

TIME TABLE

TIME	Monday September 28	Tuesday September 29	Wednesday September 30	Thursday October 1	Friday October 2
9.00 - 9.45	Registration	Dias-da-Costa	Rabczuk	Lava	Pierron
9.45 - 10.30	Bordas	Dias-da-Costa	Rabczuk	Lava	Rabczuk
11.00 - 11.45	Kerfriden	Dias-da-Costa	Kerfriden	Dias-da-Costa	Bordas
11.45 - 12.30	Kerfriden	Dias-da-Costa	Kerfriden	Pierron	Bordas
14.00 - 14.45	Kerfriden	Dias-da-Costa	Lava	Pierron	Pierron
14.45 - 15.30	Bordas	Rabczuk	Lava	Pierron	Pierron
16.00 - 16.45	Bordas	Rabczuk	Lava	Pierron	Pierron
16.45 - 17.30	Bordas	Rabczuk	Lava	Pierron	Pierron

ADMISSION AND ACCOMMODATION

The registration fee is of 575,00 Euro + VAT taxes*, where applicable (bank charges are not included).

The registration fee includes a complimentary bag, four fixed menu buffet lunches (Friday subject to numbers), hot beverages, downloadable lecture notes and wi-fi internet access.

Applicants must apply at least one month before the beginning of the course. Application forms should be sent on-line through our web site: <http://www.cism.it> or by post.

A message of confirmation will be sent to accepted participants. If you need assistance for registration please contact our secretariat.

Applicants may cancel their course registration and receive a full refund by notifying CISM Secretariat in writing (by email) no later than two weeks prior to the start of the course.

If cancellation occurs less than two weeks prior to the start of the course, a Euro 50,00 handling fee will be charged. Incorrect payments are subject to Euro 50,00 handling fee.

A limited number of participants from universities and research centres who are not supported by their own institutions can be offered board and/or lodging in a reasonably priced hotel or students' dormitories, if available.

Requests should be sent to CISM Secretariat by **July 28, 2015** 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.

Information about travel and accommodation is available on our web site, or can be mailed upon request.

Please note that the Centre will be closed for summer vacation the first three weeks in August.

* Italian VAT is 22%.

For further information please contact:

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Piazza Garibaldi 18
33100 Udine (Italy)
tel. +39 0432 248511 (6 lines)
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Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences
ACADEMIC YEAR 2015
The Villaggio Session

MODELLING, SIMULATION AND CHARACTERIZATION OF MULTI-SCALE HETEROGENEOUS MATERIALS

CISM-ECCOMAS International Summer School
coordinated by

Daniel Dias-da-Costa
The University of Sydney - Australia
and
University of Coimbra - Portugal

Stéphane Bordas
University of Luxembourg
and
Cardiff University - Wales UK

Sponsored by:



Udine Sept. 28 - Oct. 2 2015

MODELLING, SIMULATION AND CHARACTERIZATION OF MULTI-SCALE HETEROGENEOUS MATERIALS

A central topic in mechanics consists in building “virtual laboratories” to optimise heterogeneous materials so as to achieve specific targets. This requires building constitutive models on one or more scales, devising and verifying well-suited numerical schemes to solve the resulting mathematical problems numerically and, most importantly, to design and optimise experimental techniques to ensure the observability of relevant quantities, and validate the models. Materials are heterogeneous or even discrete at some scale. Those heterogeneities can be accounted for either by averaging properties at smaller scales, or by considering explicitly the micro/meso structures of the materials. However, when failure occurs, it is no longer possible to separate micro from macro effects and more advanced strategies are required, such as error-controlled adaptive model order reduction or adaptive hybrid multi-scale methods.

Discretising the heterogeneities, cracks, dislocations and defects can be cumbersome using standard finite element methods (FEM). Enrichment and implicit boundary strategies can be applied to deal with complex and evolving boundaries/geometries, whereas other approaches aim at completely abolishing the need for finite element meshes. This class of mesh-free methods can be particularly appealing, since full-field monitoring techniques typically measure data on scattered sets of points that can be directly used for simulation purposes. Sharing some appealing properties with mesh free methods, isogeometric methods were recently introduced with the aim to simplify the design-through analysis concept and were recently used for digital image correlation. Such full-field techniques, used to measure material deformation, have brought up a revolution in mechanical testing of materials. The visualisation of deformation maps enables researchers to naturally address heterogeneities.

In particular, the Digital Image Correlation (DIC) and grid-based methods are particularly appealing thanks to their simplicity and reasonably low cost. There are also techniques to measure deformation in the bulk of materials, such as Digital Volume Correlation (DVC). The identification of material parameters from such full-field kinematic measurements can be done using finite element model updating for material parameter identification. An alternative technique called the Virtual Fields Method (VFM) relies on global equilibrium equations and efficiently deals with parameter identification of non-linear constitutive laws or heterogeneous materials. Furthermore, this approach relaxes strong constraints on specimen shape and load, opening the possibility of a very large design space for novel experimental procedures. The course will include carefully crafted presentations covering in detail all these aspects, providing a comprehensive overarching

framework for experimental, numerical and theoretical mechanics of heterogeneous materials. After the course the participant will be able to:

- (1) select suitable models, implement discretisation techniques and solution algorithms for non-linear multi-scale problems for heterogeneous materials;
- (2) verify the numerical methods and validate the material models by a combination of a posteriori error estimation and advanced experimental techniques for heterogeneous materials;
- (3) develop and optimise suitable experimental techniques to observe phenomena of interest, identify material properties and characterise heterogeneous materials.

The course is addressed to doctoral students and postdoctoral researchers in mechanical, civil, material science, applied physics and applied mathematics, academic and industrial researchers.

INVITED LECTURERS

Stéphane Bordas - University of Luxembourg, Luxembourg and Cardiff University, Wales, UK
6 lectures on: Discretisation schemes for heterogeneous materials and free boundary problems. FEM and enriched iso-geometric analysis. Partition of unity enrichment for finite elements, meshless methods and isogeometric methods, with a focus on the treatment of discontinuities, singularities and boundary layers. A posteriori error estimation. [Website:](http://www.en.uni.lu/recherche/fstc/research_unit_in_engineering_science_rues/members/stephane_bordas) http://www.en.uni.lu/recherche/fstc/research_unit_in_engineering_science_rues/members/stephane_bordas

Daniel Dias-da-Costa - The University of Sydney, Australia and University of Coimbra, Portugal
6 lectures on: Quasi-brittle materials, discrete fracture, nodal and element enrichment strategies, finite elements with conforming embedded discontinuities, non-iterative algorithms for highly non-linear problems, monitoring of concrete structures. [Website:](http://sydney.edu.au/engineering/people/daniel.diasdacosta.php) <http://sydney.edu.au/engineering/people/daniel.diasdacosta.php>

Timon Rabczuk - Bauhaus-Universität Weimar, Germany
6 lectures on: Meshfree methods. Global weak forms, weighted residuals and local weak forms. Meshless shape functions. Integration and imposition of essential boundary conditions. Coupling to finite element methods. Enrichment strategies in meshless methods. Application to fracture and fluid-structure interactions. [Website:](http://www.uni-weimar.de/Bauing/rabczuk) <http://www.uni-weimar.de/Bauing/rabczuk>

Pierre Kerfriden - Cardiff University, Wales, UK
5 lectures on: Heterogeneous materials, modelling simulation with and without separation of scales. Modelling and discretisation approaches to rationalise computational expenses. Goal oriented error and adaptivity for multiscale and reduced order modelling. [Website:](http://www.engin.cf.ac.uk/whoswho/profile.asp?RecordNo=687) <http://www.engin.cf.ac.uk/whoswho/profile.asp?RecordNo=687>

Fabrice Pierron - University of Southampton, UK
6 lectures on: Virtual work and integral equilibrium equations. Linear and non-linear Virtual Fields Method. Extension to heterogeneous materials and force identification. Test design for heterogeneous materials. [Website:](http://www.southampton.ac.uk/engineering/about_staff/fp1m09.page) http://www.southampton.ac.uk/engineering/about_staff/fp1m09.page

Pascal Lava - KU Leuven, Belgium
6 lectures on: Digital image correlation 2D and 3D, Basic principles, matching, interpolation and shape functions. How to assure a good experiment and uncertainty quantification. Post-processing data and deriving strains. Applications in material identification, structural testing and biomedicine. [Website:](http://www.kuleuven.be/wieiswie/en/person/00059301) <http://www.kuleuven.be/wieiswie/en/person/00059301>

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.

PRELIMINARY SUGGESTED READINGS

Pierron, F., Grédiac, M., The Virtual Fields Method: Extracting Constitutive Mechanical Parameters from Full-field Deformation Measurements, Springer, 2012 (doi: 10.1007/978-1-4614-1824-5).

Graça-e-Costa, R., et al., Generalisation of non-iterative methods for the modelling of structures under nonproportional loading, International Journal of Fracture, 182(1):21-38, 2013 (doi: 10.1007/s10704-013-9851-2).

Dias-da-Costa, D., et al., An embedded formulation with conforming finite elements to capture strong discontinuities, International Journal for Numerical Methods in Engineering, 93(2): 224-244, 2013 (doi: 10.1002/nme.4393).

Lian, H., Bordas, S., Sevilla, R., Recent developments in CAD/ analysis integration, Computational Technology Reviews, 6, 2012 (<http://orbilu.uni.lu/handle/10993/12300>).

Nguyen, V.-P., et al., Meshless methods: A review and computer implementation aspects, Mathematics & Computers in Simulation, 79(3): 763-813, 2008 (<http://orbilu.uni.lu/handle/10993/13726>).

Bordas, S., et al., An extended finite element library, International Journal for Numerical Methods in Engineering, 71(6): 703-732, 2007 (<http://orbilu.uni.lu/handle/10993/15234>).

Nguyen, V.-P., et al., Isogeometric analysis: an overview and computer implementation aspects, Learning material, 2013 (<http://orbilu.uni.lu/handle/10993/14191>).

Lava, P., et al., Assessment of measuring errors in DIC using deformation fields generated by plastic FEA, Optics and Lasers in Engineering, 47(7-8): 747-753, 2009 (doi: 10.1016/j.optlaseng.2009.03.007).

**MODELLING, SIMULATION AND CHARACTERIZATION
OF MULTI-SCALE HETEROGENEOUS MATERIALS**

Udine, September 28 - October 2, 2015

Application Form
(Please print or type)

Surname _____

Name _____

Affiliation _____

Address _____

E-mail _____

Phone _____ Fax _____

Method of payment upon receipt of confirmation (Please check the box)

The fee is 575,00 Euro + 22% Italian VAT taxes, where applicable (bank charges are not included).

I shall send a check of Euro _____

Payment will be made to CISM - Bank Account No. 094570210900,
VENETO BANCA - Udine (CAB 12300 - ABI 05035 - SWIFT/BIC
VEBHIT2M - IBAN CODE IT46 N 05035 12300 09457 0210900).
Copy of the receipt should be sent to the secretariat

I shall pay at the registration counter with check or VISA Credit Card
(Mastercard/Eurocard, Visa, CartaSi)

**IMPORTANT: CISM is obliged to present an invoice for the above sum.
Please indicate to whom the invoice should be addressed.**

Name _____

Address _____

C.F.* _____

VAT/IVA* No. _____

(* Only for EU residents or foreigners with a permanent business activity in Italy.)

Only for Italian Public Companies

I ask for IVA exemption (ex law n. 537/1993 - art. 14 comma 10).

Privacy policy: I understand that data received via this form will be used only to provide information about CISM and its activities, within the limits set by the Italian legislative decree no. 196/2003 and subsequent amendments.

Complete information on CISM's privacy policy is available at www.cism.it.

I have read the "Admission and Accommodation" terms and conditions and agree.

Date _____ Signature _____