Theoretical and Practical Introduction to *COMSOL Multiphysics*

Introductory Course on Multiphysics Modelling

Brief Selective Summary of the Short Course

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Website, Lecture Notes, Contact

Introductory Course on Multiphysics Modelling

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- Go to: http://bluebox.ippt.pan.pl/~tzielins/
- Then, choose: *Lectures*.

Suggested *Lecture Notes*:

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6. *Introduction to Finite Element Method*
7. *Heat Transfer Problems*
8. *Galerkin Finite Element Model for Heat Transfer*

...

15. *Elementary Viscous Flow*

...

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A typical mathematical modelling process

1. Define the **problem geometry** – specify:
   - space dimension ([0D, discrete,] 1D, 2D, 3D, mixed)
   - domain or subdomains,
   - boundaries and interfaces between subdomains.
2. Choose/derive a **mathematical model**
   - decide on **transient** (time-dependent) or **steady-state** analysis;
   - choose problem **variables**/**fields** (primary and secondary ones, eg.: concentration and flux, or temperature and heat flux vector);
   - use or derive **model equations** (usually in terms of Partial Differential Equations, e.g., the diffusion equation);
   - specify **material(s)** properties, define **sources** (e.g., heat sources or sinks) or **excitations** (e.g., external forces);
   - specify **boundary conditions** (and initial conditions);
   - define **couplings** on interfaces between different subdomains.
3. **Implement** the model and **solve** the problem
   - choose a **method** (analytical if possible, or a numerical one);
   - set: the **geometry** (and time range), **material** parameters, **sources**, boundary (and initial) **conditions**;
   - specify **features of the method** (e.g., approximation functions, mesh, [time step,] etc.) and **solve**.
4. **Post-process the results** of solution and **draw conclusions** from the model predictions (re-design, optimise, etc.).

Basics of multi-scale modelling

Motivation:

- **Many complex phenomena** involve processes occurring at different scales (of space and/or time), or . . .
- . . . **multiple spatial and/or temporal scales can be distinguished** to differ between the process phases or to better/easier describe the process features.
- Usually, **it is easier to deal with different scales individually**.

Multi-scale modelling

Mathematical solution techniques of dealing with problems that have important features at multiple scales of space and/or time.

Comment: For many problems, the processes (i.e., sub-problems) at various scales can be, in practice, solved (quasi) separately, which makes such multi-scale approach very efficient.

Requirements:

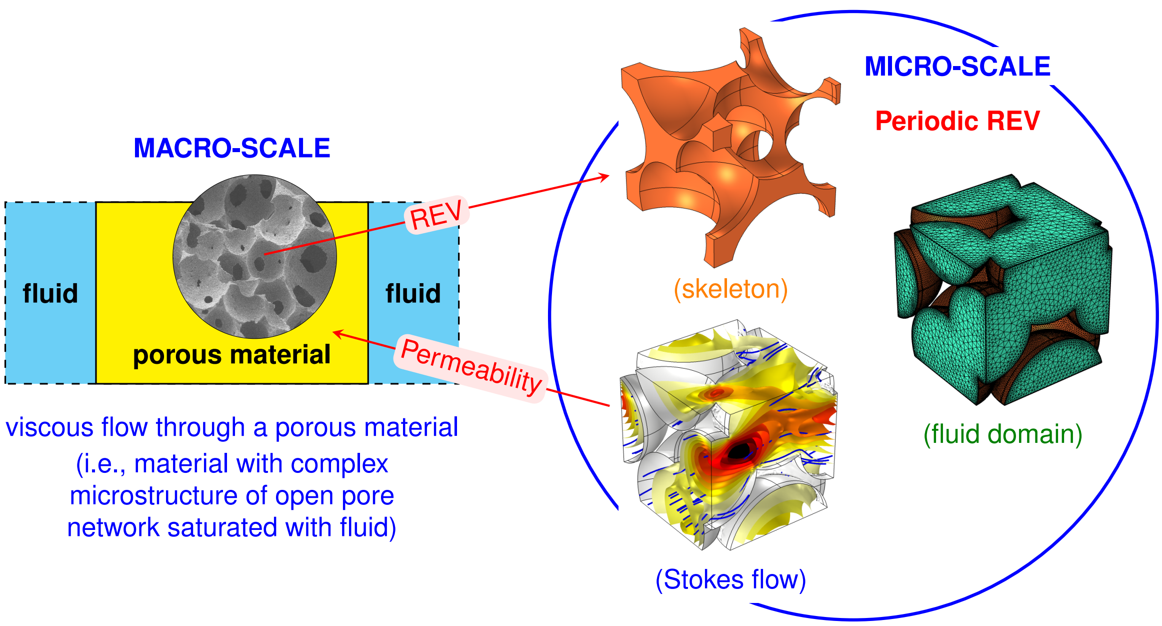
- **Separation of scales** – allows to apply different approaches to treat problems at various scales. One can distinguish:

  different spatial scales – when there are local and global phenomena, or there co-exist processes which are: essentially microscopic (i.e., occur at the micro-scale), mesoscopic (i.e., occur at the meso-scale), and macroscopic (i.e., occur at the macro-scale), etc.;

  different temporal scales – when the involved processes are: relatively slow (static or quasi-static), dynamic, or relatively fast, etc.

- **Representativeness** of the geometry or time-interval for the phenomenon considered on the scale related to this geometry or time-interval.
- Well defined way of **passing of the relevant information** (effective properties, behaviour, etc.) **between the scales**.

EXAMPLE: Transport through a porous medium



1. **MICRO-SCALE:**
   - Selection (construction) of a (periodic) **Representative Elementary Volume (REV)** of a porous medium.
   - **Stokes flow**, i.e., linear & steady, viscous, incompressible flow through the **periodic RVE**, driven by a uniform pressure gradient.
   - Averaging of the computed velocity field to determine the **permeability of the porous medium**.
2. **MACRO-SCALE:**
   - **Macroscopic flow through the porous material** characterised by its open porosity and permeability using the **Darcy's law**.

Questions & Answers

1. *What is steady-state (stationary) problem?*

   A system is in **steady state** if its recently observed behaviour will continue into the future, so that time can be eliminated from the problem description, which means that the corresponding **stationary** problem is **time-independent** (i.e. the problem variables do not depend on time). Examples: static problems, steady-state flow, time-harmonic problems.

2. *What is transient (non-stationary) problem?*

   A system is in **transient state** where it substantially changes over time, which means that the problem is essentially **time-dependent** (i.e. the problem variables depend on time). The transient state is often a start-up in many steady state systems.

3. *What is Boundary Value Problem?*

   A **Boundary Value Problem (BVP)** is a **Partial Differential Equation (PDE)** – defined on a specified domain – together with appropriate **boundary conditions** – defined on the domain boundary. BVPs are (time-independent) mathematical models of most steady-state physical phenomena.

4. *What is Initial Boundary Value Problem?*

   An **Initial Boundary Value Problem (IBVP)** is defined by a **time-dependent Partial Differential Equation (PDE)** with appropriate **initial and boundary conditions**. IBVPs are (time-dependent) mathematical models of most transient physical phenomena.

5. *What are mechanisms of heat transfer?*

   Three mechanisms of heat transfer:

   (I) the **conduction** – the heat transfer by diffusion,

(II) the **convection (advection)** – the heat transfer due to the bulk movement of fluid,

(III) the **radiation** – the heat transfer via electromagnetic waves.

6. *What is a usual modelling procedure using Finite Element Method?*

Major steps in modelling using Finite Element Method:

(I) Define the **problem geometry**: decide on 2D or 3D; if possible, take advantage of symmetry; construct domain (or subdomains) with well-defined boundaries (and interfaces).

(II) Choose a **mathematical model**: decide on steady state (BVP) or transient state (IBVP); specify material(s), sources (or excitations), boundary conditions (and initial conditions in the case of IVBP).

(III) Construct (or generate) a **finite element mesh**.

(IV) **Solve** the problem numerically (choose a numerical solver; in the case of IBVP set the time scope and time step).

(V) **Post-process** and interpret the results (draw conclusions, etc.).

7. *When can multi-scale modelling be applied (i.e. to what problems)?*

Multi-scale modelling can be applied to problems that have **important features at multiple scales** of space and/or time.

8. *What are the two main requirements in multi-scale modelling?*

Two main requirements in multi-scale modelling are:

(I) **separation of scales**,

(II) **representativeness** of the geometry domain (or time-interval) of a specific scale for the phenomenon considered on that scale.

9. *What are two types of scales suitable for multi-scale modelling?*

Multi-scale modeling can be performed with respect to:

(I) **spatial scales** and/or

(II) **temporal scales**.

10. *Which problems are more difficult (i.e. more computationally demanding) to solve: compressible or incompressible flows?*

Compressible flows are more complex (and coupled with thermal problem) and therefore computationally more demanding than incompressible flows.

11. *What is the Stokes flow?*

Stokes flow is a **linearised**, **steady-state**, **viscous** and **incompressible** flow (of Newtonian fluid).

12. *What is the fluid-structure interaction (FSI)?*

    Fluid–structure interaction is the interaction of some **movable and/or deformable structure** with an internal or surrounding **fluid flow**.