

TIME TABLE

TIME	Monday July 8	Tuesday July 9	Wednesday July 10	Thursday July 11	Friday July 12
09.00 - 09.45	Registration	Reis	Ravi-Chandar	Reis	Kuhl
09.45 - 10.30	De Simone	Reis	Ravi-Chandar	Reis	Kuhl
11.00 - 11.45	De Simone	Goriely	De Lorenzis	Kuhl	Goriely
11.45 - 12.30	De Simone	Goriely	De Lorenzis	Kuhl	Goriely
14.00 - 14.45	Reis	De Lorenzis	Goriely	Ravi-Chandar	
14.45 - 15.30	Reis	De Lorenzis	Goriely	Ravi-Chandar	
16.00 - 16.45	Ravi-Chandar	De Simone	Kuhl	De Lorenzis	
16.45 - 17.30	Ravi-Chandar	De Simone	Kuhl	De Lorenzis	
18.00	Welcome aperitif				

ADMISSION AND ACCOMMODATION

The course is offered in a hybrid format giving the possibility to attend the course also by remote (on Microsoft Teams platform). On-site places are limited and assigned on first come first served basis.

The registration fees are:

- On-site participation, 600.00 Euro + VAT*

This fee includes a complimentary bag, five fixed menu buffet lunches, hot beverages, downloadable lecture notes.

Deadline for on-site application is June 8, 2024.

- Live Streaming Online participation, 250.00 Euro + VAT*

This fee includes downloadable lecture notes.

Deadline for online application is June 26, 2024.

Application forms should be sent on-line through the following web site: <http://www.cism.it>

A message of confirmation will be sent to accepted participants.

Upon request a limited number of on-site participants can be accommodated at CISM Guest House at the price of 35 Euro per person/night (mail to: 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 CISM Secretariat in writing (by email) no later than:

- June 8, 2024 for on-site participants (no refund after the deadline);
- June 26, 2024 for online participants (no refund after the deadline).

Cancellation requests received before these deadlines will be charged a 50.00 Euro handling fee. Incorrect payments are subject to Euro 50,00 handling fee.

GRANTS

A limited number of participants from universities and research centres who are not supported by their own institutions can request the waiver of the registration fee and/or free lodging.

Requests should be sent to CISM Secretariat by **May 8, 2024** along with the applicant's curriculum and a letter of recommendation by 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

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e-mail: cism@cism.it | www.cism.it



MECHANICS OF ACTIVE AND BIOLOGICAL STRUCTURES: FROM FUNDAMENTALS TO RECENT RESULTS

10th CISM-AIMETA Summer School
coordinated by

Antonio De Simone
Scuola Superiore Sant'Anna
Pisa, Italy

Pedro Reis
Ecole Polytechnique Fédérale
Lausanne, Switzerland



Udine July 8 - 12 2024

MECHANICS OF ACTIVE AND BIOLOGICAL STRUCTURES: FROM FUNDAMENTALS TO RECENT RESULTS

The aim of this course is to provide participants with a fast track to frontier research of great contemporary interest starting from the revisiting of foundational aspects of the Mechanics of Solids and Structures. The course primarily targets beginning graduate students and young researchers who want to get an accelerated introduction to recent progress in the analysis of the response and failure of advanced materials and active systems, including biological ones.

A. De Simone and P. Reis will lecture on the mechanics of slender structures (rods, plates and shells), both active and passive, and applications to adaptive structures and to soft and bioinspired robotics. L. De Lorenzis and K. Ravi-Chandar will lecture on Fracture Mechanics, from modern experimental and theoretical foundations to recent advances on phase-field modeling and computation, and applications to biological tissues and porous media.

PRELIMINARY SUGGESTED READINGS

D. Agostinelli, A. Lucantonio, G. Noselli, and A. De Simone: Nutations in growing plant shoots: the role of elastic deformations due to gravity loading. *J Mech Phys Solids* 136, 103702 (2020).

G. Cicconofri and A. De Simone: Snake-like locomotion through the analysis of a flexible robot model. *Proc Roy Soc London A*, 471 (2184), 20150054 (2015).

A. Goriely: The mathematics and mechanics of biological growth.

A. Goriely and Ellen Kuhl will lecture on the mechanobiology of growth and morphogenesis, and applications to quantitative modeling of the human brain.

The detailed plan of the lectures is the following.

Mechanics of 2d rods from Euler's elastica to robotic arms and elephant trunks (ADS)

Kinematics and equilibrium of active planar rods in the large deformation regime; variational methods: the principle of virtual power and the finite element method. Applications 1: shape control of structural systems with cables and tendons; applications 2: shape control through active bending (snakes and elephant trunks); applications 3: spontaneous oscillations in biological filaments and growing plant shoots.

Mechanics of 3d rods, plates and shells (PR)

Mechanics of rods – Kirchhoff's rod theory: Kinematics & Equilibrium. Examples and Applications;

Springer 2017.

B. Audoly and Y. Pomeau, *Elasticity and geometry: from hair curls to the non-linear response of shells*, Oxford University Press, 2010.

P.M. Reis, "A Perspective on the Revival of Structural (in)stability with Novel Opportunities for Function: from Buckliphobia to Buckliphilia" *J. App. Mech.*, 82, 111001 (2015).

A. Lee, F. López Jiménez, J. Marthelot, J.W. Hutchinson, and

Plates I: Pure bending deformation. Wrinkling; Plates II: Föppl-von Kármán (nonlinear) theory of plates. Plate buckling; Shells I: Linear pressure vessels, A primer on differential geometry, Dimensional reduction (3D-2D). Linear shell theory; Shells II: Nonlinear DMV shell theory. Shell buckling; Magneto-active Rods, Plates, and Shells.

Fracture Mechanics (KRC)

Griffith theory of fracture – the global approach; Engineering fracture mechanics – the local approach; Experimental fracture mechanics; Mixed-mode fracture – crack path selection; Elastic plastic fracture; Dynamic fracture.

Variational phase-field modeling of fracture (LDL)

The variational approach to brittle fracture; the phase-field regularization: main modeling components; crack nucleation vs. propagation, energy decomposition; computational aspects; phase-field modeling of ductile fracture; applications to anisotropic tissues and porous media.

P.M. Reis, "The geometric role of precisely engineered imperfections on the critical buckling load of spherical elastic shells" *J. Appl. Mech.*, 83, 111005 (2016).

Budday S, Ovaert TC, Holzapfel GA, Steinmann P, Kuhl E. Fifty shades of brain: A review on the material testing and modeling of brain tissue. *Arch Comp Meth Eng*. 2020; 27:1187–1230.

K. Ravi-Chandar, (2023) *Introduction to Fracture Mechanics*,

The mathematics and mechanics of biological growth (AG)

The problem of growth; Growing in 1D: rods and filaments; Growing in 2D: membranes, plates, and shells; Growing in 3D: nonlinear elasticity and theory; Growing in 3D: applications (plants, arteries, and the brain); From 3D to 1D: dimensional reduction with applications.

Integrating mechanics and computation to understand the human brain (EK)

Introduction to Neuromechanics; Elasticity of the brain - Characterizing brain stiffness dead and alive; Growth of the brain; Understanding neurodevelopment; Damage of the brain - Traumatic brain injury and neurodegeneration; Machine learning and the brain; Integrating neuroimaging and mechanics. - Automated model discovery - Learning models for human brain.

in *Mechanics and Physics of Fracture*, Editor: L. Ponsón, CISM International Centre for Mechanical Sciences 608, https://doi.org/10.1007/978-3-031-18340-9_1.

L. De Lorenzis, T. Gerasimov (2020), *Numerical Implementation of Phase-Field Models of Brittle Fracture*. In: *Modeling in Engineering Using Innovative Numerical Methods for Solids and Fluids*, CISM – International Center for Mechanical Sciences – Courses and Lectures, 599: 75-101.

INVITED LECTURERS

Antonio De Simone - Scuola Superiore Sant'Anna, Pisa, Italy

5 lectures on:

Mechanics of 2d rods from Euler's elastica to robotic arms and elephant trunks.

Laura De Lorenzis - ETH Zurich, Switzerland

6 lectures on:

Variational phase-field modeling of fracture.

Alain Goriely - University of Oxford, UK

6 lectures on:

The mathematics and mechanics of biological growth.

Ellen Kuhl - Stanford University, USA

6 lectures on:

Integrating mechanics and computation to understand the human brain.

Krishnaswamy Ravi-Chandar - University of Texas at Austin, USA

6 lectures on:

Fracture Mechanics.

Pedro Reis - Ecole Polytechnique Fédérale de Lausanne Switzerland

6 lectures on:

Mechanics of 3d rods, plates and shells.

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.