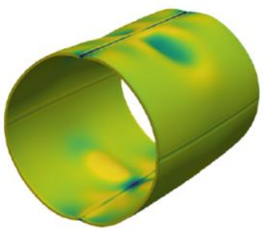
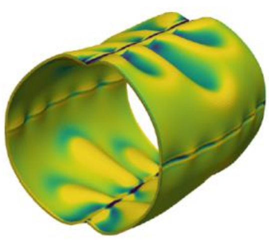
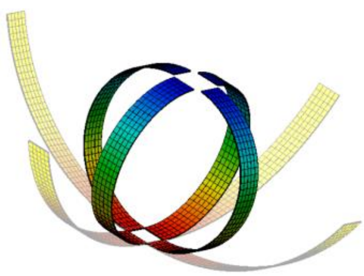
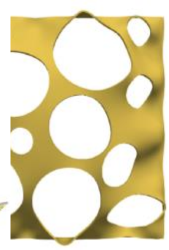
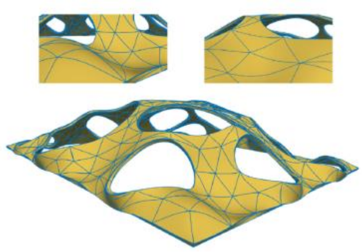
Summer School 8-10 July 2019
Pavia (Italy)

A course on: State of the art computational methods for nonlinear solid mechanics

Organised within the European Joint Doctorate Programmes **SEED** and **ProTechTion** and the European Training Network **AdMoRe**

	Monday 8th July	
08:50-09:00	Introduction to the School	**A. J. Gil**
09:00-09:50	Intro into nonlinear solid dynamics: kinematics, stresses, hyperelasticity	**F. Auricchio**
10:00-10:50	Discretisation: Finite Element Method and implicit/explicit time integrators	**F. Auricchio**
10:50-11:10	**Coffee break**	
11:10-12:00	(Smooth) explicit solid dynamics, conservation laws, hyperbolicity analysis, Petrov-Galerkin	**A. J. Gil**
12:10-13:00	Petrov-Galerkin code development in MatLab	**C. H. Lee**
13:00-14:00	**Lunch**	
14:00-14:50	(Non-smooth) explicit solid dynamics using Finite Volume Method: on Riemann solvers	**C. H. Lee**
14:50-15:10	**Coffee break**	
15:10-16:00	Finite Volume Method vertex centred code in MatLab	**C. H. Lee**
	Tuesday 9th July	
09:00-09:50	Novel tensor cross product algebra	**J. Bonet**
10:00-10:50	Computational polyconvexity	**J. Bonet**
10:50-11:10	**Coffee break**	
11:10-12:00	Static solid mechanics variational principles, Finite Element Method discretisation	**J. Bonet**
12:10-13:00	Convex Multi-Variable electromechanics and electro-constitutive models, examples	**A. J. Gil**
13:00-14:00	**Lunch**	
14:00-14:50	Variational principles, FEM discretisation, examples	**A. J. Gil**
14:50-15:10	**Coffee break**	
15:10-16:00	Coding complex constitutive models and advanced algebra packages in MatLab	**R. Ortigosa**
	Wednesday 10th July	
09:00-09:50	Time (implicit) energy-preserving time integrators	**R. Ortigosa**
10:00-10:50	Implicit time integrators code development	**R. Ortigosa**
10:50-11:10	**Coffee break**	
11:10-12:00	Intro into High Performance Computing (HPC)	**R. Poya**
12:10-13:00	HPC development for large deformations mechanics and electromechanics	**R. Poya**
13:00-14:00	**Lunch and closure**	

Lecturers in the School:

Prof. F. Auricchio

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Prof. J. Bonet

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Prof. A.J. Gil

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Dr. C. H. Lee

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Dr. R. Ortigosa

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Dr. R. Poya

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Biographical details

Javier Bonet is a Professor of Engineering, Deputy Vice-chancellor for Research and Enterprise at the University of Greenwich and a visiting professor at the Universitat Politecnica de Catalunya, Spain. He has extensive experience of teaching topics in structural mechanics, including large strain nonlinear solid mechanics, to undergraduate and graduate engineering students. He has been active in research in the area of computational mechanics for over 25 years with contributions in modelling superplastic forming, large strain dynamic analysis, membrane modelling, finite element technology including error estimation and meshless methods (Smooth Particle hydrodynamics). He has given many invited, keynote and plenary lecturers on these topics in numerous international conferences.	
Ferdinando Auricchio is a Professor of Solids and Structural Mechanics at the University of Pavia, Italy, where he started to develop collaborations with the Department of Mathematics and with several medical institutions. He received the Euler Medal by ECCOMAS in 2016 and he became Fellow Award by IACM (International Association for Computational Mechanics) since 2012. Since 2013 he is Vice-President of ECCOMAS. In 2018 he was appointed as a member of the Italian National Academy of Science, known also as Accademia dei XL. Major research interests are the development of numerical schemes, simulation tools to support medical decision, and more recently, additive manufacturing. He has organized a 3D-printing lab, exploring new materials, new printing technologies, new uses of 3D printing, ranging from civil engineering 3D printed concrete beams to bio-manufacturing.	
Antonio J. Gil is a Professor in the Zienkiewicz Centre for Computational Engineering at Swansea University. He has numerous publications in various areas of computational mechanics, with specific experience in the field of large strain nonlinear mechanics. His work covers the areas of computational simulation of bio-nanomembranes and superplastic forming of medical prostheses, fluid-structure interaction, modelling of smart electro-magneto-mechanical devices and numerical analysis of fast transient dynamical phenomena. He currently leads an interdisciplinary research group of doctoral and postdoctoral researchers comprising mathematicians, engineers and computer scientists. He has received a number of prizes for his contributions to the field of computational mechanics, including the 2011 Leverhulme Prize and the 2016 Zienkiewicz prize awarded by ECCOMAS.	

Biographical details

Chun Hean Lee is a Lecturer in the Glasgow Computational Engineering Centre at University of Glasgow and an Honorary Research Associate at Swansea University. His research interests lie in the areas of computational mechanics, with specific emphasis on the development, analysis and application of fluid-inspired computational methods for large strain fast solid dynamics. These include Streamline Upwind Petrov Galerkin Finite Element Method, Variational Multi-Scale, Cell Centred and Vertex Centred Finite Volume Method and Smooth Particle Hydrodynamics mesh-free method. He has received multiple research awards for his contributions in the field, including the UK-ACM prize for the best PhD thesis in the United Kingdom.	
Rogelio Ortigosa is a Research Fellow at the Polytechnic University of Cartagena (Spain). His work covers the areas of: development of well-posed constitutive models for nonlinear electro-mechanics at large strains; new mixed variational formulations for nonlinear electro-mechanics; structure preserving time integrators in nonlinear electro-mechanics; topology optimisation; optimum control for large strain elasticity and coupled problems. He has received several awards including the ECCOMAS Zienkiewicz prize for the best PhD thesis in computational mechanics.	
Roman Poya is a Software Engineer at Siemens UK. He is involved in the development of numerical tools for Siemens NX software specifically mesh generators and in regard to software architectural work. He is an Erasmus MSc graduate and an Erasmus PhD graduate.	

DAY 1 (Introduction, large deformations, isothermal explicit, FEM/SUPG/FVM)

1h: [F. Auricchio] Intro into nonlinear solid dynamics: kinematics, equilibrium, hyperelasticity

- Kinematics: change of configuration, deformation gradient, strain measures, change of area and volume, motion
- Equilibrium: external forces and internal actions, stress tensors, local equilibrium,
- Constitutive equations: frame-indifference, material symmetry, hyperelasticity, isotropy

1h: [F. Auricchio] Spatial discretisation via FEM

- Equilibrium weak form
- Linearization of equilibrium weak form
- FE discretization

1h: [A.J. Gil] Smooth explicit solid dynamics, conservation laws, hyperbolicity analysis, SUPG, discretisation

- Classical solid dynamics vs system of conservation laws (isothermal): p,F
- 1D analysis: hyperbolicity, Bubnov/SUPG/VMS, FEM discretisation, RK-time
- Generalisation to 3D via VMS, examples

1h: [C.H. Lee] SUPG code development in MatLab

- 1D linear advection equation (stability
- 1D explicit solid dynamics (smooth)
- Extension to 3D explicit solid dynamics (locking)

1h: [C.H. Lee] Non-smooth explicit solid dynamics using FVM and Riemann solver

- Introduction of FVM method in standard 1d linear advection equation
- 1D FVM in solid dynamics
  - Acoustic Riemann solver
  - Spatial reconstruction
  - Shocks
- Extension to 2D/3D FVM in solid dynamics

1+h: [C.H. Lee] FVM vertex centred code in MatLab

- 1D linear advection equation (stability
- 1D explicit solid dynamics (smooth)
- Extension to 3D explicit solid dynamics (locking)

DAY 2 (Polyconvexity, Implicit, multyphysics)

1h: [J. Bonet] Novel cross product algebra

- Definition of the cross product
- Properties of the tensor cross product
- Examples on solid deformation

1h: [J. Bonet] Computational polyconvexity

- Definition of polyconvexity
- Conjugate stresses, first Piola-Kirchhoff stress tensor
- Modulus of elasticity

1h: [J. Bonet] Polyconvex static solid mechanics: variational principles, FEM discretisation, examples

- Total strain energy and displacement based variational principle
- Mixed variational principle
- Hellinger-Reisner variational principle

1h: [A.J. Gil] Extension to convex multivariable electromechanics and electro-constitutive models, examples

- Mechanics/electro equations (from Maxwell), jump conditions, constitutive laws
- CMV paradigm, work conjugates, Poynting theorem, constitutive tensor, Hessian, ellipticity
- Internal/enthalpy/Helmholtz/Gibbs energy

1h: [A.J. Gil] Electro-mechanics variational principles, FEM discretisation, examples

- Constitutive model: derivation and calibration. Example
- Variational principles: classical and alternative
- FEM discretisation, examples

1h: [R. Ortigosa] Coding complex constitutive models and advanced algebra packages in MatLab

- Implementation of Mooney-Rivlin constitutive model in MatLab.
- Implementation of Mooney-Rivlin + Ideal Dielectric (electromechanical) constitutive model in MatLab.

DAY 3 (implicit dynamics, energy-preserving time integrators, HPC)

1h: [R. Ortigosa] Time (implicit) energy-preserving time integrators

- Implicit mid-point time integrator for nonlinear elasticity
- Energy-preserving time integrator for nonlinear elasticity
- Energy-preserving time integrator for nonlinear electroelasticity

1h: [R. Ortigosa] Implicit time integrators code development

- Implementation of mid-point time integrator for 3D nonlinear elasticity
- Implementation of energy-preserving time integrator for 3D nonlinear elasticity

1h: [R. Poya] Intro into High Performance Computing (HPC)

- Basics of HPC: Distributed, shared and SIMD parallelism paradigms
- Computer micro-architecture, memory hierarchy and static/dynamic analysis
- High level abstractions for parallel nonlinear mechanics solvers

1h: [R. Poya] HPC development

- Presentation on how near-machine code looks like
- Implementation of meta-engines and compiler's static analysers
- Implementation of nonlinear elasticity and electroelasticity in SIMD parallel fashion