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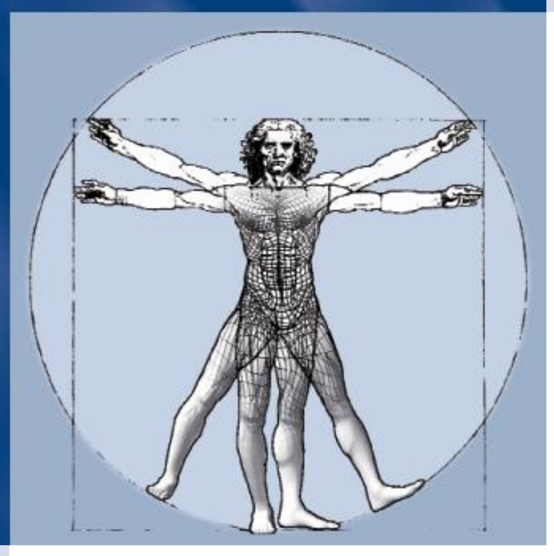

Multi-Scale Multi-Physics Numerical Models for Flow and Transport in Porous Media

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Motivation

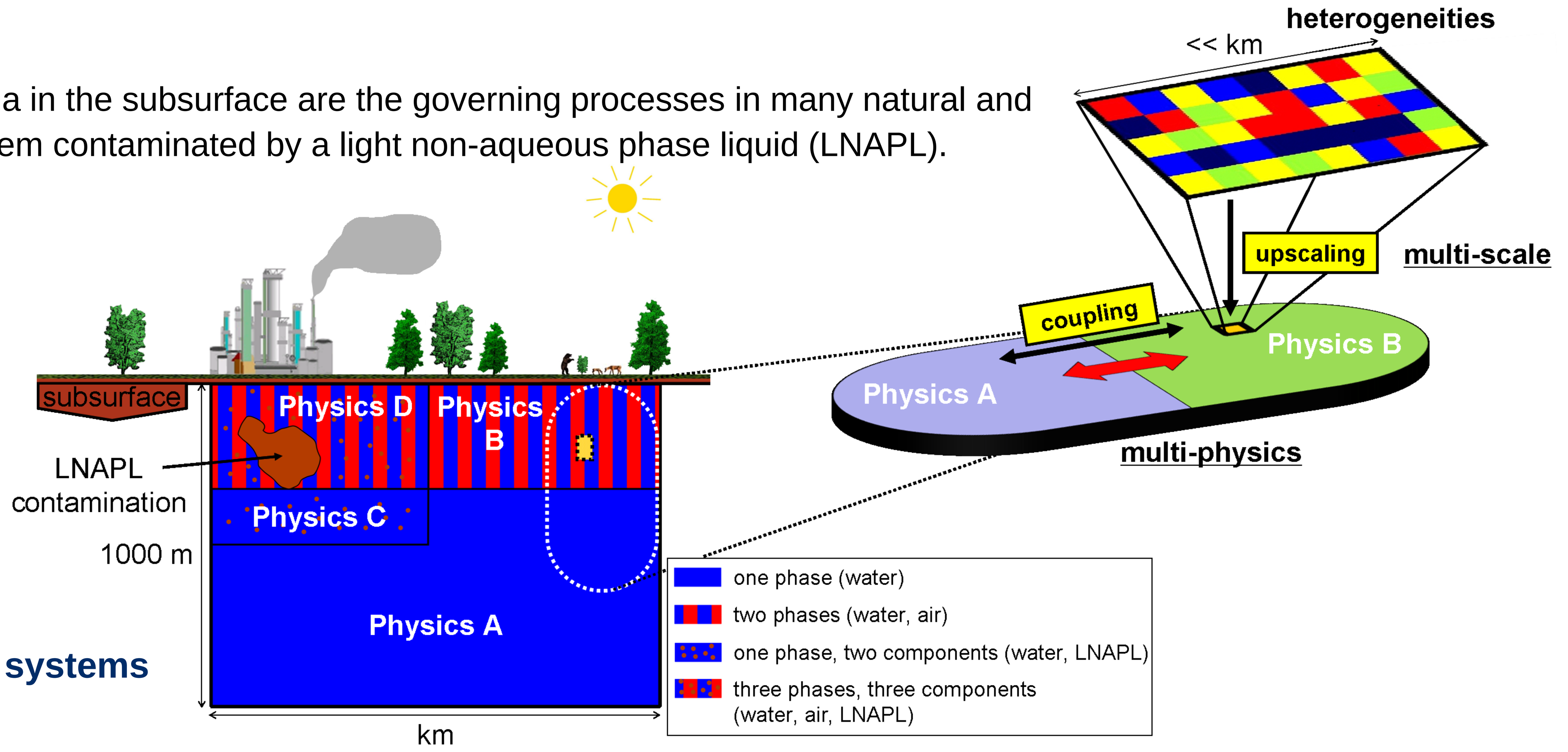
Multi-phase flow and transport phenomena in the subsurface are the governing processes in many natural and industrial systems, e.g. a subsurface system contaminated by a light non-aqueous phase liquid (LNAPL).

These systems are characterised by

- **heterogeneities**, existing (in general) on all spatial scales, and
- the predominance of **different physical processes on different scales** and in different sub domains.

➡ Take the advantages of the **combination of upscaling and multi-physics modeling**

➡ Get a framework to **calculate real systems efficiently and accurately**

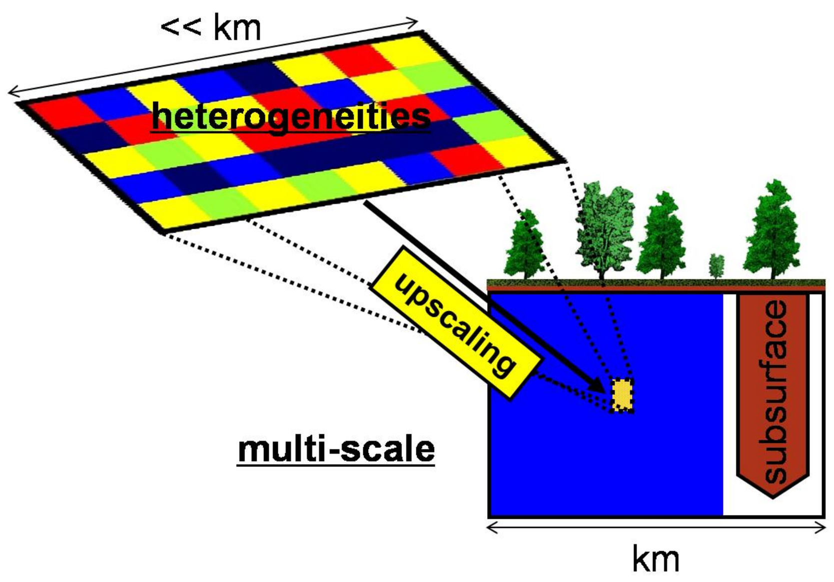


Multi-Scale Methods: Upscaling

- **Upscaling of model parameters:** Use of effective large scale parameters with existing model equations.
- **Upscaling of equations:** Upscaling of existing fine scale model equations into new large scale equations.
- **Upscaling within the discretisation method:** Multi-Scale Finite-Volume/Finite-Element Methods.

Demands on the Upscaling Method

- Ability to **account for important small scale effects** on the large scale: Capillary pressure effects and gravity effects.
- **Possibility to reconstruct fine scale quantities** (downscaling) if necessary: Coupling of sub domains of different dominating scales.
- **Applicability** within the simulation framework DUMUX [2].



Fine Scale Equations

- **Equations are well known** and tested.
- Describe **multiphase flow** on the REV-scale, or **on the scale of the finest resolved heterogeneities**.
- **Different** kinds of model **formulations** possible.

Coarse Scale Equations

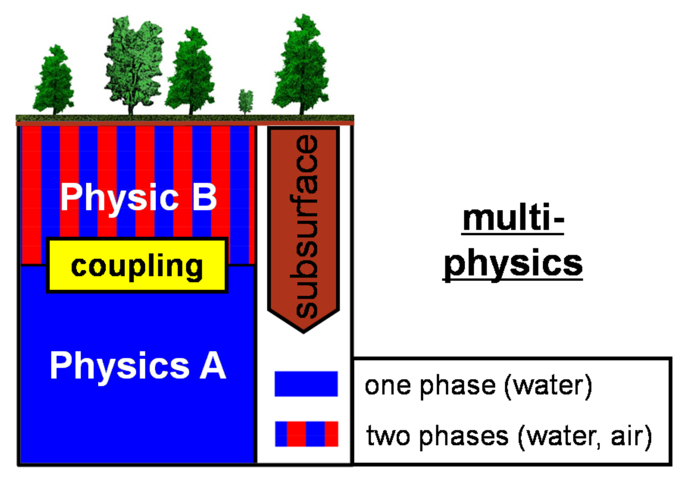
- Development of **coarse scale equations in a phenomenological approach**.
  - ➡ **Simple equations**, motivated by complex and rigorously upscaled coarse scale equations (see e.g. Quintard and Whitaker [3], Efendiev and Durlofsky [1]), **which sufficiently describe the physics** of a heterogeneous system.

Multi-Physics – Model Coupling

- In different subdomains of a system a different number of phases could be present (1-phase, 2-phase, multi-phase), different composition of phases and different kinds of fluids could occure (miscible/immiscible – 1-phase-multi-component, multi-phase-multi-component), isothermal or non-isothermal processes could dominate, etc.
  - ➡ **Idea:** Use **for every subdomain the simplest model**, which sufficiently describes the dominant physical processes occuring in this domain.

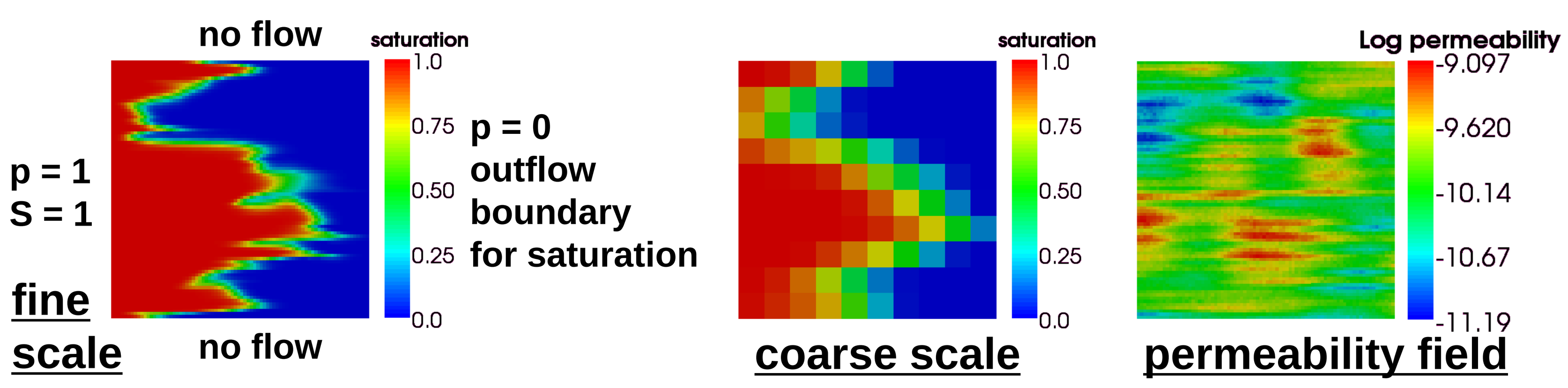
Demands on Multi-Physics Methods

- Coupling of different subdomains:
  - ➡ Coupling of physical models.
  - ➡ **Coupling of numerical methods.**
- **Up- or downscaling** might be necessary.



First Upscaling Results

- Saturation of a wetting phase infiltrating into a domain saturated with a non-wetting phase



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Next Steps

- Further **developement** of the **upscaling method**.
- **Implementation** and **investigation** of different possibilities to include **capillary pressure and gravity effects**.

Long-Term Perspective

- **Combination of Multi-Physics and Upscaling** approaches to a Multi-Scale-Multi-Physics framework.
- Simulation of a **real szenario**.

Literature

[1] Y. Efendiev and L. Durlofsky. *A generalized convection-diffusion model for subgrid transport in porous media.* SIAM MMS, vol. 1(3), pp. 504-526, 2003.

[2] B. Flemisch et al. *DUMUX: a multi-scale multi-physics toolbox for flow and transport processes in porous media.* In A. Ibrahimbegovic et al. (eds.), ECCOMAS Thematic Conference on Multi-scale Computational Methods for Solids and Fluids, Cachan, France, November 28-30, pp. 82-87, 2007.

[3] M. Quintard and S. Whitaker. *Two-phase flow in heterogeneous porous media: The method of large-scale averaging.* Transport in Porous Media, vol. 3 pp. 357-413, 1988.