University of Tehran
School of Civil Engineering

Course:	**8102… - Multiscale Analysis**		
Course type:	Optional		Credit: 3
Level:	PhD (can be attended by MSc students)		
Co-requisite(s):			
Prerequisite(s):			
Prerequisite by topic:			
Textbook(s):	[1] Analysis, Modeling and Simulation of Multiscale Problems; A. Mielke (Ed.), Springer, 2006. [2] Computational Dislocation Dynamics; N.M. Ghoniem, 1990. [3] Computational Mesomechanics of Composites; L. Mishnaevsky Jr, Wiley, 2007. [4] Crystals, Defects and Microstructures, Modeling Across Scales; R. Phillips, Cambridge University Press, 2004. [5] Foundations of Nanomechanics: From Solid-State Theory to Device Applications; A.N. Cleland, Springer, 2003. [6] Introduction to Computational Micromechanics; I.T. Zohdi, P. Wriggers, Springer, 2005. [7] IUTAM Symposium on Multiscale Problems in Multibody System Contacts; P. Eberhard (Ed.), Proceedings of the IUTAM Symposium, Stutgart, Germany, 2006, Springer. [8] Multiscale Finite Element Methods - Theory and Applications; Y. Efendiev, T.Y. Hou, Springer, 2009. [9] Multi Scale Materials Modelling; P. Gumbsch (Ed.), 3rd International Conference, Freiburg, Germany, 2006. Symposium 2: Nanomechanics and Micromechanics. and Symposium 9: Matterials for Micro-Electro-Mechanical Systems, MEMS. [10] Multi Scale Materials Modelling, Fundamentals and Applications; Z.X. Guo (Ed.), Woodhead Publishing Limited, 2007. [11] Multiscale Modeling - A Bayesian Perspective; M.A.R. Ferreira, H.K.H. Lee, Springer, 2007. [12] Nano Mechanics and Materials: Theory, Multiscale Methods and Applications; W.K. Liu, E.G. Karpov, H.S. Park, Wiley, 2006. [13] D. J. Griffiths, *Introduction to Electrodynamics*. New Jersey: Prentice-Hall, 3rd edition,1999, ch. 1 to 7.		
Coordinator:	S. Mohammadi, Professor of Computational Mechanics, School of Civil Engineering		
Goals:	Most problems in science involve many scales in time and space. An example is the overall stress state in a solid cracked beam which can		

	well be described by macroscopic continuum equations, but requires details on a microscale at the tip of the crack. Another example is the turbulent flow where important large scale quantities such as lift and drag of a wing depend on the behavior of the small vortices in the boundary layer. A common difficulty with the simulation of these problems and many others in physics, chemistry, engineering and biology is that an attempt to represent all scales will lead to an enormous computational problem with unacceptably long computation times and huge memory requirements. Hence, the derivation of coarse models from well accepted fine-scale models is one of the most challenging fields. A proper understanding of the interaction of effects on different spatial and temporal scales is of fundamental importance for the effective description of such structures. The central question arises as to which information from the small scales is needed to describe the large-scale effects correctly. The method can efficiently be used to simulate complex behaviours in a wide range of applications from aerospace industry to civil and mechanical fracture analysis and to nano-scale problems and bio-engineering applications.
Outcome:	Upon successful completion of the course, students will be able 1. to become familiar with basic physical principles at various analytical scales 2. to obtain mathematical formulation for modeling a typical engineering problem at any single analytical scales 3. to develop numerical algorithms for coupling multiple scales and to transform information from one scale to another one. 4. to use numerical methods for solving problems of various engineering fields that are vulnerable to singularities and discontinuities in time or space or both 5. to develop simple numerical codes to analyse multiple scale simulations
Topics:	1. Introduction to Multiscale Simulation a. Engineering Applications (including Crack Analysis, Shear Bands, Localisation and Plasticity, Phase Changes, Climate Change, Flow in Porous Media, Heterogeneous and Fractured Oil/Gas Reservoirs, Bio-Engineering) b. Mathematical/Fundamental Physical Applications (Solid State Physics, Astrophysics, Quantum Chemistry, Molecular Biology) c. Super/Parallel Computing d. Advanced Topics 2. Single Scale Simulations a. Macroscale (Continuum) Analysis, A Brief Review (1 unit) (including Finite Element Method, Meshless Methods, Particle Methods and Discrete Elements, Etc.) b. Mesoscale Analysis (Fibre/Matrix interactions, Bonding) c. Microscale Analysis (MicroMechanics, Dislocation Dynamics, Periodic Boundary Conditions) d. Nanoscale Analysis (Molecular Dynamics, Lattice Mechnaics, Uncertainty Principle, Nano Materials, Nano Tubes, Periodic Boundary Conditions) 3. Multi Scale Simulations

	a. A review of available techniques i. Bridging Scale Method ii. Bridging Domain Method iii. Quasi Continuum Method iv. Homogenization Techniques v. Heterogeneous Multiscale Method vi. Wavelet Based Techniques vii. Explicit and Implicit Schemes viii. Multiscale Boundary Conditions b. Macro/Micro Models c. Micro/Nano Models d. Macro/Nano Models e. Macro/Micro/Nano Models f. Bio-Nano Interfaces g. Multiscale Finite Element Method h. Multiscale Meshless Methods i. Multiscale XFEM 4. Advanced Topics a. Time Scales b. Multiscale Contact Analysis **c.** Adaptive Multiscale Simulations
Computer usage:	
Assignments:	15 homework assignments (theoretical essays and short numerical programmings)
Projects:	Final Project (At least 5 weeks of numerical research by each student)
Grading:	Assignments: 30 % Project: 40 % Final exam: 30 %
Further readings:	[1] Nanomechanics of Materials and Structures; T.J Chuang, P.M. Anderson, M.K. Wu, S. Hsieh (Eds.), Springer, 2006. [2] Multiscale Simulation Methods for Nanomaterials; R.B. Ross, S. Mohanty, Wiley, 2008. [3] Theory of Dislocations, 2nd Edition; J.P. Hirth, J. Lothe, Wiley, 1992. [4] Modelling Molecular Structures, 2nd Edition; A. Hinchliffe, Wiley, 2000.
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