جامعة الملك عبدالله
للعلوم والتقنية
King Abdullah University of
Science and Technology

Course Syllabus: Multiscale Geological Reservoir Modeling - ErSE 390K

Division	Physical Science and Engineering Division
Course Number	ErSE 390K
Course Title	Multiscale Geological Reservoir Modeling
Academic Semester	Summer
Academic Year	2017/2018
Semester Start Date	06/10/2018
Semester End Date	08/09/2018
Class Schedule (Days & Time)	09:00 AM - 12:00 PM | Sun Tue

Instructor(s)

Name	Email	Phone	Office Location	Office Hours
Shuyu Sun	shuyu.sun@kaust.edu.sa	+966128080242	Office 4417, Floor 4, Bldg 1, 1, Al-Khawarizmi (bldg. 1)	3:00-4:30pm Mondays (no appointment needed during office hours)

Teaching Assistant(s)

Name	Email

Course Information

Comprehensive Course Description	
Comprehensive Course Description	**Motivation for the Course:** Physical phenomena can be modeled at varying degrees of complexity and at different scales. Multiscale modeling provides a framework, based on fundamental principles, for constructing mathematical and computational models of such phenomena, by examining the connection between models at different scales. Flow and transport in geological formation are usually described within the continuum hypothesis at Darcy's scale that provides an up-scaled view to the various processes that are involved in these applications. In practice, reservoir simulation has been conducted in relatively coarse grids while geological information is available at much finer meshes. One challenge people face in reservoir simulation is the fact that the geological formation is intrinsically multiscale and typically displays heterogeneities over a wide range of length-scales. Recently, there has been extensive research work trying to bridge the gap between scales and to resolve certain fine-scale feature by using only coarse-scale computational efforts. **Course Description:** This course will be basically divided into two parts. In the first part, the student will get exposed to a number of general and basic multiscale methods. In the second part, the student will learn about the basic principle of modeling and simulation for single-phase and multiphase flows at multiple scales in geological reservoirs as well as multiscale multicomponent transport simulation. The student will first get exposed to the separation of time scales, spatial scales, and modeling scales. Followed will be a description of the homogenization problems and heterogeneous multiscale methods. We will move into numerical homogenization (upscaling) techniques: how to extract useful information from the micro-model for the macro-model. Different numerical challenges and approaches to bridge different scales will be described. In particular, we will emphasize the following topics: -**Conventional upscaling of grid properties in reservoir simulation**. The conventional upscaling is to substitute a heterogeneous property region consisting of fine grid cells with an equivalent homogeneous region made up of a single coarse-grid cell with an effective property value. We will cover various upscaling techniques for absolute permeability including explicit average schemes (harmonic average, arithmetic average, geometric average, harmonic-arithmetic average, arithmetic-harmonic average, etc.) flow-based methods (using sealed-side boundary conditions, open-side boundary conditions, or periodic boundary conditions, etc.), and regional upscaling (versus local and global upscaling approaches). -**The theory of effective medium approximations**. The effective medium theory (sometimes abbreviated as EMT or EMA) was conventionally applied to the analytical or theoretical modeling of macroscopic properties of composite materials. In this course, we will introduce it and apply it to Darcy flow. -**Variational multiscale methods**. We will first introduce the variational principle for Darcy flow and the theory of finite element methods, and we will then discuss variational multiscale finite element methods. -**Proper orthogonal decomposition**. We will cover engineering motivation and mathematical background of Proper Orthogonal Decomposition (POD) and its application to the global model reduction of geological reservoirs. -**Generalized multiscale finite element methods**. We will review the recently-developed Generalized Multiscale Finite Element Methods (GMsFEM). We will present details on the construction of offline local multiscale basis functions and the computation of online multiscale basis functions, including a number of tricks in designing the local eigenvalue problems. Properties and performance of snapshot spaces and offline spaces will be discussed. If time allows, we will also cover the **Discrete Empirical Interpolation Method** (DEIM) and the **Generalized Empirical Interpolation Method** (GEIM). -**Multiscale modeling of flow in fractured porous media**. We will review a number of single-scale and multi-scale modeling approaches for flow in subsurface formation with fractures, which include single-domain single-continuum models, the dual-porosity model, the dual-porosity dual-permeability model, multiple-continuum models, dimension-reduced discrete fracture models, fractional derivative non-Darcy models, and the model reduction of fractured porous media using GMsFEM. Implementation of numerical simulators is one focus of this course. Students will have opportunities to earn hands-on experiences of developing their own numerical simulators for Darcy scale (and possibly pore-scale) flow and transport using MATLAB or R (or a language of your choice with consent of instructor).

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<tr><td></td><td></td></tr>
<tr><td>Course Description from Program Guide</td><td>The course covers a number of basic multiscale methods with applications in geological reservoirs. Individual topics include: basic multiscale methods; homogenization techniques; heterogeneous multiscale methods; multiscale finite element methods; permeability upscaling single-phase and multiphase flows at multiple scales in geological reservoirs; multiscale multicomponent transport simulation; pore-scale modeling of reservoirs; molecular dynamics simulation of reservoir fluids.</td></tr>
<tr><td>Goals and Objectives</td><td>Goals and Objectives:
In this course, we will lay out the tools and fundamentals essential to carry out modeling, computation, analysis and research at different scales of flow and transport in geological subsurface reservoirs. Various physical and numerical models have been used to describe the interesting phenomena involving flow and transport in geological porous media. We will focus mainly on various scales of Darcy flow (from micrometer to kilometer), but depending on time and the progress of the class, we might also cover modeling from molecular scale to pore scale, and then to Darcy scale. Numerical techniques used to bridge these equations will be introduced. Based on comprehensive theoretical modeling and computational predictions, it provides a fundamental understanding of how microstructure affects large-scale behaviors. At the end of the course, students will be able to construct conceptual and mathematical models that represent specific examples of geological reservoirs which exhibit strong coupling between flow, transport and reaction processes across multiple scales, and students are expected to be able to implement the mathematical models into numerical simulators using a high-level programming language such as R or MATLAB.</td></tr>
<tr><td>Required Knowledge</td><td>Prerequisite:
Basic numerical PDE courses, basic programming skills in MATLAB, fluid mechanics, or consent of instructor</td></tr>
<tr><td>Reference Texts</td><td>Text:
No textbook is required in this course. Handout, class presentation slides and published papers will be distributed in the class instead. The following four reference books will be partially used.

Reference:
-Multiscale Finite Element Methods - Theory and Applications, by Yalchin Efendiev and Thomas Y. Hou, Published by Springer (2009). ISBN 978-0-387-09495-3. DOI: 10.1007/978-0-387-09496-0. (e-book available)
-Multiscale Methods: Bridging the Scales in Science and Engineering, by Jacob Fish (Editor), Published by Oxford University Press (October. 22, 2009). ISBN-10: 0199233853; ISBN-13: 978-0199233854.
-Principles of Multiscale Modeling, by Weinan E (Author). Published by Cambridge University Press (July, 2011). ISBN: 978-1-107-09654-7. (e-book available at https://web.math.princeton.edu/~weinan/papers/weinan_book.pdf)
-Upscaling Multiphase Flow in Porous Media: From Pore to Core and Beyond, edited by D.B. Das (Editor), S.M. Hassanizadeh (Editor). Published by Springer (October 19, 2010). ISBN-10: 9048168880; ISBN-13: 978-9048168880.</td></tr>
<tr><td>Method of evaluation</td><td>30.00% - Scientific review article presentation
10.00% - Quiz(zes)
50.00% - Course Project(s)
10.00% - Active participation</td></tr>
<tr><td>Nature of the assignments</td><td>Grading Policy:
-Your final grade will be determined as follows:
Attendance and active participation: 10%
Pop quizzes (oral and written): 10%
Mid-term paper presentation: 30%
Semester project (including proposal, presentation, and final report): 50%
No final exam.

-The letter grades will be assigned according to:
A: 95–100; A-: 90–94; B+: 85–89; B: 80–84;
B-: 75–79; C+: 70–74; C: 65–69; C-: 60–64;
D+: 55–59; D: 50–54; D-: 45–49; F: 0–44.

-In borderline cases, the instructor reserves the right to subjectively determine grades based on class attendance, class participation, quality of work, etc.</td></tr>
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Course Policies	**Attendance:** Each student is expected to prepare for and attend all of the class sessions during the semester. Students in the class are expected to treat one another respectfully, and to offer constructive criticism in course discussions about their classmates' work. Participation in class is strongly encouraged. Punctuality is required. Students are expected to wait 15 minutes before leaving if the instructor is not present at the scheduled start time of the class. Students' excused absences include official university business and personal emergencies (medical, legal, death in the family, etc). It is the student's responsibility to contact the instructor prior to the absence (when possible) and provide the documentation required for excused absences. It is the student's responsibility to make up any deficiency resulting from class absence in a timely manner, including getting class notes (from other students) and assignments. Please carefully read the university attendance policy for additional specifics. **Academic Integrity:** As a member of the KAUST community, you are expected to demonstrate integrity in all of your academic endeavors and will be evaluated on your own merits. Be proud of your academic accomplishments and help to maintain and promote academic integrity at KAUST. We shall not tolerate lying, cheating, or stealing in any form.
Additional Information	

Tentative Course Schedule

(Time, topic/emphasis & resources)

Week	Lectures	Topic
1	Sun 06/10/2018	To review cell-centered finite difference methods for Darcy flow in porous media; To present various explicit average upscaling techniques for absolute permeability including harmonic average, arithmetic average, geometric average, harmonic-arithmetic average, arithmetic-harmonic average, etc.
1	Tue 06/12/2018	To cover common flow-based methods for upscaling permeability; To discuss the advantages and disadvantages for various boundry condition treatment for flow-based methods, including sealed-side boundary conditions, open-side boundary conditions, or periodic boundary conditions, etc.
2	Sun 06/17/2018	[Eid Al-Fitr break]
2	Tue 06/19/2018	[Eid Al-Fitr break]
3	Sun 06/24/2018	To establish the framework of oversampling techniques for flow-based methods; To investigate local upscaling, regional upscaling and global upscaling approaches.
3	Tue 06/26/2018	To introduce the effective medium theory (sometimes abbreviated as EMT or EMA), which was conventionally applied to the analytical or theoretical modeling of macroscopic properties of composite materials; To discuss how EMT can be applied to Darcy flow.
4	Sun 07/01/2018	To establish Galerkin weak formulation for Darcy flow; To formulate Galerkin finite element methods; To introduce the variational principle for Darcy flow; To present variational multiscale finite element methods.
4	Tue 07/03/2018	To establish mixed weak formulation for Darcy flow; To formulate mixed finite element (MFE) methods; To introduce a number of popoular MFE spaces, especially the Raviart-Thomas spaces; To discuss the two major advantages of MFE, i.e. local mass conservation and high-order velocity accuracy; To presen mixed multiscale finite element methods.
5	Sun 07/08/2018	To introduce discontinuous Galerkin methods for Darcy flow, especially the four Interior Penalty Galerkin methods; To discuss mesh adaptation of discontinuous Galerkin methods; To formulate multiscale discontinuous Galerkin methods for Darcy flow.[Student presentation of scientific review articles]
5	Tue 07/10/2018	To review spectral decompositionof a matrix, and singular-value decomposition (SVD) of a matrix; To introduce Proper Orthogonal Decomposition (POD) with its engineering motivation and mathematical background; To apply Proper Orthogonal Decomposition (POD) to the global model reduction of geological reservoirs. [Student presentation of scientific review articles]
6	Sun 07/15/2018	To introduce the homogenization of elliptic equations with oscillatory coefficients: 1) one-dimensional problems; 2) heuristic homogenization; 3) multiscale asymptotic expansions.
6	Tue 07/17/2018	To cover homogenization with slowly varying periodic coefficients, homogenization of parabolic equations, and homogenization of convection-diffusion equation.
7	Sun 07/22/2018	To present numerical homogenization of elliptic equations, numerical homogenization of parabolic equations, numerical homogenization of Stokes equations, as well as hierarchical upscaling.
7	Tue 07/24/2018	To introduce Generalized Multiscale Finite Element Methods (GMsFEM) and to present the setup of GMsFEM and how to generate local multiscale basis functions (offline stage): 1) Generating snapshots by solving local problems, and 2) Generating the offline space by solving auxiliary local engenvalue problems.
8	Sun 07/29/2018	To discuss the GMsFEM procedure of computing online multiscale basis functions via local eigenvalue problems; To investigate different gloabl coupling schemes forGMsFEM: 1) Galerkin coupling, 2) Petrov-Galerkin coupling, and 3) Discontinuous Galerkin coupling. If time allows, we will also cover the Discrete Empirical Interpolation Method (DEIM) and the Generalized Empirical Interpolation Method (GEIM).
8	Tue 07/31/2018	To review a number of single-scale and multi-scale modeling approaches for flow in subsurface formation with fractures, which include single-domain single-continuum models, the dual-porosity model, the dual-porosity dual-permeability model, multiple-continuum models, dimension-reduced discrete fracture models, fractional derivative non-Darcy models, and the model reduction of fractured porous media using GMsFEM.
9	Sun 08/05/2018	To extend upscaling approaches and multiscale model reduction approaches from single-phase Darcy flow to two-phase flow and multiphase flows in geological reservoirs; To extend various multiscale approaches to the simulation of multicomponent transport. [Student presentation of course projects]
9	Tue 08/07/2018	To review various pore-scale modeling and simulation techniques, which include the Bundle of Capillary Tube Modeling (BCTM), Direct Pore Scale Modeling (DPSM) and Pore Network Modeling (PNM); To review a number of Molecular Dynamcis (MD) simulation and Monte Carlo (MC) molecular simulation techniques for unconventional subsurface reserviors; To discuss potential coupling of subsurface flow across various scales. [Student presentation of course projects]

Note

The instructor reserves the right to make changes to this syllabus as necessary.