Activity Report 2016

Team SERENA

Simulation for the Environment: Reliable and Efficient Numerical Algorithms

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Paris

THEME
Earth, Environmental and Energy Sciences

Table of contents

Team SERENA

Creation of the Team: 2015 June 01

The publications of the two members of SERENA from ENPC are not listed in the bibliography, since all administrative points of the creation of the SERENA team are not finalized for the moment. Consequently, A. Ern and L. Monasse as well as the Ph.D. students and post-docs from ENPC do not have yet the SERENA affiliation registered at the HAL preprint server.

Keywords:

Computer Science and Digital Science:

2.1.3. - Functional programming
2.4.3. - Proofs
6.1.1. - Continuous Modeling (PDE, ODE)
6.1.5. - Multiphysics modeling
6.2.1. - Numerical analysis of PDE and ODE
6.2.5. - Numerical Linear Algebra
6.2.8. - Computational geometry and meshes
6.3.1. - Inverse problems
6.3.4. - Model reduction
6.3.5. - Uncertainty Quantification

Other Research Topics and Application Domains:

3.1. - Sustainable development
3.3.1. - Earth and subsoil
3.4.2. - Industrial risks and waste
3.4.3. - Pollution
4.2.1. - Fission
5.5. - Materials

1. Members

Research Scientists

Martin Vohralík [Team leader, Inria, Senior Researcher, HDR]
François Clément [Inria, Researcher]
Alexandre Ern [ENPC, Professor, HDR]
Michel Kern [Inria, Researcher]
Laurent Monasse [ENPC, Associate Professor]
Géraldine Pichot [Inria, Researcher]
Iain Smears [Inria, Starting Research position]
Pierre Weis [Inria, Senior Researcher]

PhD Students

Sarah Ali Hassan [Inria, Contract with ANDRA]
Amina Benaceur [Cifre EDF]
Nabil Birgle [Inria, until March 24th, 2016, Contract with ANDRA]
Pierre Cantin [Cifre EDF, until November 14th, 2016]
Karol Cascavita [ENPC, Labex MMCD]

Fatma Cheikh [ENIT-Lamsin (Tunisia), until October 12th, 2016]
Jad Dabaghi [Inria, ERC GATIPOR]
Patrik Daniel [Inria, ERC GATIPOR]
Cédric Josz [Cifre RTE, until July 13th, 2016]
Frédéric Marazzato [since October 1st, 2016, Contract with CEA]
Yannick Masson [ENPC, Labex MMCD]
Nicolas Pignet [Cifre EDF, since November 1st, 2016]
Mohamed Riahi [ENIT-Lamsin (Tunisia), until October 12th, 2016]
Rita Riedlbeck [Cifre EDF]

Post-Doctoral Fellows

Elyes Ahmed [Univ. Paris XIII, ANR DEDALES]
Thomas Boiveau [ENPC, since May 1st, 2016]
Matteo Cicuttin [ENPC, since February 1st, 2016]

Visiting Scientist

Markus Köppel [University of Stuttgart, PhD Student, Visiting Scientist]

Administrative Assistants

Cindy Crossouard [Inria, until November 30, 2016]
Virginie Collette [Inria, from December 1st, 2016]

Others

Hend Ben Ameur [IPEST and ENIT-Lamsin (Tunisia), Professor, External Collaborator, HDR]
Guy Chavent [Univ. Paris IX (retired), Professor Emeritus, External Collaborator, HDR]
Jérôme Jaffré [Inria (retired), External Collaborator, HDR]
Caroline Japhet [Univ. Paris XIII, Associate Professor, External Collaborator]
Vincent Martin [UT Compiègne, Associate Professor, External Collaborator]
Zoubida Mghazli [Université Ibn Tofail, Kenitra, Morocco, Professor, External Collaborator]
Jean-Elizabeth Roberts [Inria (retired), External Collaborator, HDR]

2. Overall Objectives

2.1. Overall Objectives

The team SERENA is concerned with **numerical methods** for **environmental problems**. The main topics are the conception and analysis of *models* based on *partial differential equations*, the study of their *precise and efficient numerical approximation*, and implementation issues with special concern for *reliability and correctness of programs*. We are in particular interested in *guaranteeing* the *quality* of the *overall simulation process*. SERENA has taken over the project-team POMDAPI2 which ended on May 31, 2015. It has been given an authorization to become a joint project-team between Inria and ENPC at the Committee of Projects, September 1st, 2016.

3. Research Program

3.1. Multiphysics coupling

Within our project, we start from the conception and analysis of *models* based on *partial differential equations* (PDEs). Already at the PDE level, we address the question of *coupling* of different models; examples are that of simultaneous fluid flow in a discrete network of two-dimensional *fractures* and in the surrounding three-dimensional porous medium, or that of interaction of a compressible flow with the surrounding elastic *deformable structure*. The key physical characteristics need to be captured, whereas existence, uniqueness, and continuous dependence on the data are minimal analytic requirements that we seek to satisfy. At the modeling stage, we also develop model-order reduction techniques, such as the use of reduced basis techniques or proper generalized decompositions, to tackle evolutive problems, in particular in the nonlinear case.

3.2. Structure-preserving discretizations and discrete element methods

We consequently design *numerical methods* for the devised model. Traditionally, we have worked in the context of finite element, finite volume, mixed finite element, and discontinuous Galerkin methods. Novel classes of schemes enable the use of general *polygonal* and *polyhedral meshes* with *nonmatching interfaces*, and we develop them in response to a high demand from our industrial partners (namely EDF and IFP Energies Nouvelles). Our requirement is to derive *structure-preserving* methods, i.e., methods that mimic at the discrete level fundamental properties of the underlying PDEs, such as conservation principles and preservation of invariants. Here, the theoretical questions are closely linked to *differential geometry* for the lowest-order schemes. For the schemes we develop, we study existence, uniqueness, and stability questions, and derive a priori convergence estimates. Our special interest is in higher-order methods like the hybrid high-order method, which have recently begun to receive significant attention. Even though their use in practice may not be immediate, we believe that they represent the future generation of numerical methods for industrial simulations.

3.3. Domain decomposition and Newton–Krylov (multigrid) solvers

We next concentrate an intensive effort on the development and analysis of efficient solvers for the systems of nonlinear algebraic equations that result from the above discretizations. We have in the past developed *Newton–Krylov solvers* like the adaptive inexact Newton method, and we place a particular emphasis on *parallelization* achieved via the *domain decomposition* method. Here we traditionally specialize in *Robin transmission conditions*, where an optimized choice of the parameter has already shown speed-ups in orders of magnitude in terms of the number of domain decomposition iterations in model cases. We concentrate in the SERENA project on adaptation of these algorithms to the above novel discretization schemes, on the optimization of the free Robin parameter for challenging situations, and also on the use of the Ventcell transmission conditions. Another feature is the use of such algorithms in time-dependent problems in *space-time* domain decomposition that we have recently pioneered. This allows the use of different time steps in different parts of the computational domain and turns out to be particularly useful in porous media applications, where the amount of diffusion (permeability) varies abruptly, so that the evolution speed varies significantly from one part of the computational domain to another. Our new theme here are *Newton–multigrid solvers*, where the geometric multigrid solver is *tailored* to the specific problem under consideration and to the specific numerical method, with problem- and discretization-dependent restriction, prolongation, and smoothing. This in particular yields mass balance at each iteration step, a highly demanded feature in most of the target applications. The solver itself is then *adaptively steered* at each execution step by an a posteriori error estimate.

3.4. Reliability by a posteriori error control

The fourth part of our theoretical efforts goes towards guaranteeing the results obtained at the end of the numerical simulation. Here a key ingredient is the development of rigorous *a posteriori estimates* that make it possible to estimate in a fully computable way the error between the unknown exact solution and its numerical approximation. Our estimates also allow to distinguish the different *components* of the overall *error*, namely the errors coming from modeling, from the discretization scheme, from the nonlinear (Newton) solver, and from the linear algebraic (Krylov, domain decomposition, multigrid) solver. A new concept here is that of *local stopping criteria*, where all the error components are balanced locally within each computational mesh element. This naturally connects all parts of the numerical simulation process and gives rise to novel *fully adaptive algorithms*. We shall then address theoretically the question of convergence of the new algorithms and prove their numerical quasi-optimality, meaning that they need, up to a generic constant, the smallest possible number of degrees of freedom to achieve the given accuracy. We in particular seek to prove a guaranteed error reduction in terms of the number of degrees of freedom.

3.5. Safe and correct programming

Finally, we concentrate on the issue of computer implementation of scientific computing programs. Increasing complexity of algorithms for modern scientific computing makes it a major challenge to implement them in the traditional imperative languages popular in the community. As an alternative, the computer science community provides theoretically sound tools for *safe* and *correct programming*. We explore here the use of these tools to design generic solutions for the implementation of the class of scientific computing software that we deal with. Our focus ranges from high-level programming via *functional programming* with OCAML through safe and easy parallelism via *skeleton parallel programming* with SKLML to proofs of correctness of numerical algorithms and programs via *mechanical proofs* with COQ.

4. Application Domains

4.1. Environmental problems

We pursue *applications* of our theoretical results to current challenging *environmental problems* with numerous *academic collaborators* and with *industrial partners* such as ANDRA, IFP Energies Nouvelles, CEA, and EDF. We are traditionally interested in *porous media* for multiphase flows and transport of contaminants in the subsurface and concentrate on fractures, fracture networks, fractured porous media, subsurface depollution after chemical leakage, nuclear waste disposal in deep underground repositories, and geological sequestration of CO_2. Among our newer themes, we count complex inviscid flows interacting with a mechanical deformable structure and Navier–Stokes flows. Such problems are encountered in energy production (operation of nuclear reactors) and safety assessment (shock waves resulting from an explosion impinging on a structure).

5. New Software and Platforms

5.1. GEOFRACFLOW

GEOFRACFLOW
SCIENTIFIC DESCRIPTION GEOFRACFLOW is a Matlab software for the simulation of steady state single phase flow in Discrete Fracture Networks (DFNs) using the Mixed Hybrid Finite Element (MHFEM) method for conforming and non conforming discretizations.

- Participants: Géraldine Pichot, Jocelyne Erhel, and Jean-Raynald De Dreuzy
- Contact: Géraldine Pichot
- URL: https://bil.inria.fr/fr/software/view/2653/tab

5.2. SBM

Skew Brownian Motion
SCIENTIFIC DESCRIPTION SBM is a code allowing exact or approximated simulations of the Skew Brownian Motion. This code is used for the simulation, with a Monte-Carlo approach, of a 1D diffusion process with a discontinuous diffusion coefficient. Several benchmark tests are also implemented.

- Participants: Antoine Lejay, Géraldine Pichot
- Contact: Antoine Lejay
- URL: https://gforge.inria.fr/projects/sbm

5.3. Sklml

The OCaml parallel skeleton system

SCIENTIFIC DESCRIPTION Writing parallel programs is not easy, and debugging them is usually a nightmare. To cope with these difficulties, the skeleton programming approach uses a set of predefined patterns for parallel computations. The skeletons are higher-order functional templates that describe the program underlying parallelism. Sklml is a new framework for parallel programming that embeds an innovative compositional skeleton algebra into the OCaml language. Thanks to its skeleton algebra, Sklml provides two evaluation regimes to programs: a regular sequential evaluation (merely used for prototyping and debugging) and a parallel evaluation obtained via a recompilation of the same source program in parallel mode. Sklml was specifically designed to prove that the sequential and parallel evaluation regimes coincide.
FUNCTIONAL DESCRIPTION Sklml is a functional parallel skeleton compiler and programming system for OCaml programs. Slogan is "easy coarse grain parallelization".

- Participants: Pierre Weis and François Clément
- Contact: François Clément
- URL: http://sklml.inria.fr

6. New Results

6.1. Numerical algorithms for simulating diffusion processes in discontinuous media

Participant: Géraldine Pichot.

Grants: H2MN04 3

Software: SBM 5.2

Publications: [19]

We present several benchmark tests for Monte Carlo methods simulating diffusion in one-dimensional discontinuous media. These benchmark tests aim at studying the potential bias of the schemes and their impact on the estimation of micro- or macroscopic quantities (repartition of masses, fluxes, mean residence time,...). These benchmark tests are backed by a statistical analysis to filter out the bias from the unavoidable Monte Carlo error. We apply them on four different algorithms. The results of the numerical tests give a valuable insight of the fine behavior of these schemes, as well as rules to choose between them.

6.2. Locally space-time efficient estimates for parabolic problems

Participants: Martin Vohralík, Alexandre Ern, Iain Smears.

Grants: GATIPOR 8.3.1

Publications: [33]

In [33], we derive for the first time a posteriori error estimates for parabolic problems which are both globally reliable and locally space-time efficient. By this, one means that the error between a known approximate numerical solution and the unknown exact solution of a model parabolic PDE (the heat equation) is bounded from above on the whole space-time domain by a fully computable estimator, while this estimator does not overestimate significantly the error and localizes it both in space and in time. More precisely, the estimator also gives lower bounds on the error, up to a generic constant, and this on each time interval and in a small neighborhood of each space mesh element. We consider arbitrarily high-order conforming Galerkin spatial discretizations and arbitrarily high-order discontinuous Galerkin temporal discretizations, and the error is measured in a norm composed of the $L^2(H^1) \cap H^1(H^{-1})$-norm augmented by the temporal jumps of the numerical solution. The efficiency constant is robust with respect to (independent of) any mesh-size, time-step size, and the spatial and temporal polynomial degrees. The proposed estimators also have the practical advantage of not imposing any requirement on coarsening between the consecutive time steps.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

- Three-parts contract Inria–EDF–Sciworks Technologies (November 2015–April 2016) on "Form-L for the formalization of constraints of complex systems".
- Contract Inria–IFP Energies Nouvelles (December 2016–December 2017) on "A posteriori error analysis for porous media flow problems with fractures".
- Numerous contracts accompanying Ph.D. theses and post-doc positions, see Section 1.

8. Partnerships and Cooperations

8.1. Regional Initiatives

GT Elfic (Labex DigiCosme, 2014–2016): "Formal proof for finite element programs", with TOCCATA (Inria Saclay - Île-de-France), CEA LIST, LIPN (Université de Paris 13), and LMAC (Université de Technologie de Compiègne).

8.2. National Initiatives

8.2.1. ANR

ANR DEDALES: "Algebraic and geometric domain decomposition for subsurface flow". The project aims at developing high performance software for the simulation of two phase flow in porous media. It specifically targets parallel computers where each node is itself composed of a large number of processing cores, such as are found in new generation many-core architectures. The project had its intermediate review in December 2016, and received excellent marks from the expert panel.

The partners are HIEPACS, Laboratoire Analyse, Géométrie et Application, University Paris 13, Maison de la Simulation, and ANDRA. SERENA representants are M. Kern (grant leader) and M. Vohralík, period 2014–2017.

ANR GEOPOR: "Geometrical approach for porous media flows: theory and numerics". A new approach to numerical methods for multiphase simulations based on the concept of gradient flows is investigated. With Laboratoire Jacques-Louis Lions, University Pierre and Marie Curie. SERENA representant is M. Vohralík, period 2013–2017.

ANR H2MNO4: "Original optimized object-oriented numerical model for heterogeneous hydrogeology". The project H2MNO4 develops numerical models for reactive transport in heterogeneous media. The objective is to design both Eulerian and Lagrangian models. Three applications are concerned: freshwater supply, remediation of mine drainage, and waste geological disposal. The project relies on a consortium of six partners, involving four public research laboratories (Inria, Geosciences Rennes, University of Lyon 1, University of Poitiers, Pprime Institute), one public institution (ANDRA), and one enterprise (ITASCA). International collaborations are pursued with University of San Diego (USA) and UPC (Spain). SERENA representant is G. Pichot, period 2012–2016.

ANR HHOMM: "Hybrid high-order methods on polyhedral meshes", Theoretical foundations and applications (up to software development) for the recently-devised Hybrid high-order methods. Coordinated by D. Di Pietro, University of Montpellier. SERENA representant is A. Ern, period 2015–2019.

C2S@Exa: "Computer and Computational Sciences at Exascale". This is an Inria Project Lab (IPL). This national initiative aims at the development of numerical modeling methodologies that fully exploit the processing capabilities of modern massively parallel architectures in the context of a number of selected applications related to important scientific and technological challenges for the quality and the security of life in our society. This project supported in particular the Ph.D. of N. Birgle in the framework of the Inria–ANDRA collaboration.

8.3. European Initiatives

8.3.1. FP7 & H2020 Projects

ERC GATIPOR: "Guaranteed fully adaptive algorithms with tailored inexact solvers for complex porous media flows". The subject of this project are new approaches to porous media multiphase flows: inexact Newton-multigrid solvers, local stopping criteria, adaptivity, and a posteriori error control. The goal is to guarantee the overall simulation error and to speed-up importantly the present-day simulations. SERENA representant is M. Vohralík (grant leader), period 2015–2020.

EoCoE: "Energy Oriented Center of Excellence" This project is coordinated by Maison de la Simulationand gathers 23 partners from 13 countries to use the tremendous potential offered by the ever-growing computing infrastructure to foster and accelerate the European transition to a reliable low carbon energy supply using HPC (High Performance Computing). SERENA representant M. Kern, period 2015–2018.

8.3.2. Collaborations in European Programs, Except FP7 & H2020

8.3.2.1. ITEA 3

Program: ITEA 3

Project acronym: OPENCPS

Project title: Open cyber-physical system model-driven certified development

Duration: Dec 2015–Dec 2018

Coordinator: Magnus Eek

Other partners: AB SKF, CEA, ELTE-Soft Kft., ESI Group, EDF, Wqua Simulation AB, Ericsson, IncQuery Labs Kft., KTH, Linköping University, RTE, SICS, SIREHNA, Saab AB, Sherpa Engineering, Siemens Industrial Torbumachinery AB, VTT Technical Research Center of Finland Ltd.

Abstract: Cyber-physical systems put increasing demands on reliability, usability, and flexibility while, at the same time, lead time and cost efficiency are essential for industry competitiveness. Tools and environments for model-based development of cyber-physical systems are becoming increasingly complex and critical for the industry: tool interoperability, vendor lock-ins, and tool life-cycle support are some of the challenges. The project focuses on interoperability between the standards Modelica/UML/FMI, improved execution speed of (co-)simulation, and certified code generation.

8.3.2.2. ERC CZ

Program: Research, Development and Innovation Council of the Czech Republic

Project acronym: MoRe

Project title: Implicitly constituted material models: from theory through model reduction to efficient numerical methods

Duration: September 2012 – September 2017

Coordinator: Josef MÁLEK, Charles University in Prague. SERENA representant is M. Vohralík.

Other partners: Institute of Mathematics, Czech Academy of Sciences; University of Oxford

Abstract: A multidisciplinary project on nonlinear Navier–Stokes flows with implicit constitutive laws. It focuses on development of accurate, efficient, and robust numerical methods for simulations of the new class of implicit models.

8.4. International Research Visitors

8.4.1. Visits of International Scientists

H. Ben Ameur, Professor at IPEST and member of ENIT-Lamsin, Tunis, Tunisia, November 1–15, 2016.

G. Hammond, Applied Systems Analysis and Research Sandia National Laboratories, USA, April 18, 2016.

M. Köppel, Ph.D. student, University of Stuttgart, Germany, October 1–December 31, 2016.

Z. Strakoš, Professor at the Charles University in Prague, April, 17–21, 2016.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events Organisation

9.1.1.1. General Chair, Scientific Chair

A. Ern co-organized with D. Di Pietro and L. Formaggia the IHP Thematic Quarter on Numerical methods for PDEs from September 5th to December 16th, 2016.

M. Vohralík co-organized, together with I. Vignon-Clémentel from the project-team REO, the monthly *Scientific computing, modeling, and numerical analysis* seminar ("Rencontres Inria-LJLL en calcul scientifique"), see the web page https://project.inria.fr/rencontresljll/, until July, 2016. Since September, 2016, I. Smears co-organizes this seminar together with C. Grandmont from the project-team REO.

9.1.2. Scientific Events Selection

9.1.2.1. Member of the Conference Program Committees

A. Ern and M. Vohralík are members of the Scientific Committee of the ENUMATH 2017 conference (Voss, Norway).

M. Vohralík is a member of the Scientific Committee of the Finite Volumes for Complex Applications 8 conference (Lille, France).

9.1.3. Journal

9.1.3.1. Member of the Editorial Boards

A. Ern is a member of the editorial boards of SIAM Journal on Scientific Computing, ESAIM Mathematical Modelling and Numerical Analysis, IMA Journal of Numerical Analysis, Computational Methods in Applied Mathematics, and Journal de l'Ecole polytechnique, Mathématiques.

M. Vohralík is a member of the editorial boards of SIAM Journal on Numerical Analysis and of Acta Polytechnica.

9.1.3.2. Reviewer - Reviewing Activities

M. Kern was a reviewer for the journal Mathematics and Computers in Simulation, Electron. Trans. Numer. Anal., and Oil and Gas Science and Technology,

L. Monasse was a reviewer for J. Comput. Phys. and J. Comput. Particle Mech.

A. Ern and M. Vohralík served as reviewers for tens of papers in different journals.

9.1.4. Invited Talks

A. Ern, plenary speaker, ECCOMAS 2016, Crete.

A. Ern, plenary speaker, WONAPDE 2016, Concepción, Chile.

M. Kern, minisymposium speaker at the German Priority Programme, Software for Exascale Computing, Germany.

M. Vohralík, invited speaker, Adaptive algorithms for computational PDEs, Birmingham, Great Britain.

M. Vohralík, plenary speaker, WONAPDE 2016, Concepción, Chile.

M. Vohralík, plenary speaker, ALGORITMY 2016, Podbanske, Slovakia.

9.1.5. Leadership within the Scientific Community

M. Kern was a member of the nominating committee for the SIAM Activity Group on Geosciences.

M. Kern is a reviewer for the German Supercomputing Center JARA program.

M. Kern is a member of the Scientific Committee of Orap (ORganisation Associative du Parallélisme), of the Scientific Board of GDR Calcul and of the jury and executive board of Label C3I.

M. Vohralík is a member of the steering committee of GIS Géosciences franciliennes.

9.1.6. Research Administration

F. Clément is a member of the *Comité local d'hygiène, de sécurité et des conditions de travail* of the Inria Research Center of Paris.

F. Clément is the *correspondant Inria-entreprise* of the Inria Research Center of Paris for AMIES.

M. Kern is Deputy Director of Maison de la Simulation, a joint project between CEA, CNRS, Inria, Université de Paris 11, and Université de Versailles, focused on applications of high end computing.

M. Kern is a member of the *Comité de site* of the Inria center of Paris.

G. Pichot is a member of the *Comité local d'hygiène, de sécurité et des conditions de travail* of the Inria center of Paris.

G. Pichot is member of the Conseil de département MAM of Polytech Lyon.

G. Pichot is member of the Commission de developpement technologique (CDT) of the Inria center of Paris.

G. Pichot is a member of the CES commission of the Inria center of Paris.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

A. Ern, Analyse numérique et optimisation, 78h, L3, Ecole Polytechnique (professeur chargé de cours), France.

A. Ern, Méthodes de Galerkine Discontinu, 20h, M2 Mathématiques de la modélisation, Paris 6, France.

M. Kern, Modélisation et simulation des écoulements de fluides dans la géosphère (with E. Mouche, CEA), 30h, M2 Mathématiques et Applications (parcours Analyse, Modélisation et Simulation), Université Paris Saclay, France.

M. Kern, Eléments finis (avec D. Ryckelynck), 30h, 2nd year students, Ecole Mines-ParisTech, France.

M. Kern, Problèmes inverses, 24 h, 2nd year students, Ecole Mines-ParisTech, France.

M. Kern, Analyse numérique avancée, 20h, 3rd year students, MACS, Université Paris Nord, France.

L. Monasse, Analyse et Calcul Scientifique, 30h, L3, ENPC, France.

M. Vohralík, A posteriori error estimates for efficiency and error control in numerical simulations, 36h, M2, Charles University in Prague, Czech Republic.

M. Vohralík, A posteriori error estimates and adaptive error components balancing in numerical simulations, summer school "IHP quarter on Numerical Methods for PDEs", Cargèse, Corsica & Paris, France, 15h.

9.2.2. Supervision

PhD: N. Birgle, *Underground flow, numerical methods and high performance computing*, University Paris VI, defended on March 24th, 2016, advisor J. Jaffré, co-advisor J. E. Roberts.

PhD: F. Cheikh, *Identification of fractures in a porous medium by a method of indicators*, University Paris VI and University of Tunis El Manar, defended on October 12th, 2016, advisors J. E. Roberts and H. Ben Ameur, co-advisors V. Martin and F. Clément.

PhD: M. H. Riahi, *Identification of hydrogeological parameters in a porous medium*, University Paris VI and University of Tunis El Manar, defended on October 12th, 2016, advisors J. Jaffré and H. Ben Ameur.

PhD in progress: S. Ali Hassan, *A posteriori error estimates and stopping criteria for domain decomposition solvers with local time stepping*, University Paris VI, November 2013, advisor M. Vohralík, co-advisors C. Japhet and M. Kern.

PhD in progress: J. Dabaghi, *Adaptive modeling via complementarity of phase appearance and disappearance in fractured and porous media*, University Paris VI, November 2015, advisor M. Vohralík, co-advisor V. Martin.

PhD in progress: P. Daniel, *Adaptive multilevel solvers with a posteriori error control for porous media flows* University Paris VI, October 2015, advisor M. Vohralík, co-advisor A. Ern.

PhD students at ENPC are listed in Section 1.

9.2.3. Juries

A. Ern, external examiner of the PhD of Z. Dong, University of Leicester, November 24, 2016.

A. Ern, chair of jury of the PhD of M. Giacomini, Ecole Polytechnique, December 9, 2016.

M. Kern, jury member for the PhD of V. Groza, Identification de paramètres et analyses de sensibilité pour un modèle d'usinage par jet d'eau abrasif, Université de Nice, November 9, 2016.

M. Kern, jury member for the PhD of M. Massaro, Méthodes numériques pour les plasmas sur architectures multicoeurs, Université de Strasbourg, December 16, 2016.

M. Kern, jury member for the Habilitation of Y. Mesri, Méthodes numériques massivement parallèles à base de maillages non structurés adaptatifs et anisotropes pour la mécanique numérique, Université de Nice, December 19, 2016.

G. Pichot, jury member of the PhD of A. Botella, Unstructured volumetric meshing of geological models for physical phenomenon simulations, University of Lorraine, April, 1st, 2016.

G. Pichot, jury member of the PhD of A. Dartois, Study of the macro-dispersion of inert particles in highly heterogeneous 3D porous media, University of Poitiers, December, 14, 2016.

M. Vohralík, reviewer and jury member of the PhD of R. Tittarelli, University Lille 1, September 27, 2016.

M. Vohralík, chair of jury of the PhD of M. Groza, Université de Nice, November 10, 2016.

9.3. Popularization

F. Clément was member of the Organizing Committee of the *17e Salon Culture & Jeux Mathématiques*, held in Paris, 26–29 May, 2016. He was member of the Editorial Board of the *Maths Société Express* booklet distributed during the exhibition. He was also coordinator of the Maths-Enterprises booth for AMIES.

F. Clément realized, with the Communication Department of the Inria Research Center of Paris, an exhibition illustrating the results of the *Etude de l'impact socio-économique des mathématiques en France* sponsored by AMIES, FSMP, and FMJH.

F. Clément coordinated an article about AMIES in the magazine PLOT published by the *Association des Professeurs de Mathématiques de l'Enseignement Public*.

Major publications by the team in recent years: [1], [2], [3], [4], [5], [6], [7], [8], [9], [10].

10. Bibliography

Major publications by the team in recent years

[1] S. BOLDO, F. CLÉMENT, J.-C. FILLIÂTRE, M. MAYERO, G. MELQUIOND, P. WEIS. *Wave equation numerical resolution: a comprehensive mechanized proof of a C program*, in "Journal of Automated Reasoning", April 2013, vol. 50, n° 4, pp. 423–456, http://dx.doi.org/10.1007/s10817-012-9255-4

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