TIME TABLE

TIME	Monday	Tuesday	Wednesday	Thursday	Friday
	September 29	September 30	October 1	October 2	October 3
09.00 - 09.45	Registration	Schoenlieb	Mohr	Kowachki	Bhattacharya
09.45 - 10.30	DeSimone	Schoenlieb	Mohr	Kowachki	Bhattacharya
11.00 - 11.45	Bhattacharya	Kowachki	Stainier	Schoenlieb	DeSimone
11.45 - 12.30	DeSimone	Kowachki	Stainier	Schoenlieb	DeSimone
14.00 - 14.45	DeSimone	Mohr	Kowachki	Stainier	
14.45 - 15.30	Bhattacharya	Mohr	Kowachki	Stainier	
16.00 - 16.45	Bhattacharya	Stainier	Schoenlieb	Mohr	
16.45 - 17.30	Poster Bites	Stainier	Schoenlieb	Mohr	
18.00	Welcome aperitif				

ADMISSION AND ACCOMMODATION

The course is offered in a hybrid format, allowing participants the flexibility to attend either in person or remotely via the Microsoft Teams platform. Admission to on-site attendance is granted on a first-come, first-served basis to comply with the capacity of the lecture room.

Registration fees:

- **Early Bird On-Site Participation: € 650.00 + VAT***
  Deadline: July 29, 2025
- **Late On-Site Participation: € 800.00 + VAT***
  Deadline: September 16, 2025
- **Live Streaming Online Participation: € 250.00 + VAT***
  Deadline: September 16, 2025

On-site participation includes a complimentary bag, five fixed menu buffet lunches, hot beverages, downloadable lecture notes.
Online participation includes downloadable lecture notes.

Application forms should be submitted online through the website: http://www.cism.it. A confirmation message will be sent to participants whose applications are accepted.
Upon request, and subject to availability, a limited number of on-site participants can be accommodated at the CISM Guest House for € 35 per person per night. To request accommodation, please contact foresteria@cism.it.

** where applicable; bank charges are not included - Italian VAT is 22%.*

CANCELLATION POLICY

Applicants may cancel their registration and receive a full refund by notifying the CISM Secretariat in writing (via email) no later than:
- July 29, 2025, for early bird on-site participation;
- August 29, 2025, for late on-site participation;
- September 16, 2025, for online participation.

No refunds after the deadlines. Cancellation requests received before these deadlines and incorrect payments will be subject to a € 50.00 handling fee.

CISM GRANTS

A limited number of participants from universities and research centers who do not receive support from their institutions can request a waiver of the registration fee and/or free lodging. Requests should be sent to the CISM Secretariat by **July 29, 2025**, along with the applicant's curriculum vitae and a letter of recommendation from the head of the department or a supervisor confirming that the institute cannot provide funding. Preference will be given to applicants from countries that sponsor CISM.

For further information please contact:
CISM (Seat of the course)
Palazzo del Torso - Piazza Garibaldi 18 - 33100 Udine (Italy)
tel. +39 0432 248511 (6 lines)
e-mail: cism@cism.it | www.cism.it

ACADEMIC YEAR 2025
The J. L. Ericksen Session
Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences

CISM motus est vita

MACHINE LEARNING FOR SOLID MECHANICS

CISM-AIMETA Advanced School
coordinated by

Kaushik Bhattacharya
California Institute of Technology
Pasadena, USA

Antonio De Simone
Scuola Superiore Sant'Anna
Pisa, Italy

Udine *September 29 - October 3* 2025

MACHINE LEARNING FOR SOLID MECHANICS

Recent progress in artificial intelligence techniques has delivered tools to solve complex and very high dimensional optimization problems that allow to discover correlations in large data sets, and hence to extract features and patterns from measurements or simulations of complex phenomena.

Applications of these machine learning techniques to the field of solid mechanics range from the identification of constitutive equation from full-field time-dependent measurements, to machine learning techniques for the regularization of ill-posed inverse problems in imaging and control, and to the automatic discovery of reduced order models recapitulating the main features of observed patterns in complex multi-physical systems, thanks to the automatic discovery of hidden structures and symmetries in nonlinear dynamical systems.

Building upon some introductory lectures on the mathematical foundations of machine learning and on the basic computational tools required, these recent and potentially revolutionary approaches to long standing problems in nonlinear solid mechanics will be discussed in the context of specific case studies from engineering applications.

We plan to cover the fundamental mathematical background of machine learning techniques to explain and rationalize the reasons for their success, to illustrate the possibility of automated discovery of dimensionally-reduced hidden structures and symmetries in solid mechanics problems, and to illustrate the potential of machine learning techniques in the context of application to specific classes of material systems ranging from metals, to polymers, to granular materials.

The school will be structured according to the following plan:

Mathematical background to neural networks and neural operators.

Lectures by Carola Schönlieb (Cambridge) and Nikola Kovachki (Nvidia/NYU).

Discovery of internal variables and invariant manifolds in history-dependent phenomena

Lectures by Antonio DeSimone (SISSA/Pisa) and Kaushik Bhattacharya (Caltech).

Learning from experimental data and connections to numerical methods.

Lectures by Dirk Mohr (ETH) and Laurent Stainier (Nantes).

PRELIMINARY SUGGESTED READINGS

Gilbert Strang, Linear Algebra and learning form data, Wellesley-Cambridge Press 2019.

Tamara Grossmann et al.: Can physics-informed neural networks beat the finite element method?
IMA Journal Applied Mathematics (2024) 89, 143-174.

Kaushik Bhattacharya et al.: Learning homogenization for elliptic operators, SIAM Journal on Numerical Analysis 62 (4), 1844-1873.

P. Carrara et al.; Data-driven fracture mechanics. Computer Methods in Applied Mechanics and Engineering 372, 113390 (2020).

J. Ulloa et al.: Data-driven micromorphic mechanics for materials with strain localization. arXiv preprint arXiv:2402.15966.

A. Leygue et al.: Data-based derivation of material response. Comput. Methods Appl. Mech. Engrg., 331, pp. 184-196 (2018).

A. Leygue et al.: Non-parametric material state field extraction from full field measurements. Computational Mechanics 64:501-509 (2019).

L. Stainier et al.: Model-free data-driven methods in mechanics: material data identification and solvers. Computational Mechanics 64:381-393 (2019).

LECTURES

All lectures will be given in English. Lecture notes can be downloaded from the CISM web site. Instructions will be sent to accepted participants.

INVITED LECTURERS

Kaushik Bhattacharya - California Institute of Technology, Pasadena, CA, USA
5 lectures on: Learning history-dependent multi-scale phenomena:
History-dependent multi-scale phenomena in continuum mechanics; Internal variables and gradient flows; Recurrent neural operators; Application to experimental learning of constitutive behavior; Application to polycrystalline plasticity.

Antonio De Simone - Scuola Superiore Sant'Anna, Pisa, Italy
5 lectures on: Mesh-free discretization and model reduction in time-dependent problems:
Oscillatory instabilities in the mechanics of solids; Analytical and computational techniques for model reduction in nonlinear dynamical systems; Center manifold theory; Mesh-free methods based on PINNs; Applications to self-oscillating active elastic systems and light-activated Liquid Crystal Elastomers.

Carola Bibiane Schoenlieb - University of Cambridge, UK
6 lectures on: The mathematical bases of machine learning and neural networks and on their use in image analysis and in the solution of inverse problems in the mechanics of solids:
Mathematical operators and applications; Learning an operator from data; Neural networks for operator learning: Fourier neural operator, PINNs; Structure-preserving learning with neural networks; Inverse problems and applications; Learning an inverse operator.

Nikola Kovachki - Nvidia Research Labs, Pasadena, CA, USA
6 lectures on: Learning Solution Operators for the PDEs of Solid Mechanics:
Neural Networks and Deep Learning; Approximation Theory of Neural Networks; Operator Learning; Approximation Theory of Neural Operators; Homogenization of Elliptic Equations; Data-driven Approximation of Crystal Plasticity.

Dirk Mohr - ETH Zurich, Switzerland
6 lectures on: Artificial Intelligence techniques in optimal design problems in the Mechanics and Manufacturing of Lightweight Solid Materials.

Laurent Stainier - Ecole Centrale de Nantes, France
6 lectures on: The use of machine learning in the extraction of constitutive equations from experimental data:
Constitutive model-free data-driven computational mechanics (DDCM): from non-linear elasticity to history-dependent material response; Model free data-driven identification (DDI) from field measurements and elastography; DDCM driven concurrent multiscale simulations and goal-oriented data sampling/discovery. Examples and applications will include nonlinear (hyper-)elasticity, damage, viscoelasticity of polymers, plasticity of granular materials.