RHIZOSPHERE SPATIOTEMPORAL ORGANISATION
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A micro-macroscale approach coupling processes that shape rhizosphere diffusivity and permeability

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Context

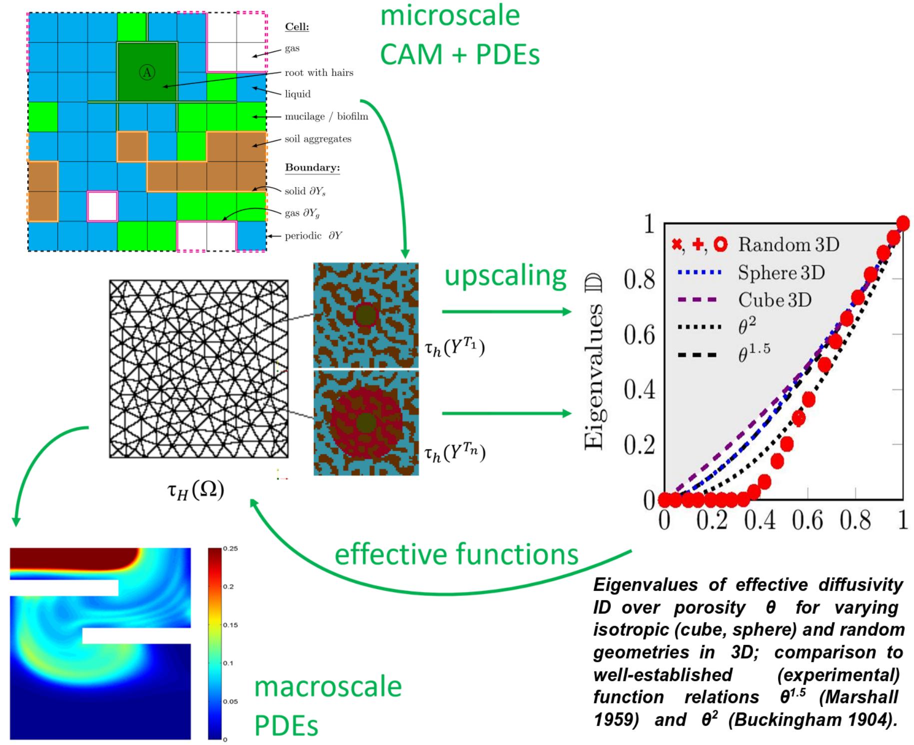
- **Mechanistic and process-based modelling** approach allowing for:
  - **dynamic structural reorganisation** of the soil at the pore scale;
  - coupling of the evolving microscale model to the macroscale including the inference of **soil functions**.

- **Aim**:
  - gain a model-based understanding of **rhizosphere dynamics** in soils;
  - study the influence of root **exudates** on the properties and temporal evolution of the rhizosphere.

Hybrid Modelling Approach to Bridge the Scales

Modelling on two **coupled scales** :

- **Microscale** [μm] with **explicit, evolving** aggregate/pore structures interacting with **reactive, charged species** in fluid and mucilage, biomass/EPS
- **Upscaling techniques** for the derivation of **effective quantities/functions**
- **Macroscale** [mm]: use effective parameters as input for macroscale **root models**



Eigenvalues of effective diffusivity ID over porosity θ for varying isotropic (cube, sphere) and random geometries in 3D; comparison to well-established (experimental) function relations $\theta^{1.5}$ (Marshall 1959) and θ^2 (Buckingham 1904).

See [Ray, Rupp, Prechtel, 2017], [Rupp et al., 2018], [Ray et al., 2018], [Rupp, 2019]

Derive Effective Diffusivity and Permeability of Real (CT) Structures

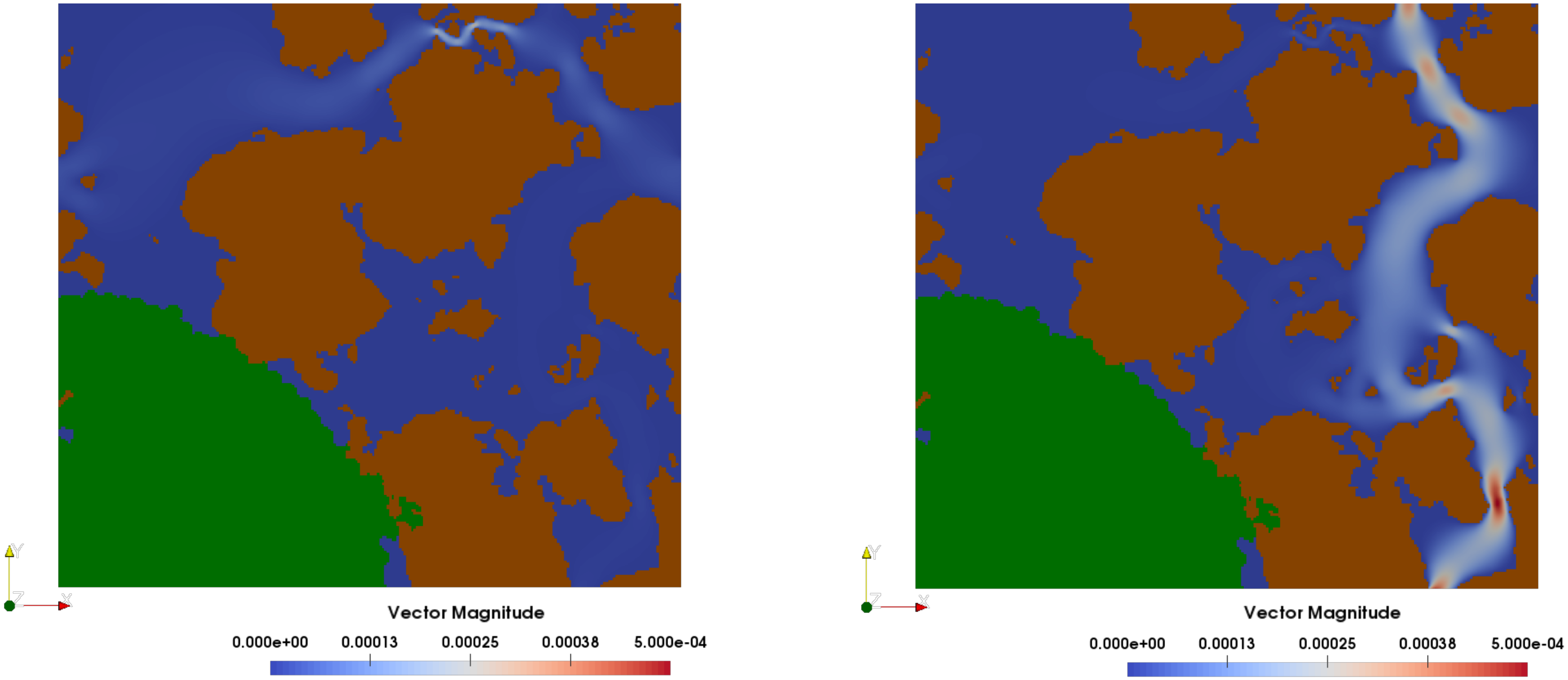


Figure: Solution of the Stokes cell problems for a 2D slice of 256×256 elements (0.3×0.3 mm) of a μ-CT scan *(P. Duddek, University of Bayreuth)* of connected pore space and maize root (green). Effective diffusion coefficient and permeability:

$$\mathbb{D}_{\text{eff}} = \begin{pmatrix} 0.0525 & 0.0109 \\ 0.0109 & 0.0621 \end{pmatrix}, \quad \mathbb{K}_{\text{eff}} = 10^{-5} \begin{pmatrix} 0.1507 & 0.0252 \\ 0.0252 & 1.0342 \end{pmatrix}$$

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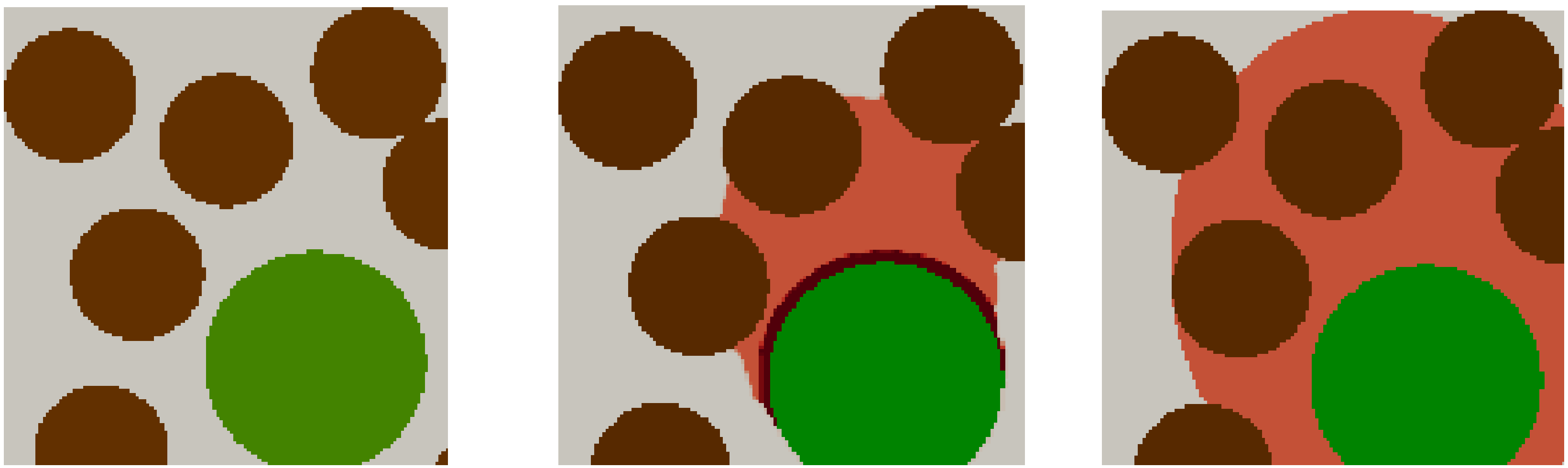
Study the Influence of a Growing Bio Phase on the Effective Diffusion Coefficient



$$\mathbb{D}_{\text{eff}} = \begin{pmatrix} 0.1843 & -0.0057 \\ -0.0569 & 0.2464 \end{pmatrix} \quad \mathbb{D}_{\text{eff}} = \begin{pmatrix} 0.1016 & -0.0482 \\ -0.0482 & 0.1818 \end{pmatrix} \quad \mathbb{D}_{\text{eff}} = \begin{pmatrix} 0.0448 & -0.0080 \\ -0.0080 & 0.0757 \end{pmatrix}$$

Figure: Effective diffusion coefficient matrices with different amount of bio phase (shades of red) in the domain with root (green) and solid grains (brown):

$$D_{fluid,O_2}/D_{\text{ref},O_2} = 1,\ D_{bio,O_2}/D_{\text{ref},O_2} = 0.1.$$

In the **saturated case**, the presence of a bio phase such as mucilage may **reduce the effective diffusion coefficients** (up to a factor 3 in this artificial case)...

Study Systematically the Influence of Spatial Distribution of Mucilage and Liquid Phase in CT based Configurations

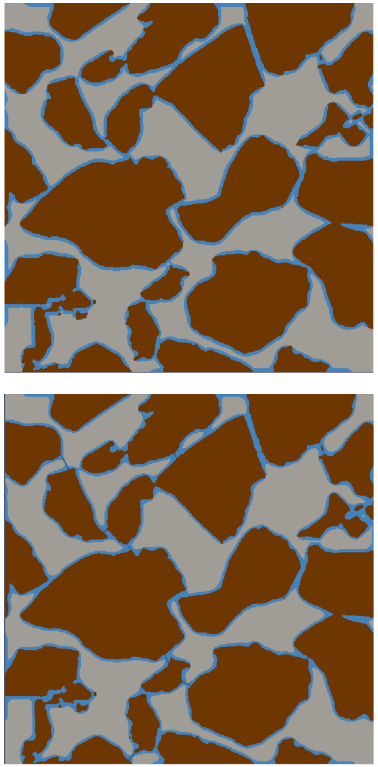


Figure: Geometry from CT-scan and mucilage bridges: courtesy of P. Benard, University of Bayreuth. Sand particles of 0.125-0.2 mm (brown). Artificial water distribution (blue) (with water content of 10 %) without (top) and with (bottom) mucilage bridges.

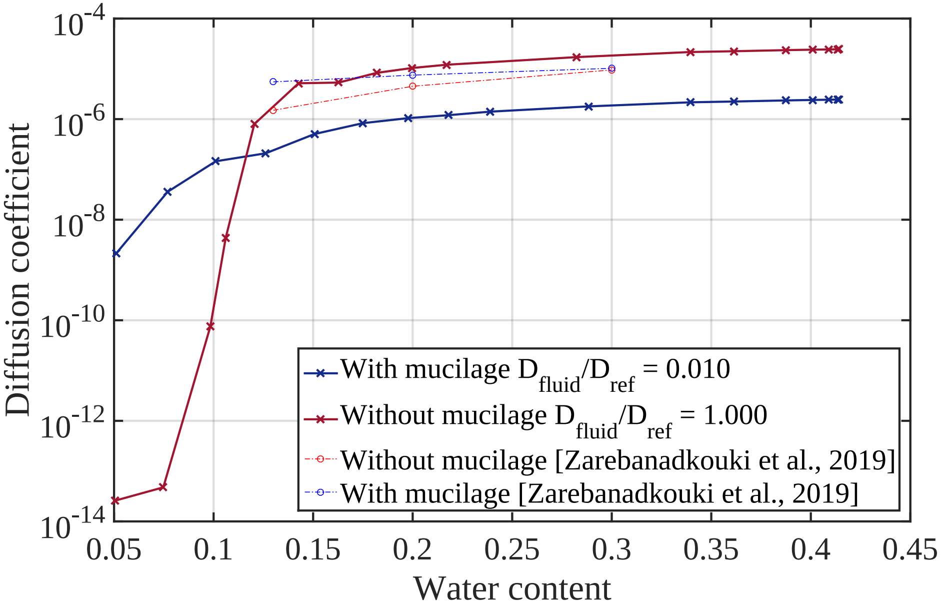


Figure: Mean of the diffusion coefficient matrices entries as a function of the water content. The results from [Zarebanadkouki et al., 2019] are shown for reference.

But: mucilage can also **increase** the diffusion coefficients in **dry situations**!

References

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