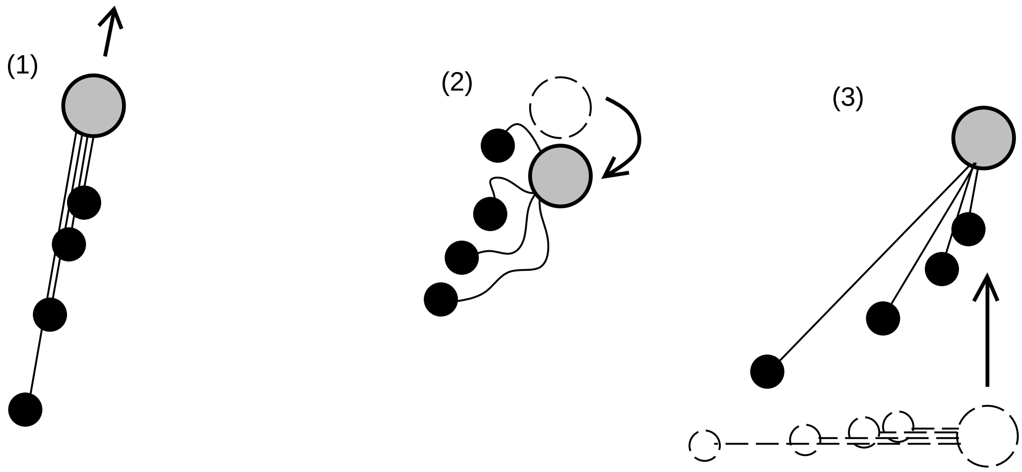
soil structure $\equiv$ size and the orientation of the yield surface



Phenomenological structure characterization

Examples ("brick" model – Simpson, 1992)

soil structure ≡ number of pulled bricks

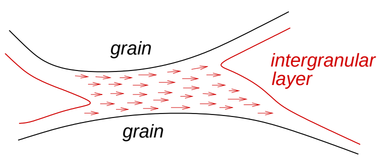


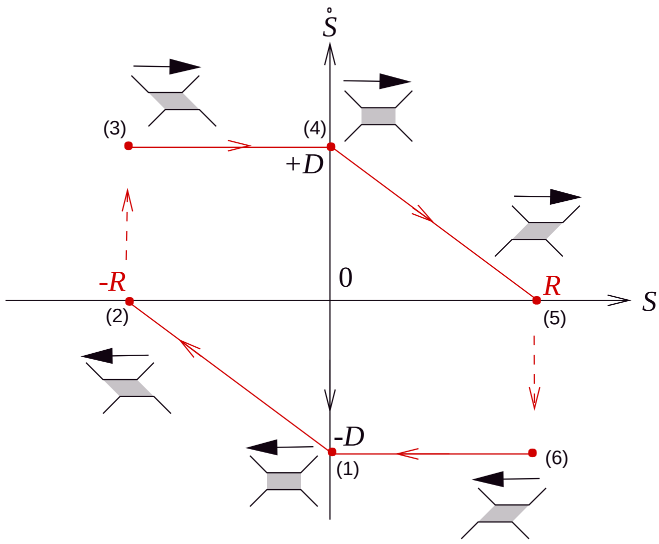
stiffness = f(pulled ropes)

Phenomenological structure characterization

Examples ("intergranular strains" – Niemunis & Herle, 1997)

soil structure ≡ interface zone at grain contacts

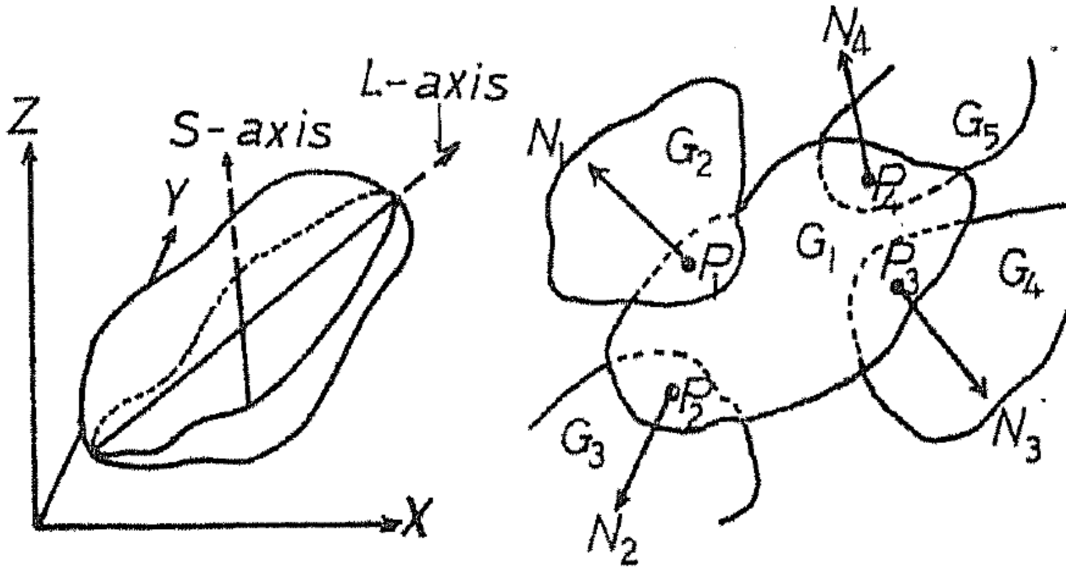




stiffness = f(S)

Micromechanical structure characterization

Orientation: grains, contact planes

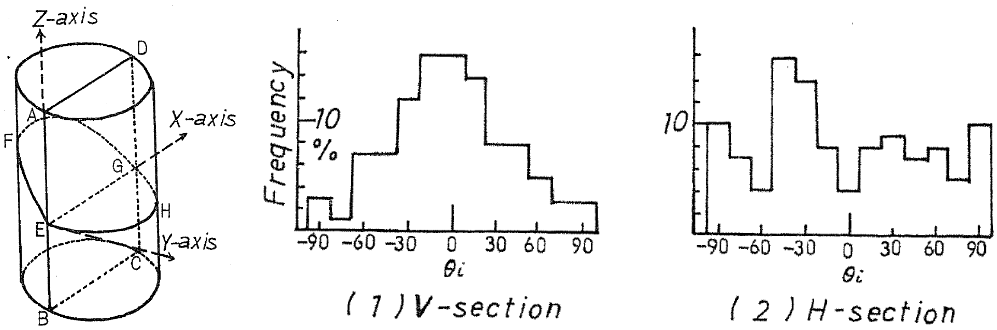


(Oda, 1972)

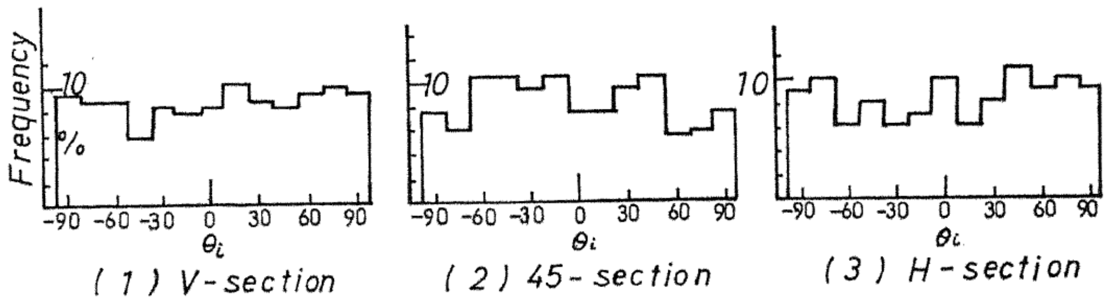
Micromechanical structure characterization

Frequency distribution of the long grain axes

elongated grains



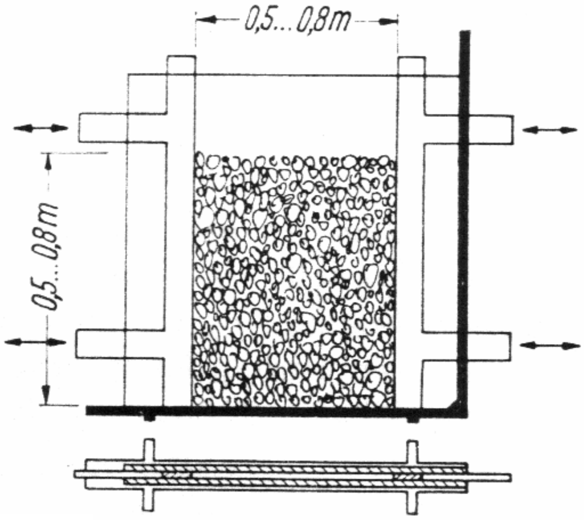
rounded grains



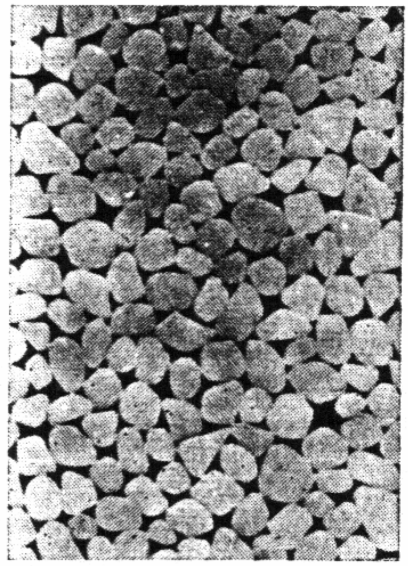
(Oda, 1972)

Micromechanical structure characterization

Orientation of the grain contact planes



Versuchseinrichtung



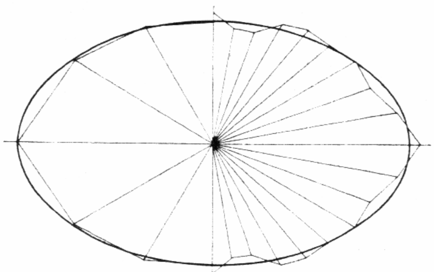
Ausschnitt eines zweidimensionalen Aggregats

(Wiendieck, 1967)

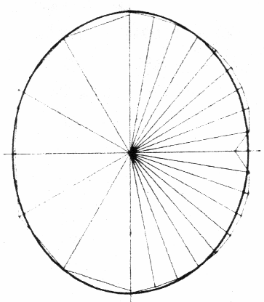
Introduction Contacts Perspectives

Micromechanical structure characterization

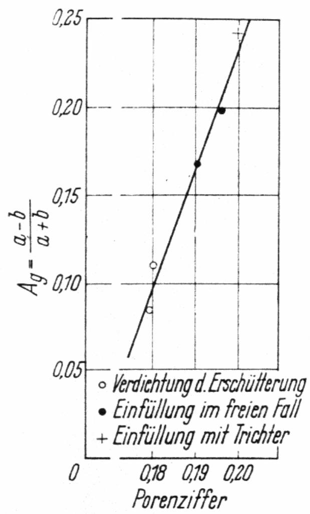
Orientation of the grain contact planes



Strukturbild des unverformten, lockeren Aggregats. Horizontale Stauchung $\varepsilon_h = 0$, geometrische Anisotropie $A_g = 0{,}242$



Strukturbild des horizontal gestauchten Aggregats. Horizontale Stauchung $\varepsilon_h = 15\,\%$, geometrische Anisotropie $A_g = -0{,}095$



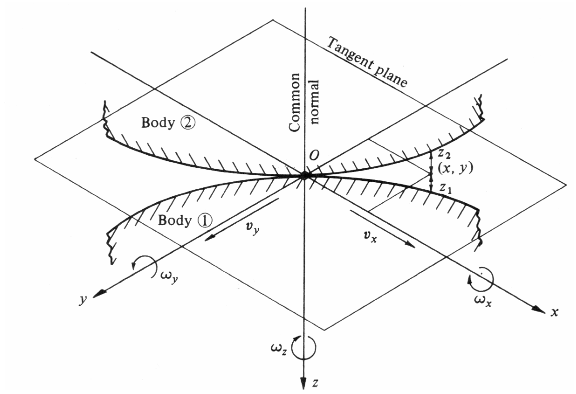
Zusammenhang zwischen geometrischer Anisotropie und Porenziffer (vgl. Bild 1)

(Wiendieck, 1967)

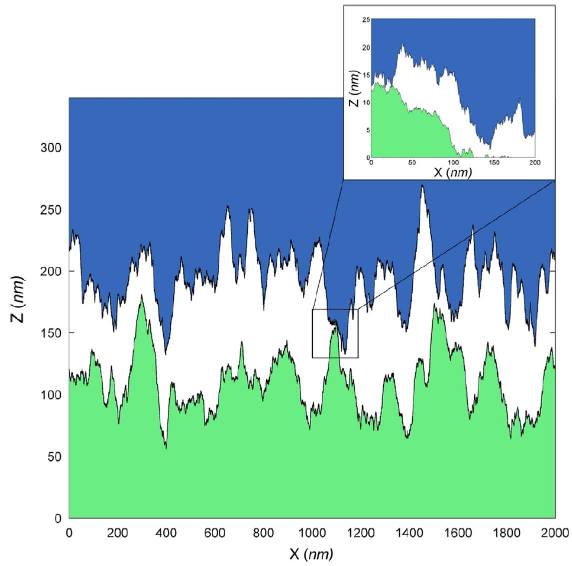
evolution of the contact orientation during deformation (coins)

Micromechanical structure characterization

Grain contact: theory and reality



(Johnson, 1985)



(Hanaor et al, 2016)

Structure characterization

Phenomenological description

- models based on continuum (solid) description
- structure is reflected in ingredients arising from a theory
- development based on "curve fitting"

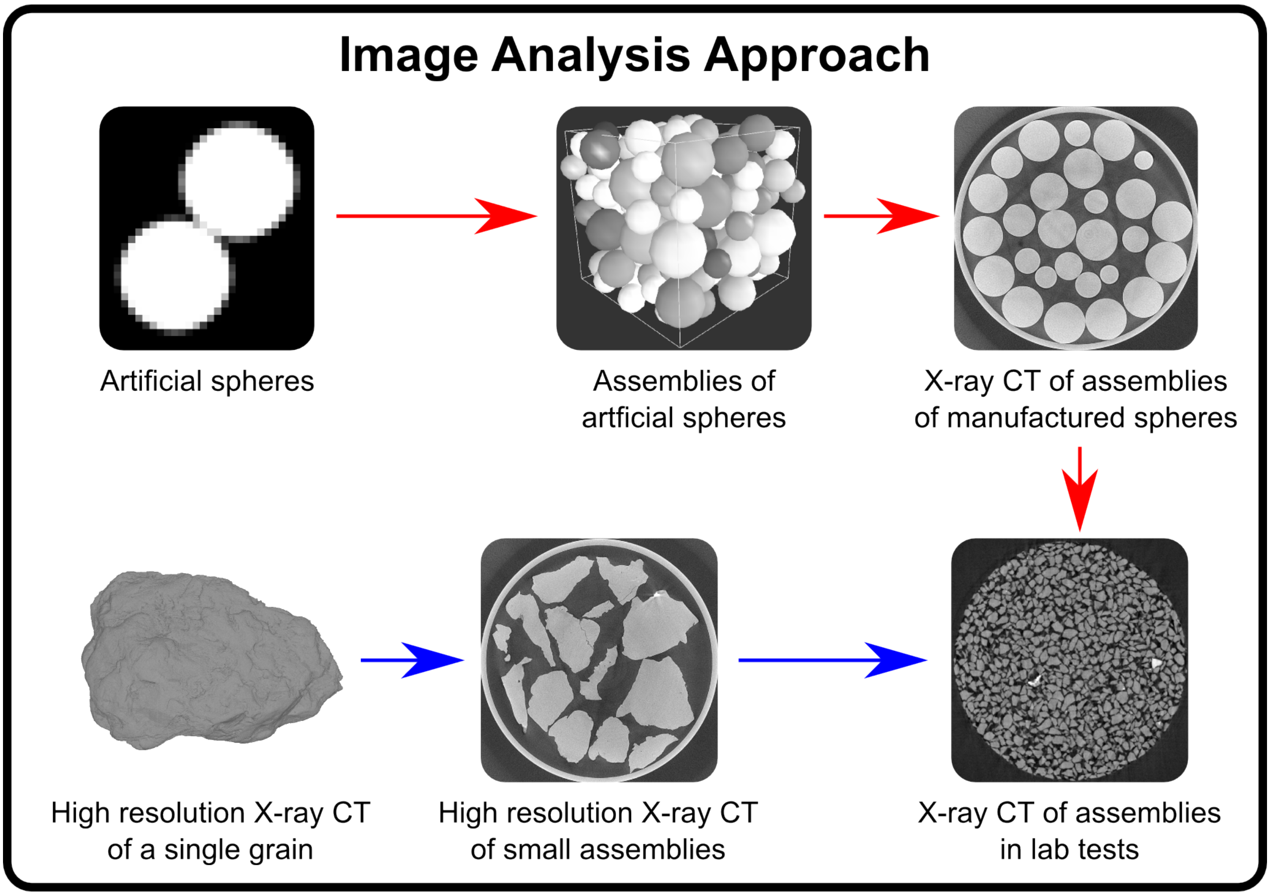
Micromechanical description

- soil structure reflects the arrangement of the grains
- grain contacts are essential for the soil structure
- identification of the grain contacts is crucial for the experimental observation of soil structure

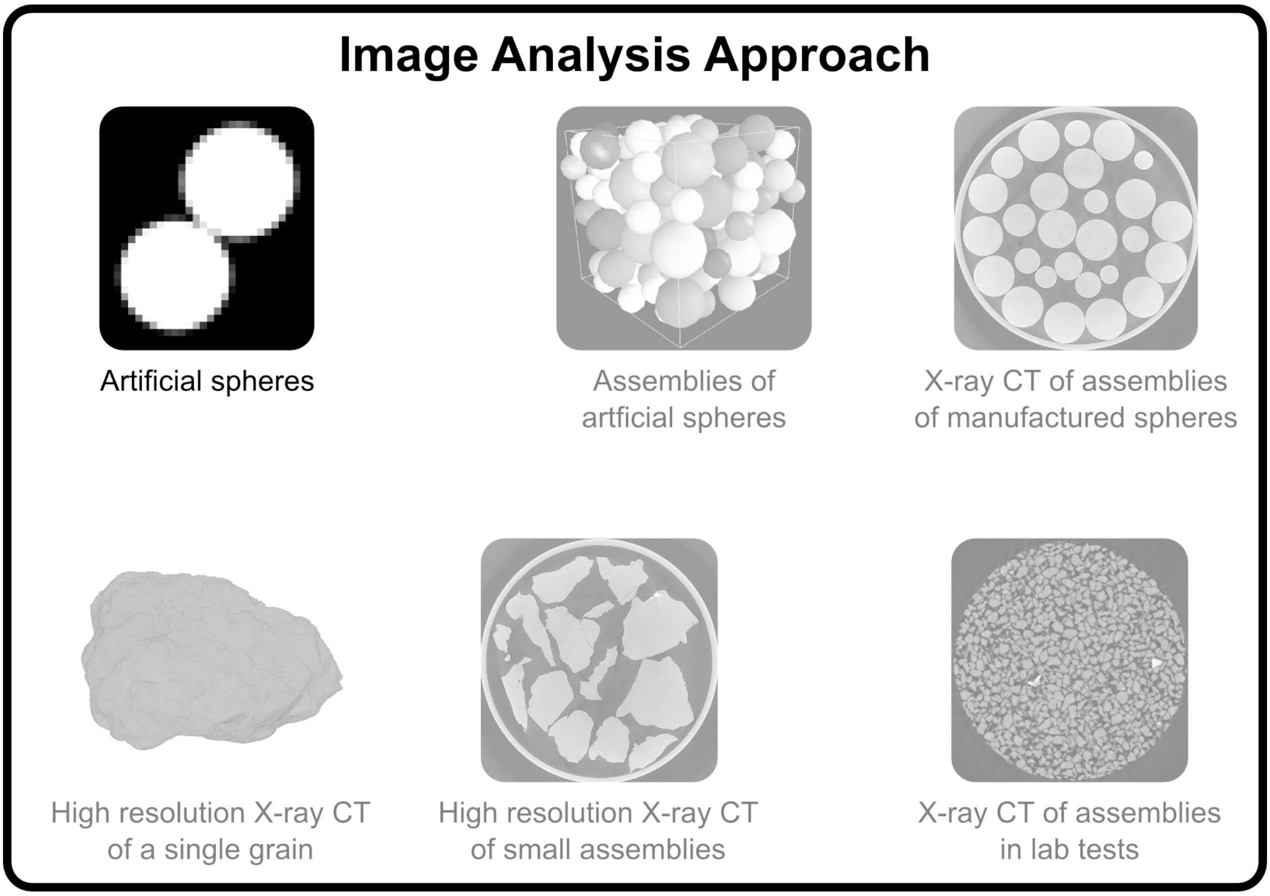
$\rightsquigarrow$ Link between phenomenological and micromechanical description?

Focus on hysteretic behaviour: small changes in the structure but large changes in the stiffness!

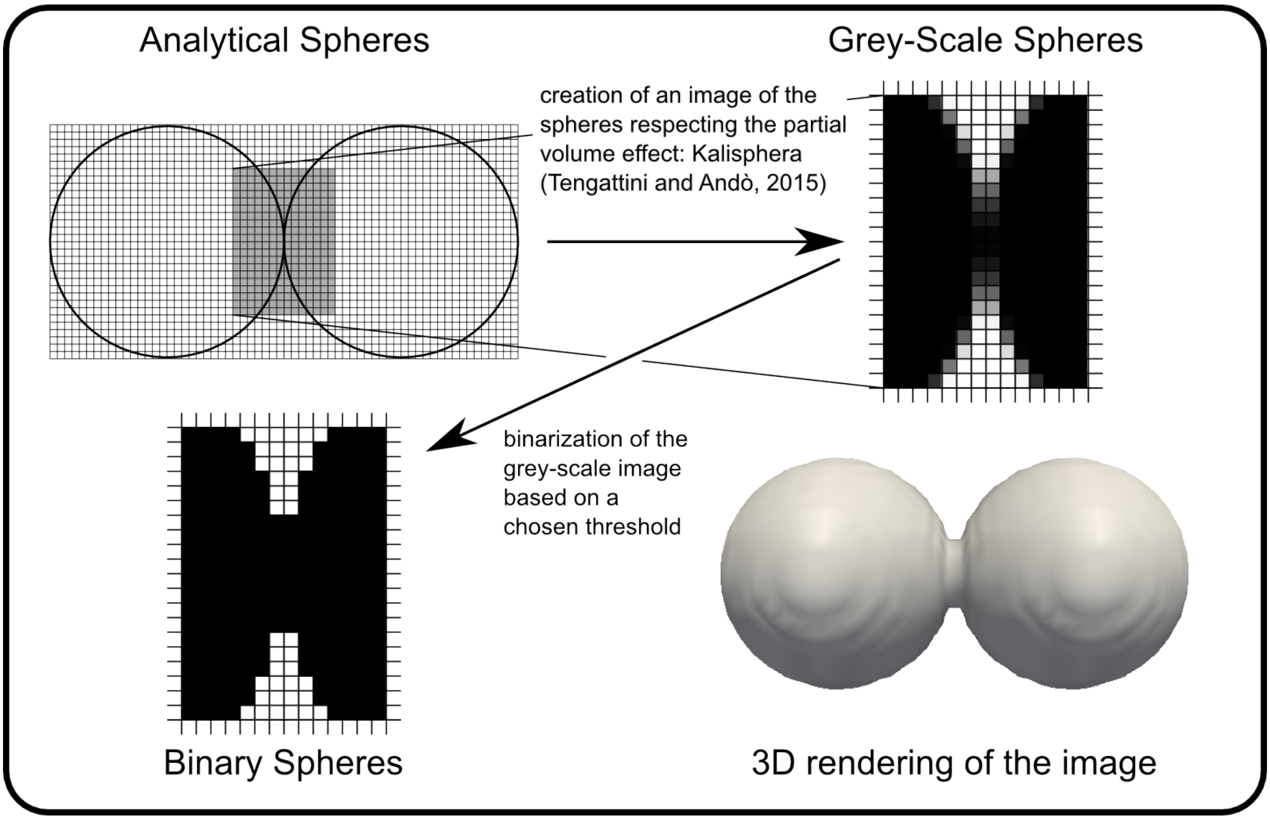
Our approach to contacts



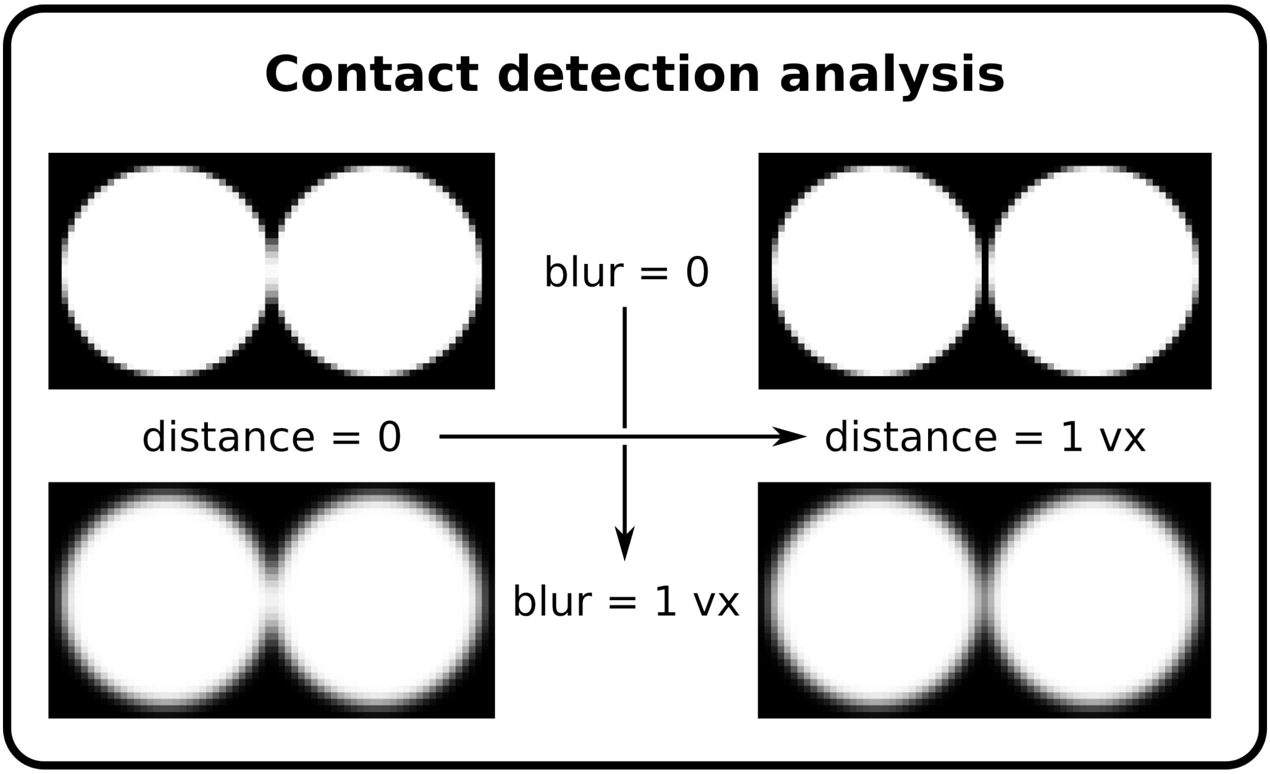
Our approach to contacts



Creation of artificial spheres

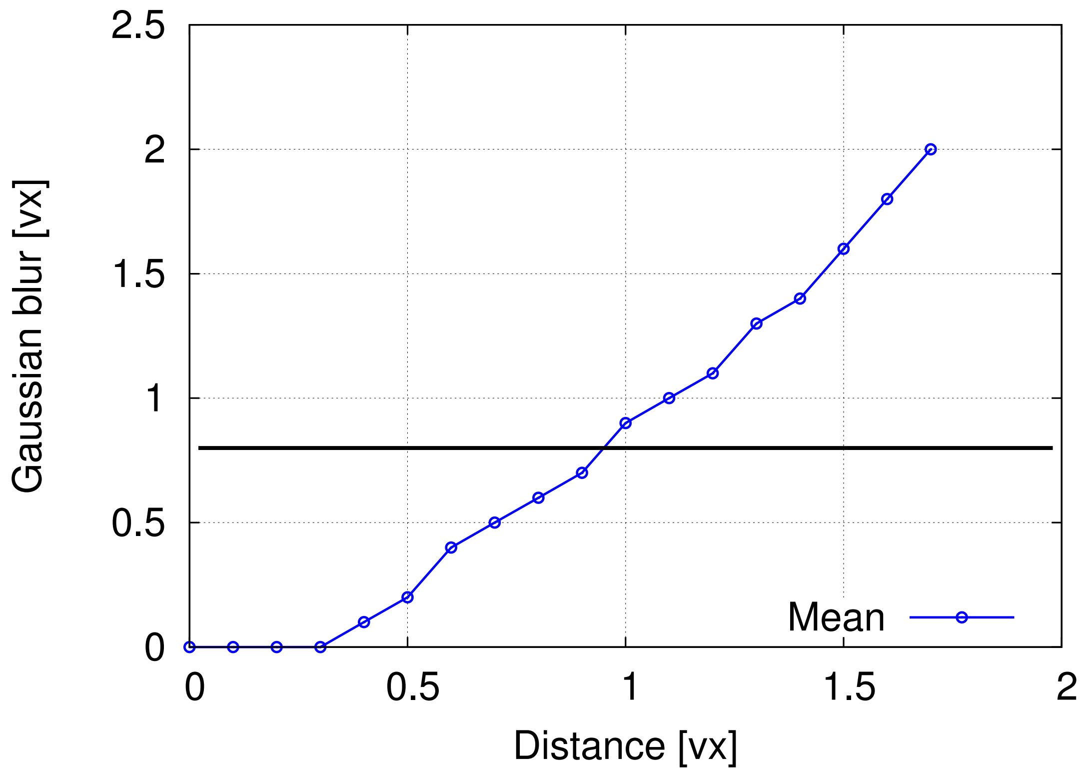


Identification of Contacts

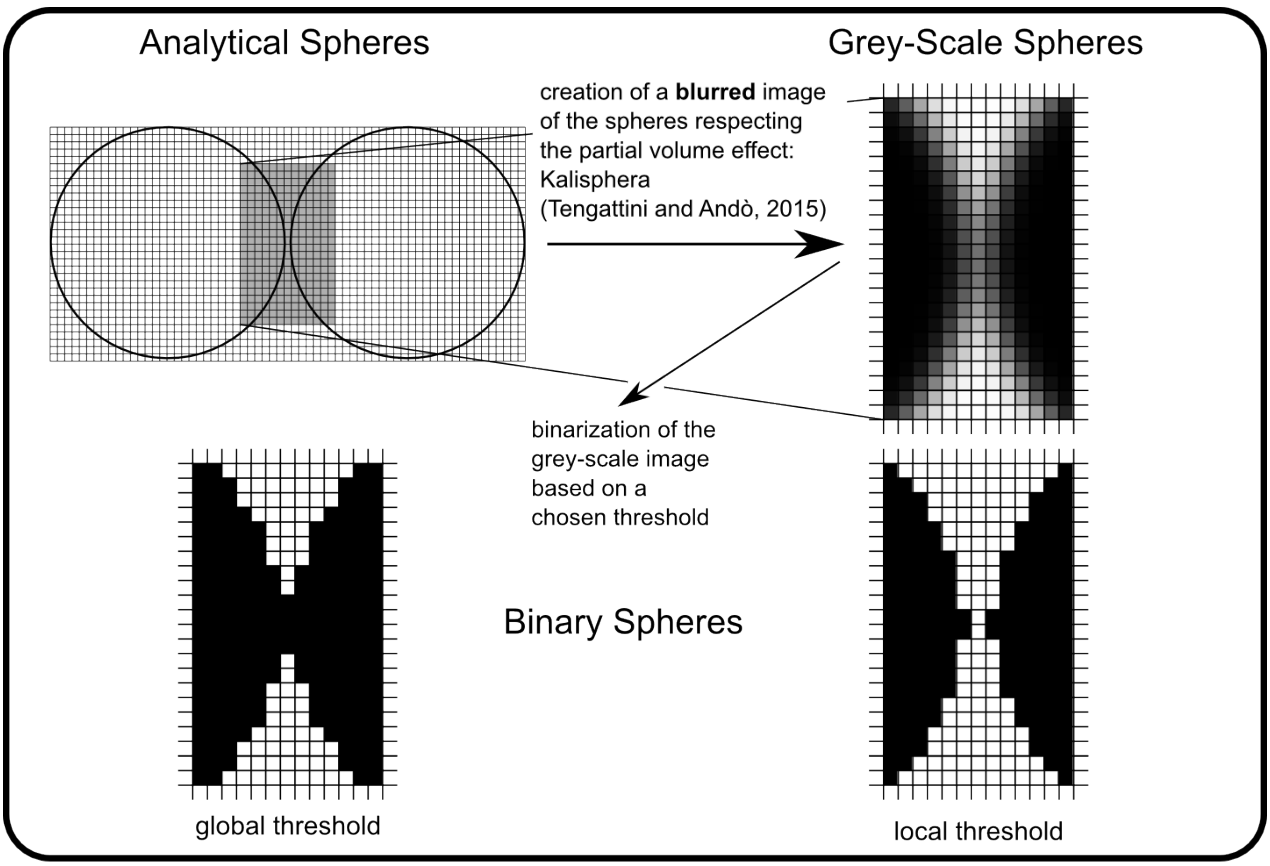


Identification of Contacts

Analysis on 5,000 equally distributed branch vectors

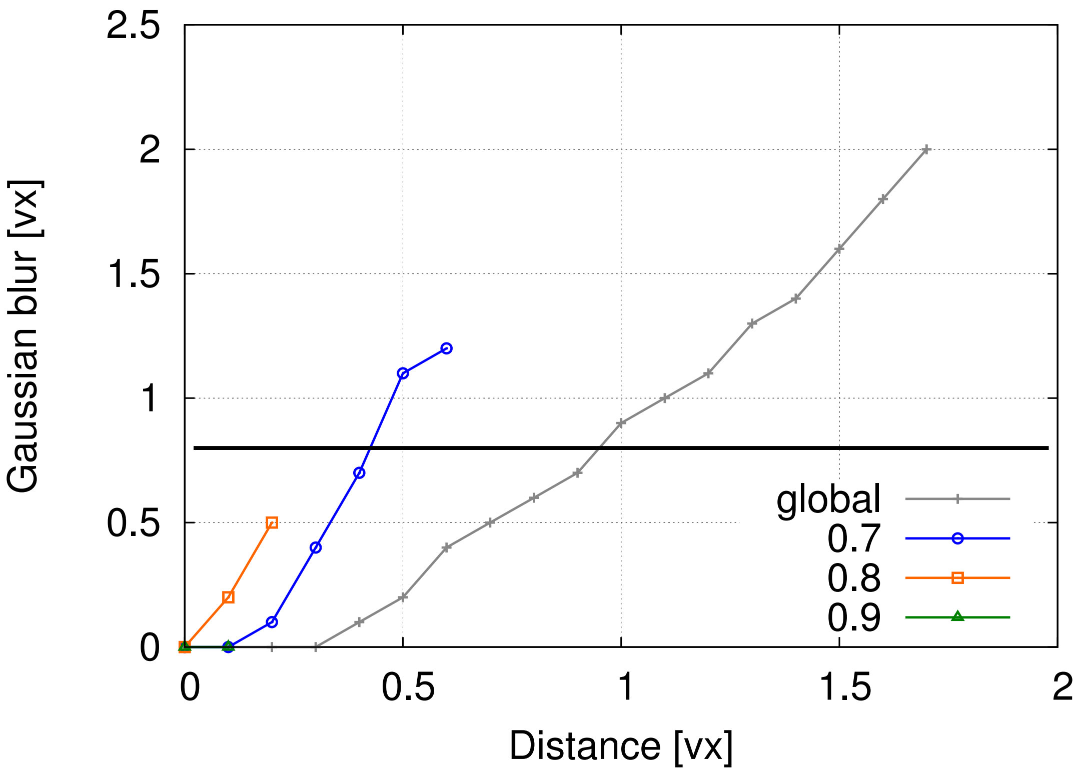


Identification of Contacts - Local Thresholding

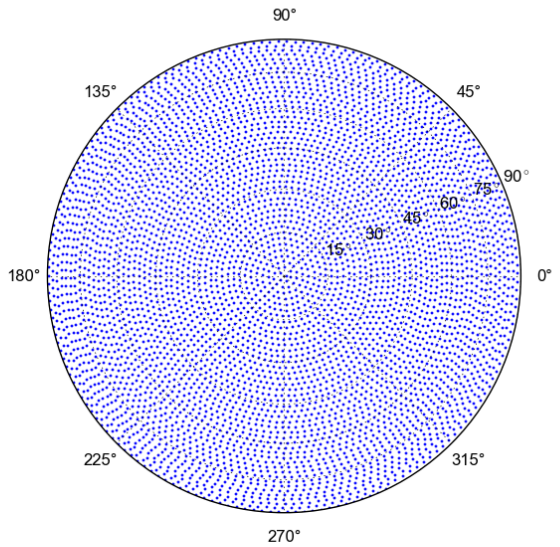


Identification of Contacts - Local Thresholding

Analysis on 5,000 equally distributed branch vectors



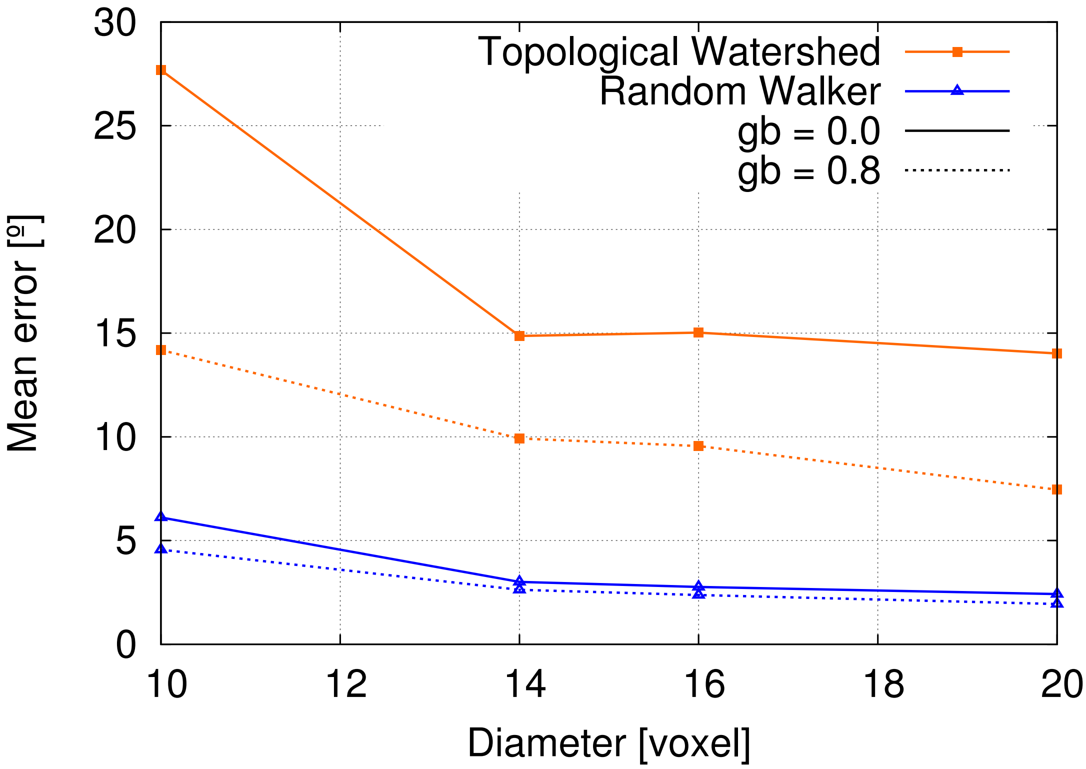
Orientation of Contacts



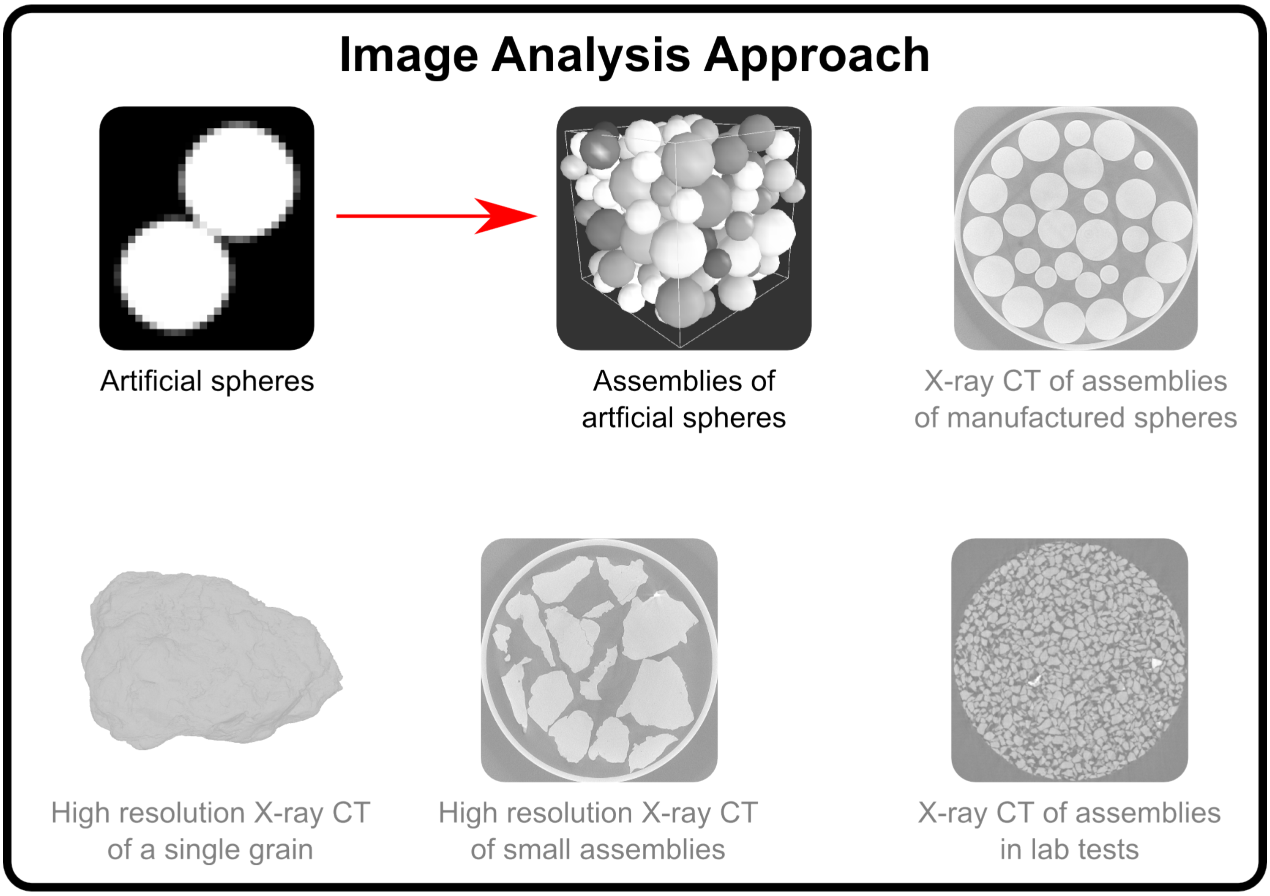
Lambert azimuthal equal-area projection of the imposed orientations

- creation of 5,000 pairs of spheres with equally distributed branch vectors
- error is defined as the angle between the orientation and the imposed branch vector

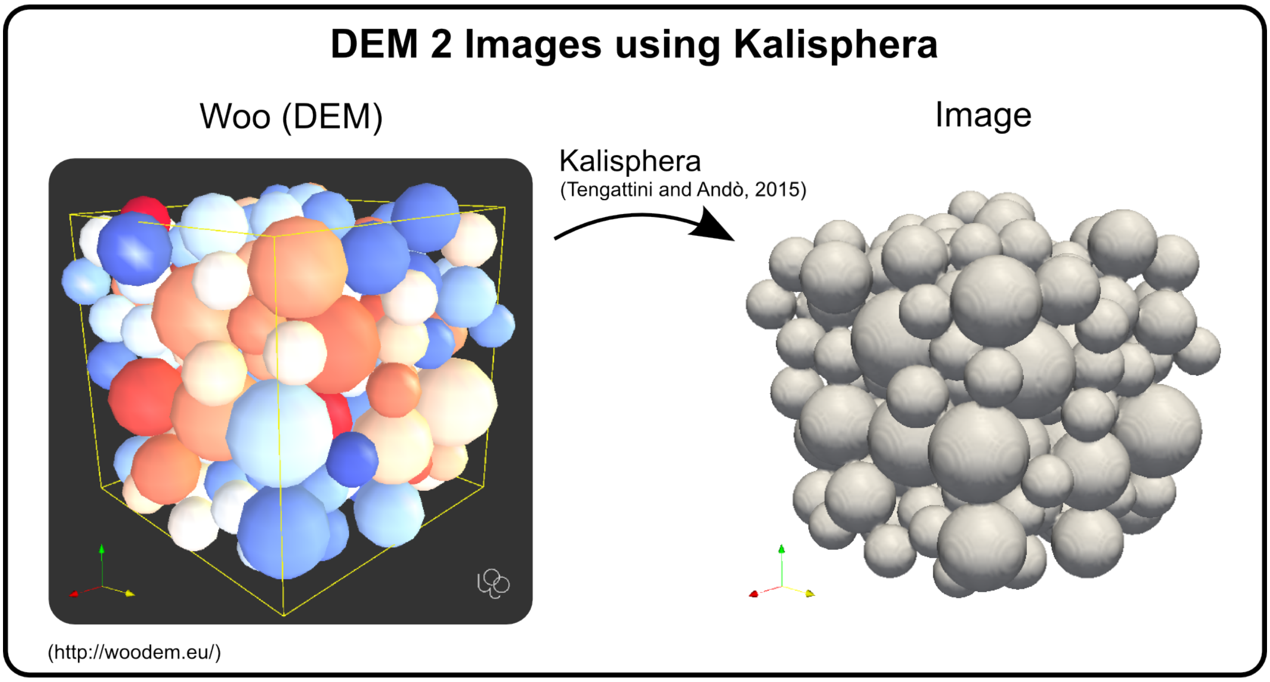
Orientation of Contacts



Our approach to contacts



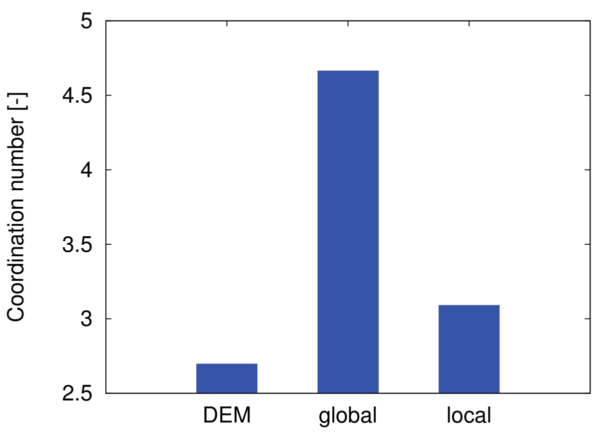
Assemblies of artificial spheres



Showcase sample

A small showcase sample of 244 particles was created using WooDEM and turned into a grey-scale image with Kalisphera.

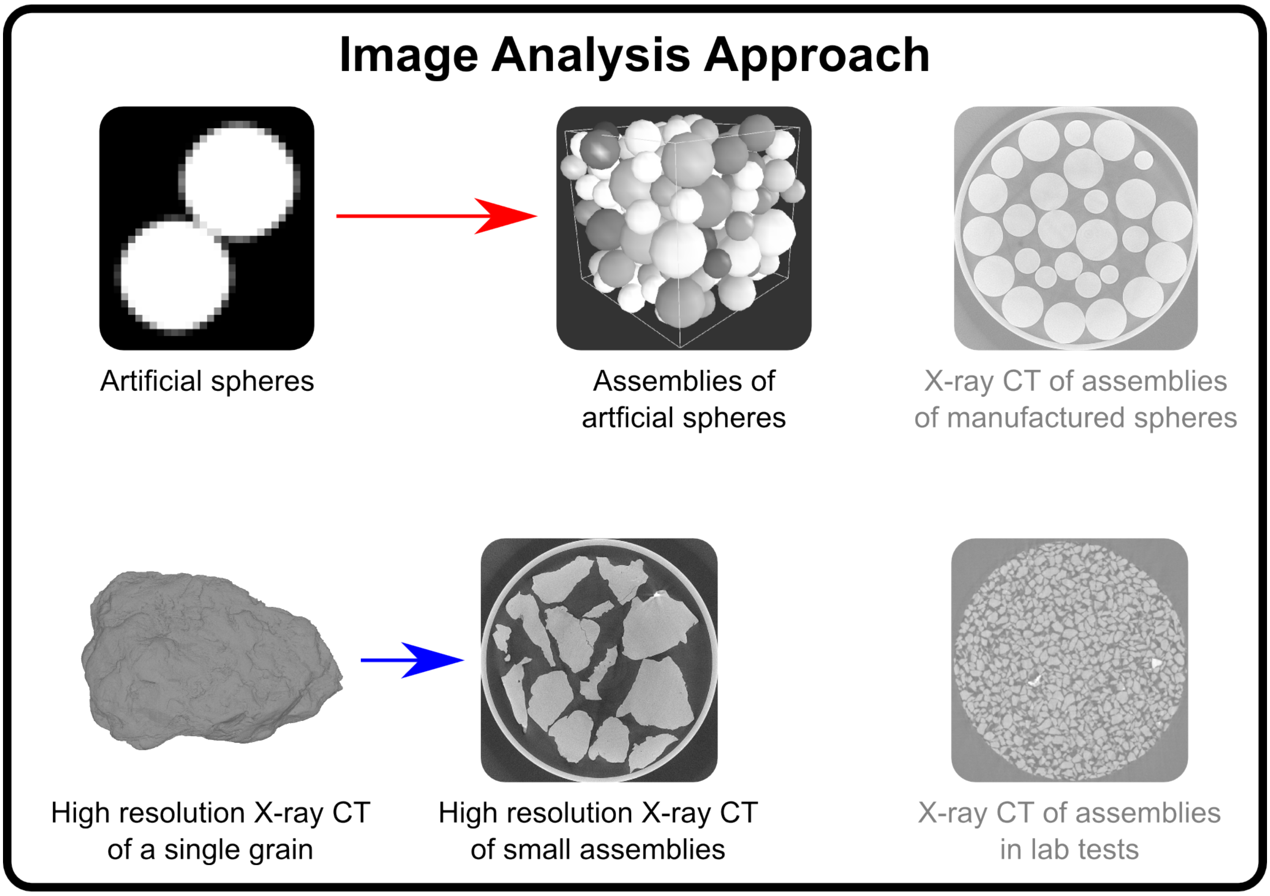
Detection of contacts



Orientation of contacts

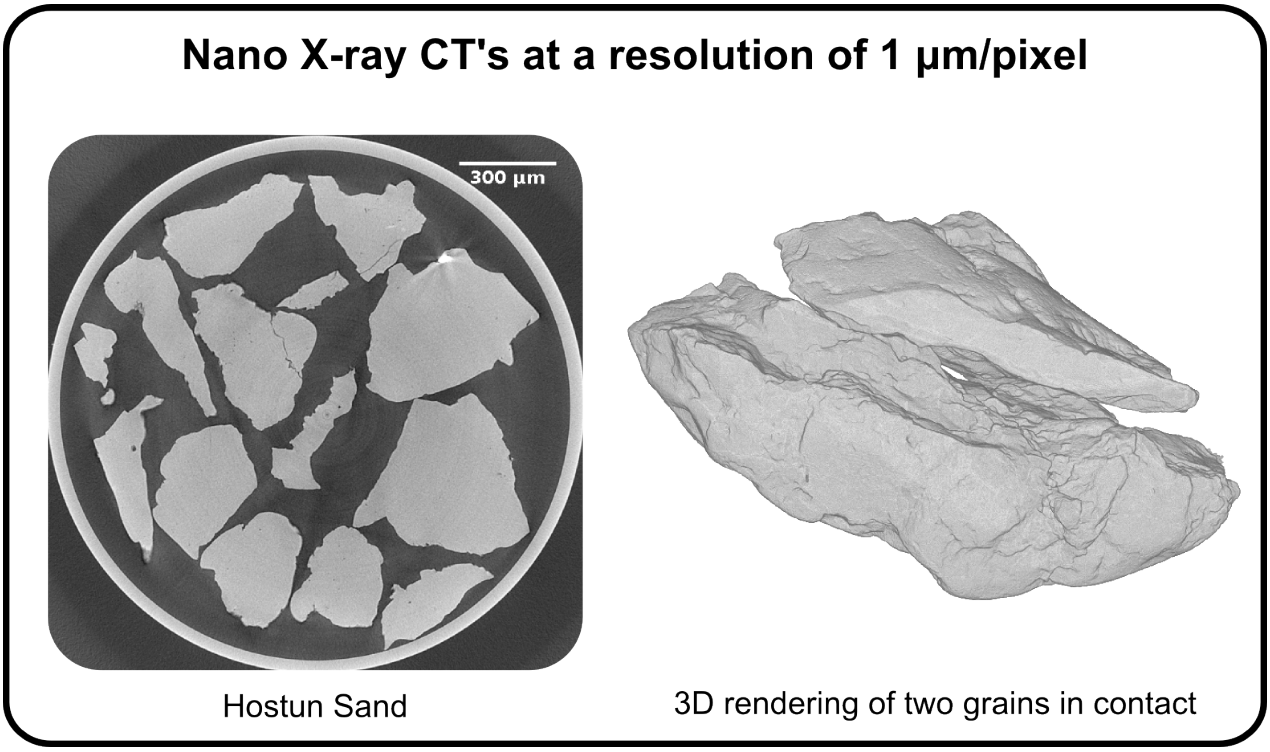
- Determined for the contacts detected using the local refinement
- Mean error
  - Watershed $\mu = 7.56°$
  - Random Walker $\mu = 1.63°$

Our approach to contacts

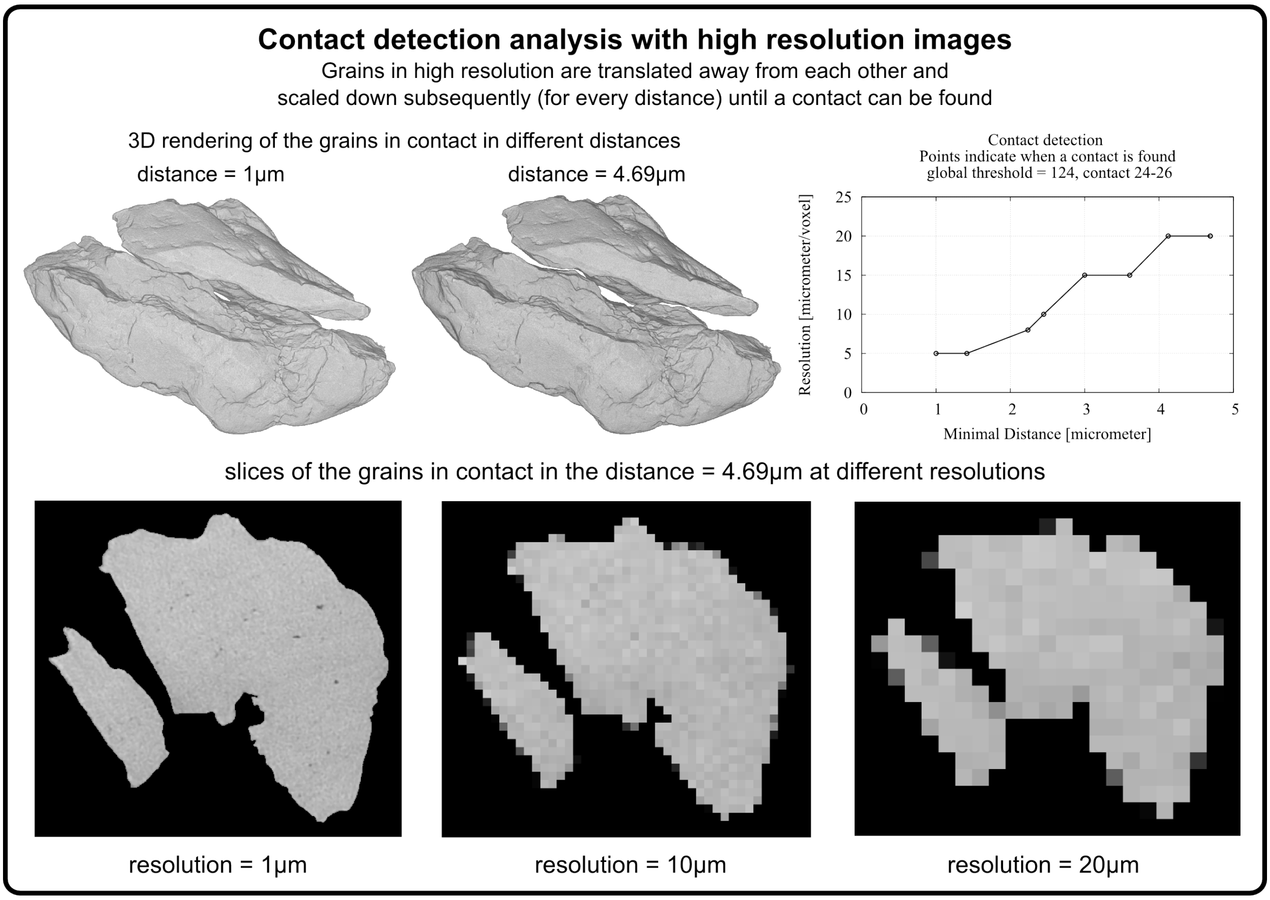


Introduction Contacts Perspectives
Two natural grains

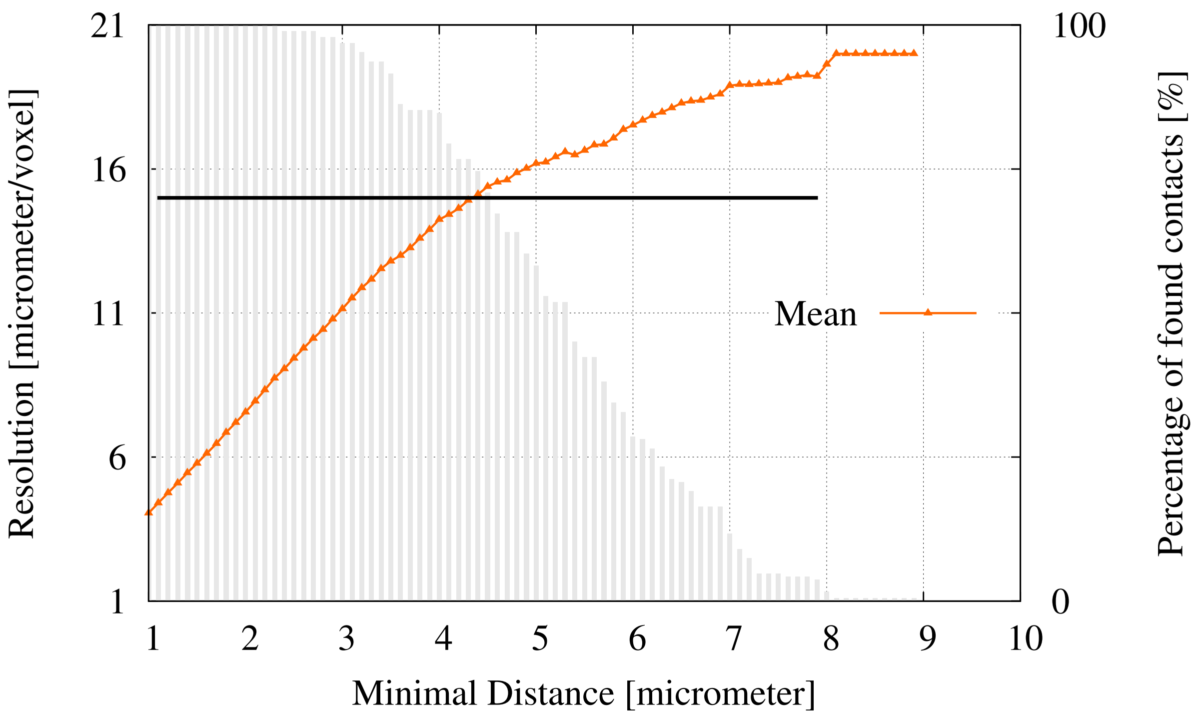
High resolution x-ray CT



Identification of contacts on real shapes

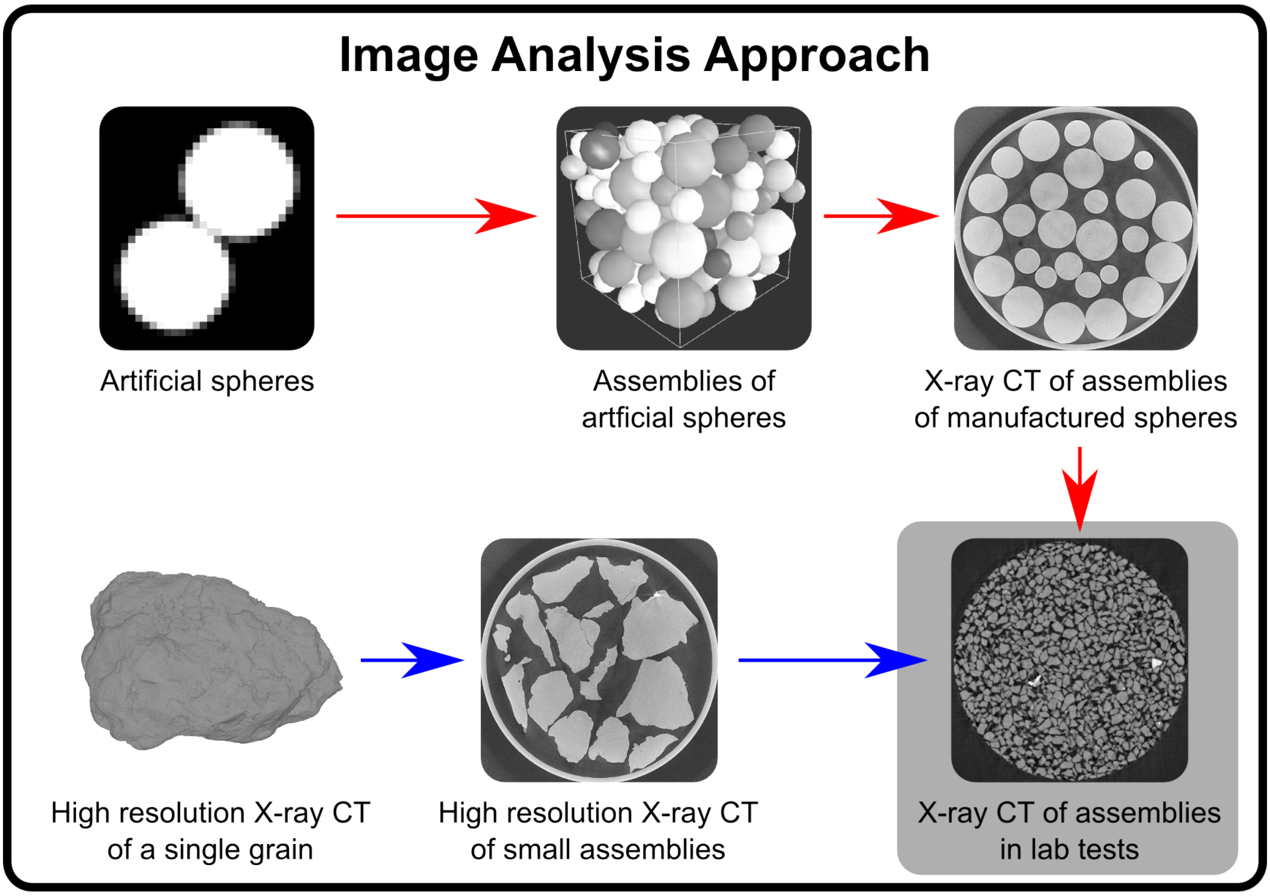


Identification of contacts on real shapes, 189 contacts



Perspectives

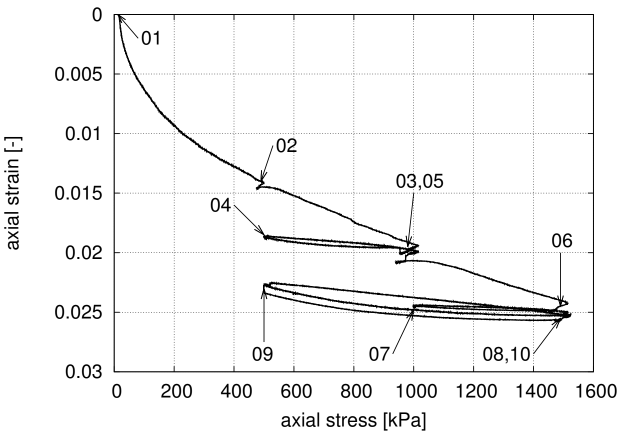
Our approach to contacts



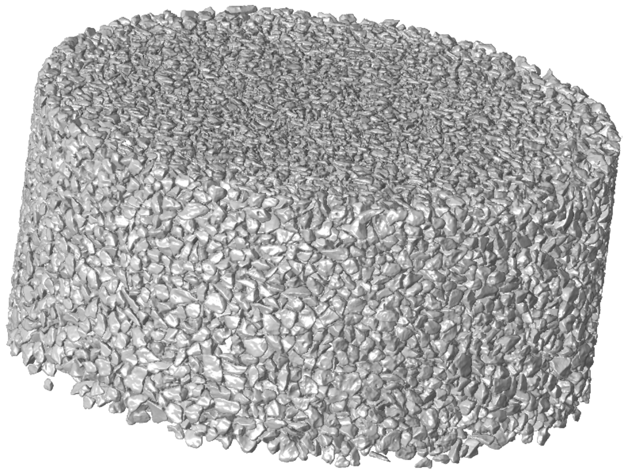
Experiments in the x-ray CT

Oedometric compression on Hostun Sand

Macroscopic Curves



3D rendering of an image of the initial state



Fabric evolution

Fabric tensor of the first kind (Moment tensor)

$$\mathbf{N} = \frac{1}{C}\sum_{\alpha=1}^{C} \mathbf{o}_1^{\alpha} \otimes \mathbf{o}_2^{\alpha} \cdots \otimes \mathbf{o}_n^{\alpha}$$

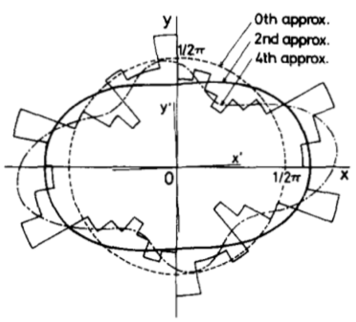


Fig. 1. The contact distribution of a two dimensional granular material (before loading).

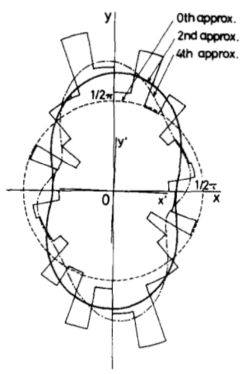
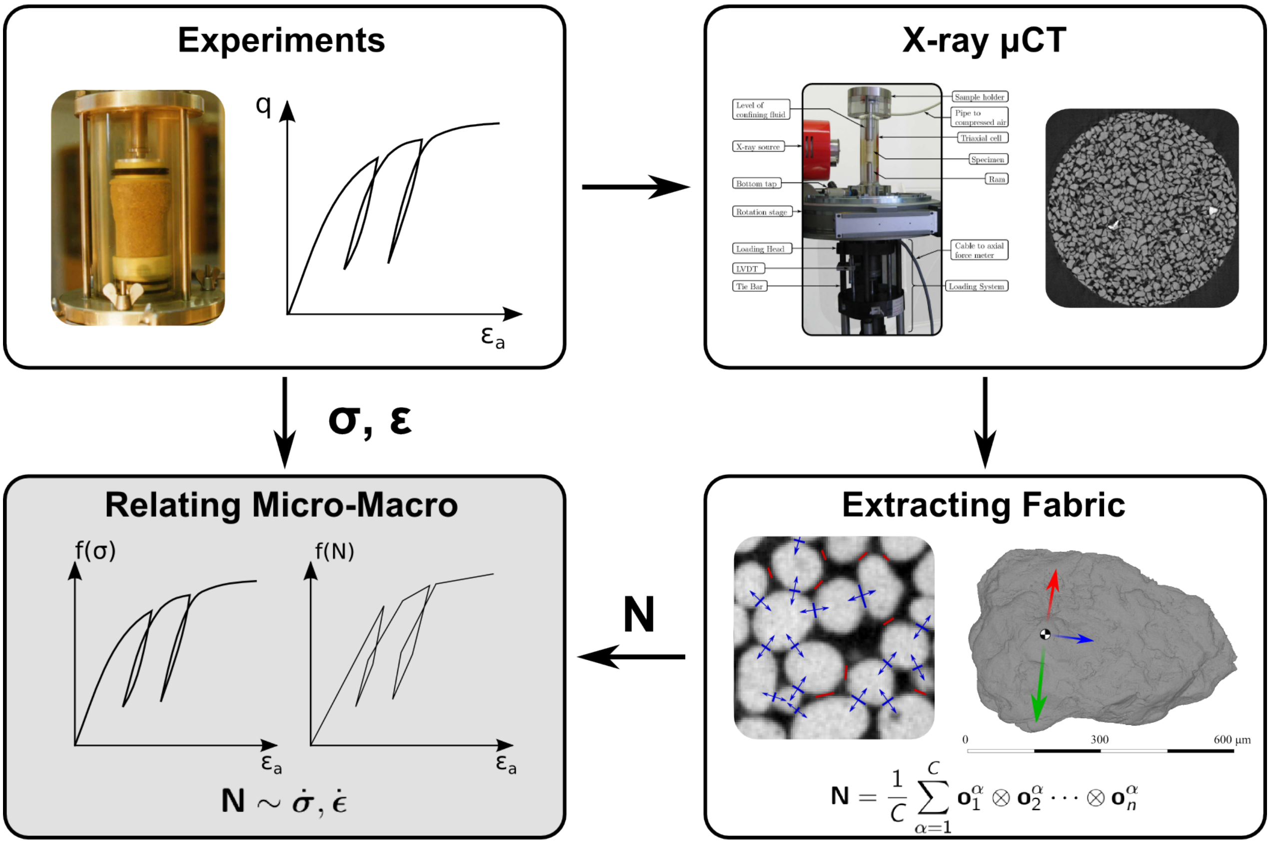


Fig. 2. The contact distribution of a two dimensional granular material (after loading).

(Kanatani, 1984)


Experiments
q
εa
X-ray μCT
Level of confining fluid
X-ray source
Bottom tap
Rotation stage
Loading Head
LVDT
Tie Bar
Sample holder
Pipe to compressed air
Triaxial cell
Specimen
Ram
Cable to axial force meter
Loading System
σ, ε
Relating Micro-Macro
f(σ)
f(N)
εa
εa
N ∼ σ̇, ε̇
N
Extracting Fabric
0
300
600 μm
N = 1/C Σ_{α=1}^{C} o_1^α ⊗ o_2^α ⋯ ⊗ o_n^α