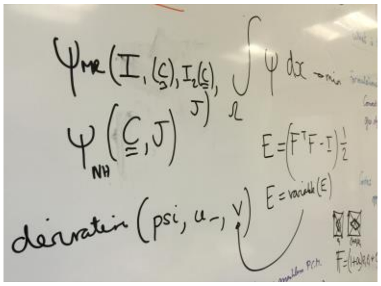
# Free Boundary Problems in Mechanics



## Overview

The course will cover basic principles behind the modeling and simulation of (coupled) free boundary problems. Free boundary problems (FBPs) form a coherent branch of science. They describe phenomena where interfaces or boundaries are free to move and they are ubiquitous in nature, engineering and science: crack growth, macroscopic phase changes are only a few examples. Most phenomena of practical engineering interest or of scientific relevance require addressing the behaviour of systems over a range of spatial and temporal scales. At some scale, materials become heterogeneous, or even discrete, and cannot be considered as continua. Evolving interfaces such as dislocations, cracks, contact surfaces, often associated with discontinuities, in the field of interest or its derivatives, have to be treated, usually in a multi-field/physics setting, including various unknown quantities such as temperature, pore pressure and mechanical fields. We attempt to provide a unified framework, to facilitate progress in this field of fundamental scientific importance and growing industrial relevance.

The intended learning outcomes of the course are such that the students will be:

- able to critically assess discretization schemes for free boundary problems
- able to implement simple error estimators for free boundary problems
- familiar with basic interface update and tracking methods
- able to follow basic literature in extended finite element methods, collocation methods and isogeometric discretization techniques
- aware of industrial applications based on real-world examples

Course participants will learn these topics through lectures and hands-on numerical experiments.

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| **Modules** | **Dates for the course: 23rd Oct 2019 to 31st Oct 2019.**<br>**Number of participants for the course will be limited to fifty.** |
| **You Should Attend If…** | ▪ You are a senior under graduate student, postgraduate students or a faculty in engineering and applied mathematics.<br>▪ Engineers and researchers from industry, government organization and R&D laboratories. You are interested in numerical methods for engineering. |
| **Fees** | The participation fees for taking the course is as follows:<br><br>**Participants from abroad : US $**<br>**Student participants: INR 2000**<br>**Faculty participants: INR 6000**<br>**Industry: INR 10,000**<br>**Research Organizations: INR 6,000**<br><br>The above fee include all instructional materials, computer use for tutorials and assignments, laboratory equipment usage charges, 24 hr free internet facility.<br><br>**Modes of payment:**<br>Online transfer:<br>Account Name: CCE IIT Madras |

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| | Acc. No: **36401111110** Branch: SBI, IIT Madras Branch, Chennai<br>IFSC Code: SBIN0001055 Swift Code: SBININBB453<br>Note: The participants should be mentioned the purpose of GIAN while the transaction and have to send the transaction details to cceoffice@iitm.ac.in<br>**OR**<br>Demand draft in favour of "**CCE IIT Madras**" payable at **Chennai**. The demand draft is to be sent to the course coordinator at the address given below.<br><br>Address of the Course Coordinator:<br>Sundararajan Natarajan<br>Room 207, Machine Design Section<br>Department of Mechanical Engineering<br>Indian Institute of Technology Madras<br>Chennai - 600036 |
| **Accommodation** | The participants may be provided with hostel accommodation, depending on availability, on payment basis. Request for hostel accommodation may be submitted through the link:<br>http://hosteldine.iitm.ac.in/iitmhostel/ |
| **Registration Procedure** | Please follow the following steps for the registration:<br><br>1. Go to GIAN website (http://www.gian.iitkgp.ac.in/GREGN/index) First time users need to register and pay a one-time fee of INR 500 /<br><br>2. Enroll for the course: *Free Boundary Problems in Mechanics*. Once you enroll for the course, an Enrollment/Application number will be generated, and the course coordinators will be notified. |

# Course Faculty

**Prof. Stéphane P.A. Bordas** is an ERC starting fellow and Professor of Computational Mechanics at the University of Luxembourg and Cardiff University. He leads the Legato Team based jointly at the University of Luxembourg and at Cardiff University. He is an Adjunct Professor at the University of Western Australia. He heads the Computational Science Research Priority at the University of Luxembourg. Prof. Bordas' research focuses on method development, *a posteriori* error estimation, free boundary problems and cutting in soft tissue. Prof. Bordas is Editor of the Elsevier Book Series *Advances in Applied Mechanics* with Dr Daniel Balint http://legato-team.eu

**Dr. Sundararajan Natarajan** is a faculty member in the Department of Mechanical Engineering at IIT Madras. His research interests lie in the areas of computational solid mechanics and applied mathematics.

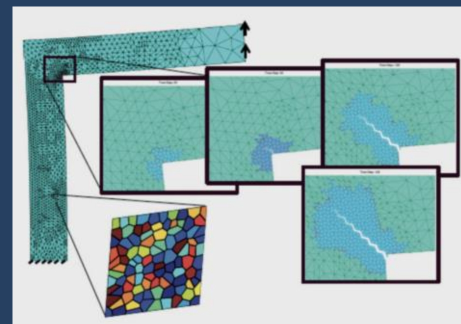
# Preliminary Reading


Akbari, A., Kerfriden, I., & **Bordas**, S. (2015). Error Controlled Adaptive Multiscale Method For Fracture Modelling in Polycrystalline materials. *Philosophical Magazine*. 95(28-30), pp 3328-3347 http://hdl.handle.net/10993/18262

Kerfriden, P., Gosselet, P., Adhikari, S., & **Bordas**, S. (2011). Bridging proper orthogonal decomposition methods and augmented Newton-Krylov algorithms: An adaptive model order reduction for highly nonlinear mechanical problems. *Computer Methods in Applied Mechanics & Engineering*, *200*(5-8), 850-866. http://hdl.handle.net/10993/14475

Hoang, K. C., Kerfriden, P., **Bordas**, S., & Khoo, B. C. (2015). An efficient goal-oriented sampling strategy using reduced basis method for parametrized elastodynamic problems. *Numerical Methods for Partial Differential Equations*. *31*(2), pp.575-608. http://hdl.handle.net/10993/15814

Kerfriden, P., Goury, O., Rabczuk, T., & **Bordas**, S. (2013). A partitioned model order reduction approach to

Hybrid multi-scale approach to fracture of polycrystalline materials, Akbari, Kerfriden, Bordas. *Philosophical Magazine*, 2015

# Course Coordinator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rationalise computational expenses in nonlinear fracture mechanics. *Computer Methods in Applied Mechanics & Engineering*, *256*, 169-188. http://hdl.handle.net/10993/10206

Kerfriden, P., Ródenas, J. J., & **Bordas**, S. (2013). Certification of projection-based reduced order modelling in computational homogenisation by the constitutive relation error. *International Journal for Numerical Methods in Engineering*. *97*(6), pp.395-422. http://hdl.handle.net/10993/10040

Kerfriden, P., Schmidt, K. M., Rabczuk, T., & **Bordas**, S. (2013). Statistical extraction of process zones and representative subspaces in fracture of random composites. *International Journal for Multiscale Computational Engineering*, *11*(3), 253-287. http://hdl.handle.net/10993/10066

Agathos, K., Chatzi, E., **Bordas**, S., & Talaslidis, D. (2015). A well-conditioned and optimally convergent XFEM for 3D linear elastic fracture. *International Journal for Numerical Methods in Engineering*. DOI: 10.1002/nme.4982 http://onlinelibrary.wiley.com/doi/10.1002/nme.4982/full http://hdl.handle.net/10993/19960

**Bordas**, S., González-estrada, O. A., Ródenas, J. J., Nadal, E., Kerfriden, P., & Fuenmayor, F. J. (2015). Locally equilibrated stress recovery for goal oriented error estimation in the extended finite element method. *Computers & Structures*. 152, pp.1-10. http://hdl.handle.net/10993/19509

Beex, L., Kerfriden, P., Rabczuk, T., & **Bordas**, S. (2014). Quasicontinuum-based multiscale approaches for plate-like beam lattices experiencing in-plane and out-of-plane deformation. *Computer Methods in Applied Mechanics & Engineering*, *279*, 348-378. http://hdl.handle.net/10993/17424

Talebi, H., Silani, M., **Bordas**, S., Kerfriden, P., & Rabczuk, T. (2013). A computational library for multiscale modeling of material failure. *Computational Mechanics*, 1-25. http://hdl.handle.net/10993/16054

Nguyen, V.-P., Anitescu, C., **Bordas**, S., & Rabczuk, T. (2015). Isogeometric analysis: an overview and computer implementation aspects. *Mathematics and Computers in Simulation*. 117, pp 89-116 http://hdl.handle.net/10993/21428

Duflot, M., & **Bordas**, S. (2008). A posteriori error estimation for extended finite elements by an extended global recovery. *International Journal for Numerical Methods in Engineering*, *76*(8), 1123-1138. http://hdl.handle.net/10993/15308

**Bordas**, S., & Duflot, M. (2007). Derivative recovery and a posteriori error estimate for extended finite elements. *Computer Methods in Applied Mechanics and Engineering*, *196*(35-36), 3381-3399. http://hdl.handle.net/10993/21337

**Bordas**, S., Nguyen, P. V., Dunant, C., Guidoum, A., & Nguyen-Dang, H. (2007). An extended finite element library. *International Journal for Numerical Methods in Engineering*, *71*(6), 703-732. http://hdl.handle.net/10993/15234