POLITECNICO DI MILANO

PhD in MODELLI E METODI MATEMATICI PER L'INGEGNERIA / MATHEMATICAL MODELS AND METHODS IN ENGINEERING - 41st cycle

THEMATIC Research Field: OPERATOR LEARNING FOR COUPLED PROBLEMS WITH APPLICATION TO SUBSURFACE MODELING

Monthly net income of PhDscholarship (max 36 months)
€ 1400.0 In case of a change of the welfare rates during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	Operator learning is a novel and highly effective technique for approximating differential problems using high-fidelity data or high-fidelity approximations. It has proven to be particularly efficient for solving both forward and inverse problems. The aim of this thesis is to explore the use of operator learning to develop upscaled differential models for subsurface flow in the presence of significant heterogeneities and fracture networks.
Methods and techniques that will be developed and used to carry out the research	Operator learning is an emerging paradigm aimed at approximating mappings between infinite-dimensional spaces, such as those associated with partial differential equations (PDEs). By leveraging machine learning, particularly neural operator architectures, operator learning provides a supervised framework to address computational challenges in scientific and engineering problems where traditional approximation methods struggle due to high dimensionality or complexity (N. Boullè A. Townsend, A Mathematical guide to operattor learning, Handbook of Numerical Analysis, 25:83-125, 2024, Andrew M. Stuart, Nicholas H. Nelsen. Operator Learning Using Random Features: A Tool for Scientific Computing. SIAM Review, 66(3):737–776, 2024).The objective of this thesis project is to study and analyse possible estensions of operator learning architectures to time-dependent coupled problems, improve sample

	efficiency and integrate operator learning with physical models to ensure interpretability and reliability. The target application is modeling subsurface problems to enable more sustainable exploitation of subsurface resources and CO_2 sequestration. The heterogeneity of the subsoil and the presence of fractures at varying length scales make the study of underground flow highly complex and computationally expensive. Standard upscaling techniques, whether analytical or numerical, often fail to produce reliable and cost-effective models. However, well-established high-fidelity models are available, which can be used to leverage numerical high-fidelity results for constructing an upscaled differential model through the novel operator learning architectures analysed in this study.
Educational objectives	The student will get acquainted with state of the art techniques for simulation of complex problems and develop skills to critically analyse operator learning architectures and apply them to physically relevant contexts. He will acquire skill in scientific computing, machine learning, and numerical approximation of partial differential problems.
Job opportunities	The profile proposed here are broadly relevant for a range of employers including (but not limited to): renewable energy providers, research centers, consulting or high-tech companies. The skill acquired are also propaedeutic for an academic career.
Composition of the research group	2 Full Professors 2 Associated Professors 1 Assistant Professors 0 PhD Students
Name of the research directors	Proff. Luca Formaggia e Paolo Zunino

Contacts
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Additional support - Financial aid per PhD student per year (gross amount)			
Housing - Foreign Students	**1st year**	**2nd year**	**3rd year**

	1500.0 € per student	0.0 € per student	0.0 € per student
	max number of financial aid available: 1, given in order of merit ..		
Housing - Out-of-town residents	--		

Scholarship Increase for a period abroad	
Amount monthly	700.0 €
By number of months	6

Additional information: educational activity, teaching assistantship, computer availability, desk availability, any other information
Educational activities (purchase of study books and material, funding for participation to courses, summer schools, workshops and conferences): financial aid per PhD student per year 1st year: max 1.902,40 euros per student 2nd year: max 1.902,40euros per student 3rd year: max 1.902,40 euros per student. The PhD students are encouraged to take part in activities related to teaching, within the limits allowed by the regulations. 1 individual PC per student +several shared PC, as well as access to Departmental high performance cluster and the computer resources available through the CINECA consortium.