WAVES

Large Scale Simulation of Waves in Complex Media (WAVES)

ARC Proposal

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The Great Wave off Kanagawa

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1. Title of the project

Large Scale Simulation of Waves in Complex Media (WAVES)

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3. Summary

Accurately predicting the behavior of wave-like phenomena is crucial in a great variety of scientific and technical fields: from quantum mechanics to geophysics, from medical imaging to aero-acoustics… The WAVES project focuses on **geophysical wave phenomena**: the propagation of mechanical waves in the underground soil and the propagation of waves in geophysical fluid flows. These application areas hold major challenges, from both the scientific, technical, environmental and social perspective. To give a single, topical example, hydraulic fracking, a controversial technique to extract hydrocarbons, poses important questions with respect to the potential for triggering earthquakes. Studying this phenomenon requires the development of novel computational methods, both to handle the description of the heterogeneous soil and to solve the associated (extremely) large-scale wave propagation problems.

The research proposed in the WAVES project aims to contribute to the solution of **two major bottlenecks** for the **solution of large-scale wave propagation problems in complex heterogeneous media, in frequency and in time domain**. The first challenge concerns the automatic **generation of finite element meshes** in complex, anisotropic domains described in non-standard fashion. Two examples of such domains are the underground soil, made of geological layers and potentially crossed by faults; and a continental shelf with all its spatial scales, going from a few meters to hundreds of kilometers. The second challenge concerns the **high-fidelity numerical solution of the wave equations**, in frequency and time domain, in such complex media, which requires the design of novel, scalable algorithms that can deal with extremely large grids on distributed high performance computing (HPC) clusters. These two challenges are **intimately linked**: indeed, even if it is nowadays possible to generate "a mesh" in about any geometrical situation, it is the numerical solution scheme that will impose its limits on this mesh (anisotropy, gradation, density).

The project proposes an innovative approach to overcome these two major difficulties, based on locally cartesian hexahedral meshes and the associated frequency- and time-domain solvers. The project is organized around four main research axes. The first axis concerns the **generation of hexahedral meshes on the non-standard geometries** encountered in geophysical applications. Based on these meshes, the three other axes deal respectively with the design of **scalable domain decomposition solvers in the frequency domain** (for steady-state time-harmonic linear wave propagation); the design of **scalable time-domain schemes** (for transient, possibly non linear wave propagation); and the design of **interface capturing techniques** (to represent sharp discontinuities without explicitly taking them into account in the hexahedral grids).

All the developments will be carried out in the open software platform Gmsh (http://gmsh.info), which is actively developed and used by the members of the WAVES consortium. The resulting software, including both the mesh generation algorithms and the scalable high-performance solvers, will be distributed as **open source building blocks directly usable by the scientific community at large**. Numerous applications in the fields of geophysical exploration and seismic modeling will directly benefit from the developments of the WAVES project. Other domains of application such as electromagnetics, acoustics and computational quantum mechanics will also benefit from the theoretical results and the proposed algorithmic developments.

4. Project description

4.1. Introduction

The WAVES project focuses on the efficient, scalable numerical solution of large-scale **geophysical wave phenomena**: the **propagation of mechanical waves in the underground soil** and the **propagation of waves in geophysical fluid flows**. Studying these phenomena **requires the development of novel computational methods**, both to handle the **geometrical description of the heterogeneous, often highly anisotropic propagation media** and to solve the associated **large-scale wave propagation problems**.

To provide some orders of magnitude, let us examine two representative examples.

Figure 1 represents a **typical underground model** for the propagation of seismic (mechanical) waves. Computing compression waves in this specific 20 km x 20 km x 4.65 km parallelepipedic domain with a standard finite difference or finite element scheme requires about **250 million grid points**. Moreover, in order to capture the highly heterogeneous nature of the soil (different geological layers crossed by a fault), the optimal mesh has to be **strongly graded and anisotropic**. Solving the partial differential equations describing the wave propagation problems on such a mesh is extremely challenging, both in the frequency domain (for the steady state analysis of time-harmonic, linear waves) or in the time domain (for the transient analysis of time-domain, possibly non linear waves). Figure 2 shows an example solution of a time-harmonic, linear acoustic (scalar) **direct problem** in a two-dimensional slice of the computational domain, with a wave source located inside the domain. The top figure shows the real part of the pressure wave if the propagation medium is homogeneous, and if no reflection occurs on the interface between the underground soil and the air. The middle figure shows the velocity profile in the actual underground soil. The bottom figure displays the pressure profile in this heterogeneous soil, taking into account the additional reflection on the soil-air interface. While the solution of this direct problem is in itself challenging, in many practical applications, and in particular in geophysical prospection, the direct problem actually arises as one solution step in the even more challenging **inverse problem**, which consists in determining the nature of the medium (e.g. for petroleum exploration) or the location of the source (e.g. for earthquake epicenter detection) given some measurements of the wave—typically on the soil-air interface. The optimization algorithms used to solve such inverse problems require many solutions of the associated direct problem, which makes the **quest for computationally efficient solvers paramount**.

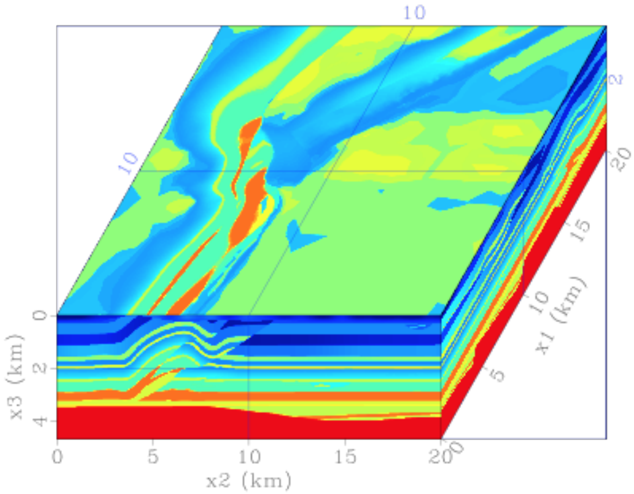

Figure 1 - Typical underground model: 20 km x 20 km x 4.65 km parallelepipedic domain containing an overthrust fault [Poulson-Engquist-Li-Ying]. Computing seismic (mechanical) compression waves with typical wavelengths comprised between 600 m to 6 km, with a standard second order numerical scheme with 30 points per wavelength, leads to 250 million grid points.

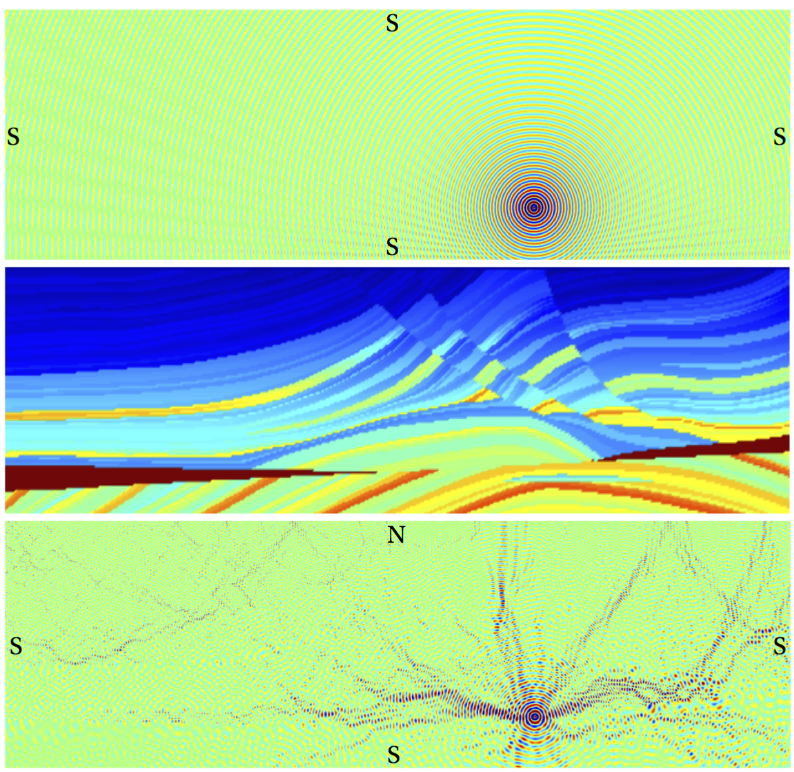

Figure 2 - Solution of the time-harmonic acoustic (scalar) problem in a two-dimensional slice (from the Marmousi[1] model), with a source inside the domain. Top: real part of the pressure wave for homogeneous propagation medium, with Sommerfeld (S) radiation conditions on the boundary (no reflection on the soil/air interface). Middle: velocity profile for the heterogeneous medium. Bottom: pressure wave in the heterogeneous case, taking into account the additional reflection on the soil-air interface (Neumann (N) condition).

[1] http://www.reproducibility.org/RSF/book/data/marmousi/paper_html/

As a second application example, consider Figure 3, which depicts the disparity of scales of motion in the oceans and in the atmosphere. The range of time and space scales of motions in the oceans (and atmosphere) is enormous, with the ratio of the largest to the smallest ones generally in excess of one billion. Nowadays it is impossible to resolve explicitly all of the scales of motion and it will remain so for the foreseeable future. Global or basin scales models as well as models focusing on smaller (and usually shallow) domains are able to simulate explicitly only the largest scales of motion, implying that the rest of the spectrum has to be accounted for by means of parameterisations whose relevance remains questionable—though significant progress has been achieved since the development of the very first numerical marine models in the 1950's and 1960's. See, for instance, [Baumert-Simpson-Sündermann], [Burchard] and [Griffies-et-al] and references therein. To make matters worse, the largest scales of motion are not always those containing the largest fraction of the energy of the flow so that the most energetic are sometimes parameterized rather than resolved. In the realm of oceanography, numerical techniques aiming at enhancing the resolution when and where needed are still in their infancy.

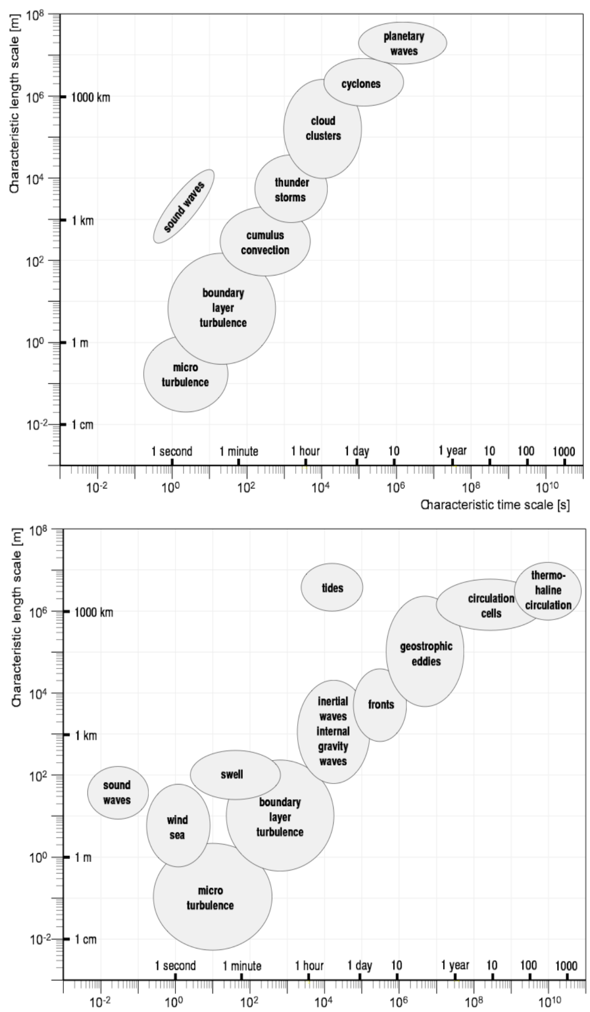

Figure 3 - Different scales of motion in the ocean (top) and in the atmosphere (bottom). Figure courtesy of Prof. Hans von Storch.

4.2. State of the art and relevance of the proposal

Solving wave propagation problems in the kind of configurations presented in the previous section can only be achieved using numerical methods, on (powerful) computers. The non-local behavior of wave-like phenomena usually makes this numerical solution extremely **difficult**, in particular when the problem involves **several spatial and/or time scales**—for example when the wavelength is much smaller than the size of the domain (high-frequency problems, as in Figure 2), or when geometrical features of the domain or solution span several orders of magnitudes (spatially multiscale problem, as in Figure 3). Moreover, for the example problems examined above, the representation of the domain itself is a major challenge: the velocity dataset of Figure 1 alone contains 810 x 801 x 187 ≅ 120 million data points.

When wave propagation phenomena are described by linear partial differential equations and when the propagation takes place in (piecewise) homogeneous media, very efficient numerical schemes based on the fundamental solution of these equations exist, and have been in use for more than two decades. These fast integral-type methods rely on the discretization of the interfaces/boundaries of the domain and on sparse-approximations (e.g. using the Fast Multipole Method [Coifman-Rokhlin-Wandzura] [Cheng-et-al] or H-matrices [Hackbusch]) of the integral operators to achieve near-linear complexity with respect to grid size. These methods can be further combined with asymptotic methods to solve extremely large scale high-frequency problems (several thousand wavelengths in the domain of study) [Bruno-Geuzaine-Monro-Reitich]. When the equations are not linear and/or the propagation media is not homogeneous, however, these techniques cannot be used, and one must resort to techniques based on volumetric discretisations like finite difference, finite volume or finite element methods. These volumetric methods, as used in engineering offices around the world, are currently based on low order (typically second order) schemes, which have been developed in the second half of the 20th century. This helps to explain the growing consensus in the computational physics community that today's state of the art solver technology requires, and will continue to require too expensive computational resources to provide the necessary resolution for demanding applications, even at the rate at which computational power increases.

Recent developments thus favor the development of higher-order methods, which are a key enabling technology for **high fidelity simulations** [Kroll-et-al] that are out of reach of today's solver technology. This is especially the case in wave propagation problems where low order solvers exhibit large dispersion errors [Babuska-Sauter]. However, even with today's best, state-of-the-art high-order methods, solving the kinds of wave propagation problems described above is **extremely challenging, and sometimes impossible**.

Mesh generation

Even though efficient 2D mesh generation techniques were already available in the early 1970's [Lawson], the first automatic unstructured mesh generation system for general 3D domains was proposed in the early 1990's with Paul-Louis George's seminal work on 3D constrained Delaunay triangulation [Georges-Hecht-Saltel]. It is interesting to note that today's most widely used 3D mesh generation algorithm is still the one developed at that time by those 3 authors[2].

Three-dimensional mesh generation is a problem that is extraordinary complicated. Only half a dozen research teams in the world have the technology to build tetrahedral meshes for general domains in an automatic manner [Georges-Hecht-Saltel] [Shephard-Georges], [Löhner-Parikh] [Weatherill-Hassan] [Si] [Schöberl] [Ito-Shih-Soni] [Geuzaine-Remacle]. The members of WAVES are among that short list with Gmsh [Geuzaine-Remacle], the only open source complete mesh generator available today. Members of WAVES are the organizers of both the two most important conferences dedicated to mesh generation which are the International Meshing Roundtable[3] and the Tetrahedron workshop[4]. The next "Tetrahedron workshop" will be organized in 2016 in Belgium, jointly by UCL and ULg.

Finite elements have now gained a large amount of interest in geosciences, both in ocean modeling [Danilov-Kivman-Schröter], [White-Legat-Deleersnijder] and in geo-engineering [Ewing-Russell-Wheeler] [Yoon-Shin-Suh-Lines-Hong]. **Finite elements come with the price of mesh generation**. Specific mesh generation procedures have been proposed for reservoir simulations [Edwards-Bin-Aziz] [Flandrin-Borouchaki-Bennis] or for ocean modeling [Lambrechts-et-al]. In the case of simulation of wave propagation in soils, few references are available and no robust solution exists for now. A solution to the mesh generation problem in this domain will be a breakthrough and would have considerable impact in the domain, even with tetrahedral meshes.

Hexahedral meshes in 3D and quadrilateral meshes in 2D are considered to be superior to triangular meshes in the scientific computing community. In reservoir engineering, hex-meshes are also considered to be the only option: semi automatic meshing procedures are presently used that includes significant human interactions [Bennis-Sassi]. In the specific context of wave propagation in large scale domains, the availability of "hex-based" high quality **spectral preconditioners** [Fischer] in the time domain and **Analytic Incomplete LU (AILU) preconditioner** [Gander-Nataf] in the frequency domain makes the use of hex grids highly valuable for our problems.

Figure 4 is taken from a short course on mesh generation that is given by Dr. S. Owen at the international meshing roundtable about once every two years [Owen]. Structured mesh generation procedures allow the construction high quality hex-meshes. Yet, those methods are not automatic: they require significant human interaction and are not applicable for general 3D domains. Even though direct tet-meshing techniques have reached a level of robustness that allow to treat general 3D domains, there may never exist a direct algorithm for building unstructured hex-meshes in general 3D domains.

The only reliable alternative for automatic hex meshing is the indirect approach [Remacle-et-al] [Baudouin-et-al] [Yamakawa-Shimada] [Remacle-et-al-2]. In an indirect approach, a tet-mesh is build and elements are recombined to form hexes. Techniques for

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[2] This algorithm is called GHS3D, GHS being for George-Hecht-Saltel.
[3] www.imr.sandia.gov/
[4] mox.polimi.it/**tetrahedron**/

generating hexahedra from tetrahedra in a reliable way rely on recent developments in various domains of applied mathematics such as graph theory (maximum weight independent set problem [Warrier]), optimization (mixed integer programming [Bommes]) and computational geometry (LP Central Voronoi Tessellations [Lévy-Liu]). Time is rope for making a breakthrough in hex-meshing and WAVE's consortium is very relevant for making this breakthrough.

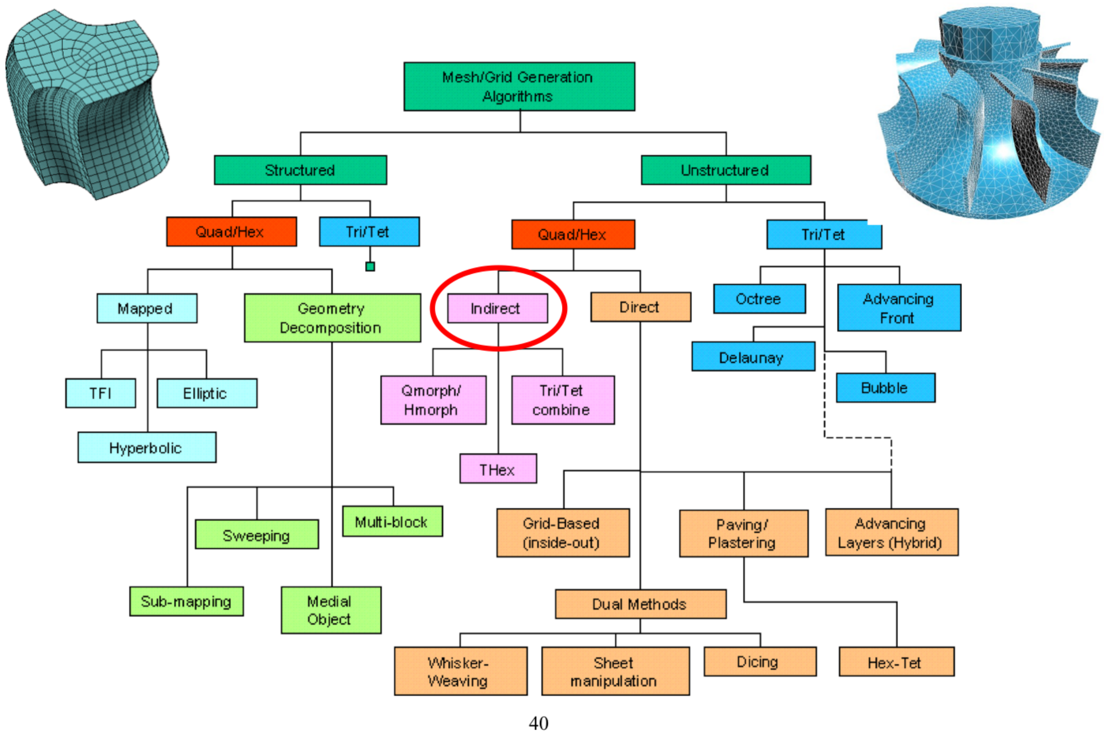


Figure 4: Mesh generation techniques [Owen]

Frequency-domain solvers

In the **frequency domain**, the main issue is the solution of the large, complex and possibly indefinite linear system of equations arising from the discretization of the (linear) partial differential equations. Standard parallel direct solvers [Amestoy-Duff-L'Excellent-Koster] do not scale to such problem sizes, and, due to the indefinite nature of the matrices, iterative linear solvers (preconditioned Krylov solvers or multigrid methods) exhibit slow convergence, or even diverge [Ernst-Gander]. **Domain decomposition methods (DDMs)** currently provide the only viable alternative, by iterating between sub problems of smaller sizes, amenable to sparse direct solvers [Toselli-Widlund].

Non-overlapping DDMs were introduced by Lions [Lions] for the Laplace equation and first extended to the Helmholtz equation by Després at the beginning of the 1990's [Després]. Essentially, the method consists in combining the continuity conditions (of the field and its normal derivative) on the artificial interfaces between subdomains, in order to obtain Robin boundary conditions and to solve the overall problem by iterating over the subdomains.

Robin conditions (also called absorbing or impedance boundary conditions) are chosen to couple the subdomains because using the natural conditions leads to divergent iterative algorithms [Bendali-Boubendir-Fares]. Developments in the last decade have focused on improving the convergence properties of Robin-type DDMs by constructing more **accurate approximations of the non-local Dirichlet-to-Neumann (DtN)** on the interfaces. A great variety of techniques have been proposed: these include the class of FETI-H methods [Farhat-Macedo-Lesoinne], the optimized Schwarz approach [Gander-Magoules-Nataf], and the evanescent modes damping algorithm [Bendali-Boubendir-Fares]. Very recently, an algorithm with quasi-optimal convergence properties was proposed in [Boubendir-Antoine-Geuzaine], which uses a complex **Padé-localized approximation** of the DtN to accurately approximate its key spectral properties. **Perfectly matched layers (PMLs)** are also currently studied to build overlapping DDMs, which, while harder to setup computationally, exhibit very promising behavior in the presence of heterogeneities [Engquist-Ying] [Vion-Geuzaine] [Stolk].

In addition to improvements to the transmission operators, various preconditioners have been proposed, either for the original Helmholtz operator, or for the DDM iteration. In the former category, the so-called **Analytic Incomplete LU (AILU) preconditioner** [Gander-Nataf] relies on the availability of globally cartesian meshes to build symbolic factorizations of the Helmholtz operator. If **locally cartesian hexahedral meshes** were available, this AILU preconditioner could be used in a block-type algorithm on each subdomain. The difficulty there is to generate locally cartesian hexahedral grids in geometrically complex domains. In the latter category, much recent work has been devoted to so-called **sweeping preconditioners**, which, at the cost of decreased parallelism, can result in iteration counts virtually independent of the number of subdomains [Engquist-Ying] [Stock] [Vion-Geuzaine]. The parallelization of such preconditioners is currently an active research area [Poulson-Engquist-Li-Ying] [Vion-Geuzaine-2]. Most of these promising developments are made for the scalar Helmholtz equation; theoretical and computational advances are required to apply them to realistic geophysical problems.

Time-domain solvers

The Runge-Kutta discontinuous Galerkin (RKDG) method associates explicit Runge-Kutta (ERK) time stepping with a discontinuous Galerkin (DG) spatial discretization. The RKDG approach, introduced by Cockburn and Shu in 1998 [Cockburn-Shu], results in methods which are **stable**, **high-order accurate**, **highly parallelizable** and **able to handle complex geometries**. Explicit DG methods have been successfully applied to acoustics waves [Atkins-Shu] [Chevaugeon-Remacle-Gallez], elastic waves [Wilcox-et-al] [Käser-Dumbser], electromagnetic waves [Lu-Zhang-Cai] [Fezoui-Lanteri-Lohrengel-Piperno], ocean waves [Giraldo-Warburton] [Bernard], atmospheric waves [Giraldo-Hesthaven-Warburton] [Nair-Thomas-Loft]. Specific extensions have been proposed that are tailored for hex meshes [Cohen-Ferrieres-Pernet].

The main advantage of time-domain formulations is **scalability**: RKDG methods have proven to scale to thousands of processors [deWiart-et-al, Dawson-et-al]. The excellent dispersion properties of the high order DG scheme [Ainsworth] allows one to use a limited amount of points per wavelength (typically 6 for a polynomial order of 4, [Chevaugeon-et-al]). Yet, due to stability reasons (CFL condition, [Cockburn-Shu-2]), solving wave problems in the time domain requires many more timesteps per period that points per wavelength. Because signals have to travel several times the computational domain for attaining an “harmonic equilibrium”, the number of time steps in a simulation can be extremely large, especially for high frequencies.

The number of time steps being constrained by stability conditions, the objective of WAVES should be to **accelerate computations**. There are essentially three paths that can be followed that could lead to substantial acceleration. The first one is algorithmic, the other ones are “pure number crunching”.

For explicit time integration methods, the local CFL constraint is dependent on both the mesh spacing and the maximum wave speed. In many realistic scenarios, it may occur that mesh size and wave speed vary dramatically in space yielding relatively low computational efficiency. Explicit multirate methods allow the use of different time steps, which are integer ratios of each other. Osher and Sanders have proposed the first multirate scheme in 1983 in the context of the finite volume method [Osher-Sanders]. Osher and Sanders’s approach was only of the first order of accuracy. Tang and Warnecke [Tang-Warnecke] constructed a second-order multirate scheme based upon Heun’s method. The *recursive flux splitting multirate* (RFSMR) method that has been proposed by Schlegel et al. [Schlegel-et-al] is of the third order of accuracy. An efficient parallel implementation of second and third order multirate schemes has recent been proposed by this consortium [Seny-et-al, Seny-et-al-2].

The use of **tensor product based operators** on hexahedral meshes allow to dramatically reduce the operation count [Fisher, Deville-Fischer-Mund] at the price of a reduced integration [Hesthaven-Warburton]. This is another clear advantage of hex-meshes.

Most of the bits we’ve been crunching up to now were run through the Central Processing Unit of our computer (CPU). Off-the-shelf **computer’s massively parallel Graphic Processing Units** (GPUs) are increasingly being used for general computing tasks. GPUs are not only cheaper (less Euros per floating point operation) but they are also way more efficient (less Watts per floating point operation [Huang-Xiao-Feng]). The problem has always been to design applications that can take advantage of the incredible raw computing power of GPUs. CPUs have several cores (typically 4 in today’s CPUs) capable of running a few processing threads. A GPU typically has a large number of slower processing cores (typically over 1000 on today’s GPUs) which can run more simultaneous threads. GPU computing is inherently more parallel than its CPU counterpart. Moving from multi-core to many-core is a clear trend that computer codes will have to deal with. It implies to re-think most of our algorithms in a way that they would perform “many simultaneous slow threads”. Not all of the methods designed for CPUs will be able to take advantage of GPUs. It has been shown in the literature that the DG scheme is one of the numerical methods for which a significant speedup has been observed while implemented on GPUs [Klöckner-et-al]: in their paper, Klöckner and his co-authors have obtained speedups of about 30 on an inexpensive off-the-shelf GPU.

Interface capturing

In both frequency domain and time domain, discontinuities (in physical properties such as e.g. wave velocity, density, stiffness…) are usually taken into account by ensuring they are part of the mesh used to carry out the simulation. In our case, these discontinuities are not represented in a fashion that makes it straightforward to have them meshed in a conformal way with the bulk of the domain. Event if it were the case, there are good reasons to have the possibility to **represent discontinuities in a non conformal way**: among those, the fact that we favor quasi-structured hexahedral meshes for our numerical schemes because they are much more efficient on such meshes over large chunks of the domain is the most important reason. Meshes made up from hexahedra are however not as versatile as those made up from tetrahedra when it comes to selective refinement and anisotropy—the tools are simply not mature enough to be used in that context. Therefore, one of the important issues in this proposal is to find a suitable numerical scheme able to mimic the presence of these discontinuities, without degrading the numerical efficiency—namely scalability and low algorithmic complexity—that is sought in this project. The most recent works dealing with this issue in the literature are based on **partition of unity methods (PUM)** and/or the **extended finite elements (XFEM)**; see e.g. [Moes-Dolbow-Belytschko] and [Babuska-Melenk] for seminal works, [Liu-Oswald-Belytschko] and [Annavarapu-et-al] for more recent works. These methods were used in various settings, but so far little exists in (i) the case of Helmholtz equations for the frequency domain and (ii) the case of time domain with high order DG approximations. In addition, we found no trace in the literature about the application of these methods to geophysical problems.

4.3. General objective

The research proposed in the WAVES project aims to contribute to the solution of **two major bottlenecks** for the **solution of large-scale wave propagation problems in complex heterogeneous media, in frequency and in time domain**. The first challenge concerns the automatic **generation of finite element meshes** in complex, anisotropic domains described in non-standard fashion. Two examples of such domains are the underground soil, made of geological layers and potentially crossed by faults; and a continental shelf with all the spatial scales, going from a few meters to hundreds of kilometers. The second challenge concerns the **high-fidelity numerical solution of the wave equations**, in frequency and time domain, in such complex media, which requires the design of novel, scalable algorithms that can deal with extremely large grids on distributed high performance computing (HPC) clusters. These two challenges are **intimately linked**: indeed, even if it is nowadays possible to generate “a mesh” in about any geometrical situation, it is the numerical solution scheme that will impose its limits on this mesh (anisotropy, gradation, density).

The project proposes an innovative approach to overcome these two major difficulties, based on locally Cartesian hexahedral meshes and the associated frequency- and time-domain solvers. The project is organized around four main research axes. The first one concerns the **generation of such hexahedral meshes on the non-standard geometries** encountered in geophysical applications. Based on these meshes, the three other axes deal respectively with the design of **scalable domain decomposition methods (DDM) in the frequency domain** (for steady-state time-harmonic linear wave propagation); the design of **scalable time-domain schemes** (for transient, possibly non linear wave propagation); and the design of **interface capturing techniques** (to represent sharp discontinuities without explicitly taking them into account in the hexahedral grids).

All the developments will be carried out in the open software platform Gmsh (http://gmsh.info) [Geuzaine-Remacle], which is actively developed and used by the members of the WAVES consortium. The resulting software, including both the mesh generation algorithms and the scalable high-performance solvers, will be distributed as **open source building blocks directly usable by the scientific community at large**.

4.4. Project description

The project is organized in four work packages:

WP1: Generation of hexahedral meshes on non-standard geometries
WP2: Domain decomposition techniques for time-harmonic waves
WP3: High-order time-domain schemes on hexahedral meshes
WP4: Interface capturing techniques on non-conformal hexahedral meshes

In the detailed work plan, two other work packages (WP0 and WP5) are not detailed in this description.

These four work packages are described hereafter.

WP1 Generation of hexahedral meshes on non-standard geometries

Using finite element type methods in new application domains like geophysics [Hanert-et-al] requires a re-thinking of a range of fundamental assumptions, in particular mesh generation. In classical engineering applications, the geometrical description of models is carried out using Computer Aided Design (CAD) software (see Figure 5). CAD models are widely used as the input for analysis: finite element meshes are directly generated on the basis of CAD models [Geuzaine-Remacle].

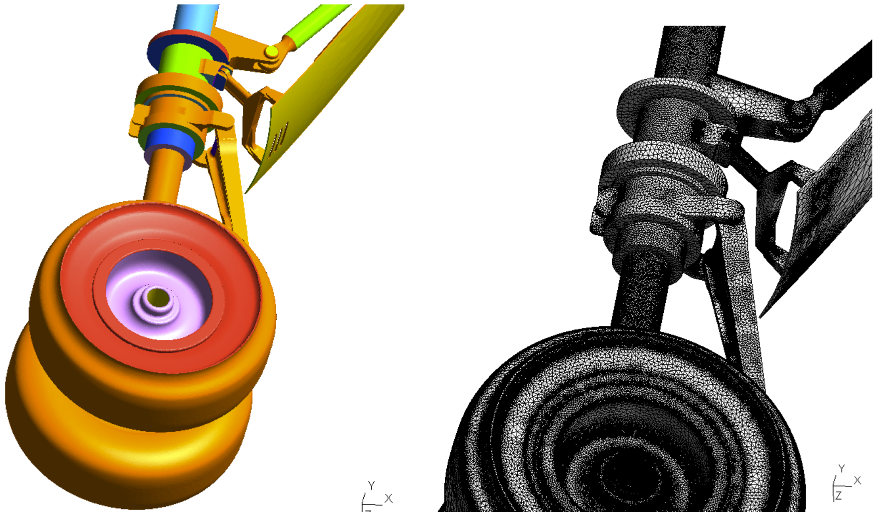


Figure 5 - A Landing Gear: CAD model (left) and Mesh (right)

The geometrical description of an oil reservoir or of a continental shelf requires a different approach that is not based on a CAD description.

The oil or the gas that is present in a reservoir is contained in high-porosity channel sands. Those are usually contrasted with rocks or muds. The distribution rock types and the nature of the boundaries between them (sedimentary or structural) are critical informations in order to simulate underground seismic waves with a high fidelity. Measurements are available in the form of very large data sets that describe the local nature of the soils together with discrete data that describe the interfaces between bodies. The size of such datasets typically exceeds the Terabyte.

The anisotropic nature of such domains, the large range of spatial scales involved, the noisy character of the input data requires new approaches. There exists today no solution for generating meshes in an automatic manner for geophysical applications in general. One of the main objectives of this project is to develop innovative approaches to treat those large data sets and generate hexahedral meshes that are readily usable for wave simulations. The teams involved in this project are widely recognized as international experts in mesh generation: Gmsh is used in thousands engineering offices and universities around the world. This project will allow us to move our research from standard CAD-based systems to more challenging BigData-based applications.

Task 1.1: Mesh generation for Non-CAD systems

The members of WAVES consortium have already gained some experience in the generation of meshes for non-CAD systems (see Figure 6a and 6b). In a recent work, Profs. Deleersnijder, Remacle and Geuzaine have developed mesh generation procedures that allow representing coastal domains with a prescribed accuracy [Lambrechts-et-al]. Coastline[5] and bathymetry[6] raw data are used to produce high quality 2D and 3D meshes of any coastal zone of the earth. Our system is now widely used in the ocean modeling community. Profs. Remacle and Geuzaine have also developed mesh generation procedures for generating meshes based on medical imaging [Marchandise-deWiart-Vos-Geuzaine-Remacle] [Marchandise-et-al]. Dicom[7] medical imaging data were used as input to produce high quality meshes of the cardiovascular system, of human upper airways or of bones. Special surface reparametrization procedures were developed that allow reducing the size of raw data and that are readily usable for mesh generation [Remacle-Geuzaine-Compère-Marchandise].

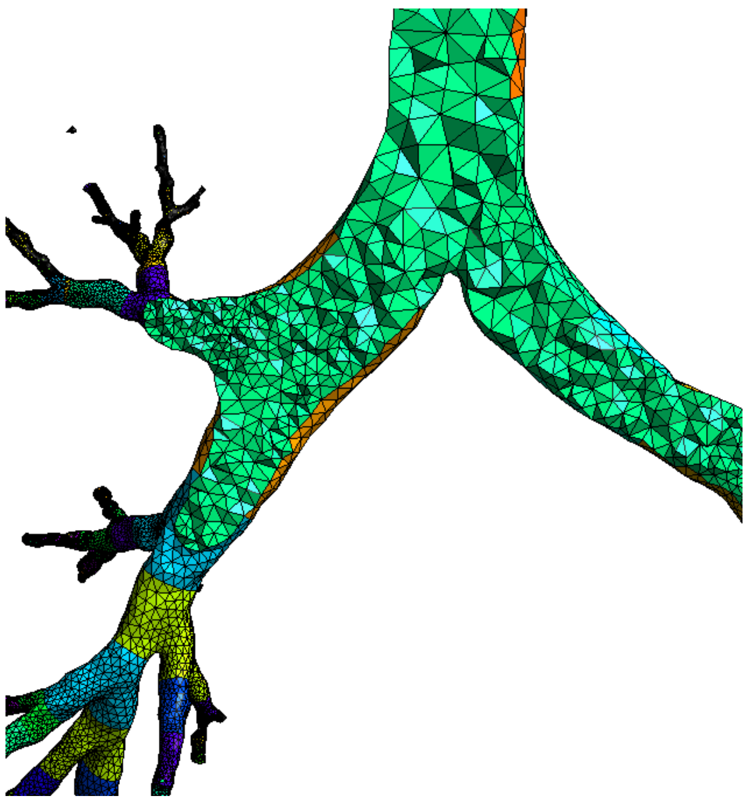


Figure 6a - 3D mesh of the human lungs

5 http://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html
6 http://www.gebco.net/data_and_products/gridded_bathymetry_data/
7 http://en.wikipedia.org/wiki/DICOM

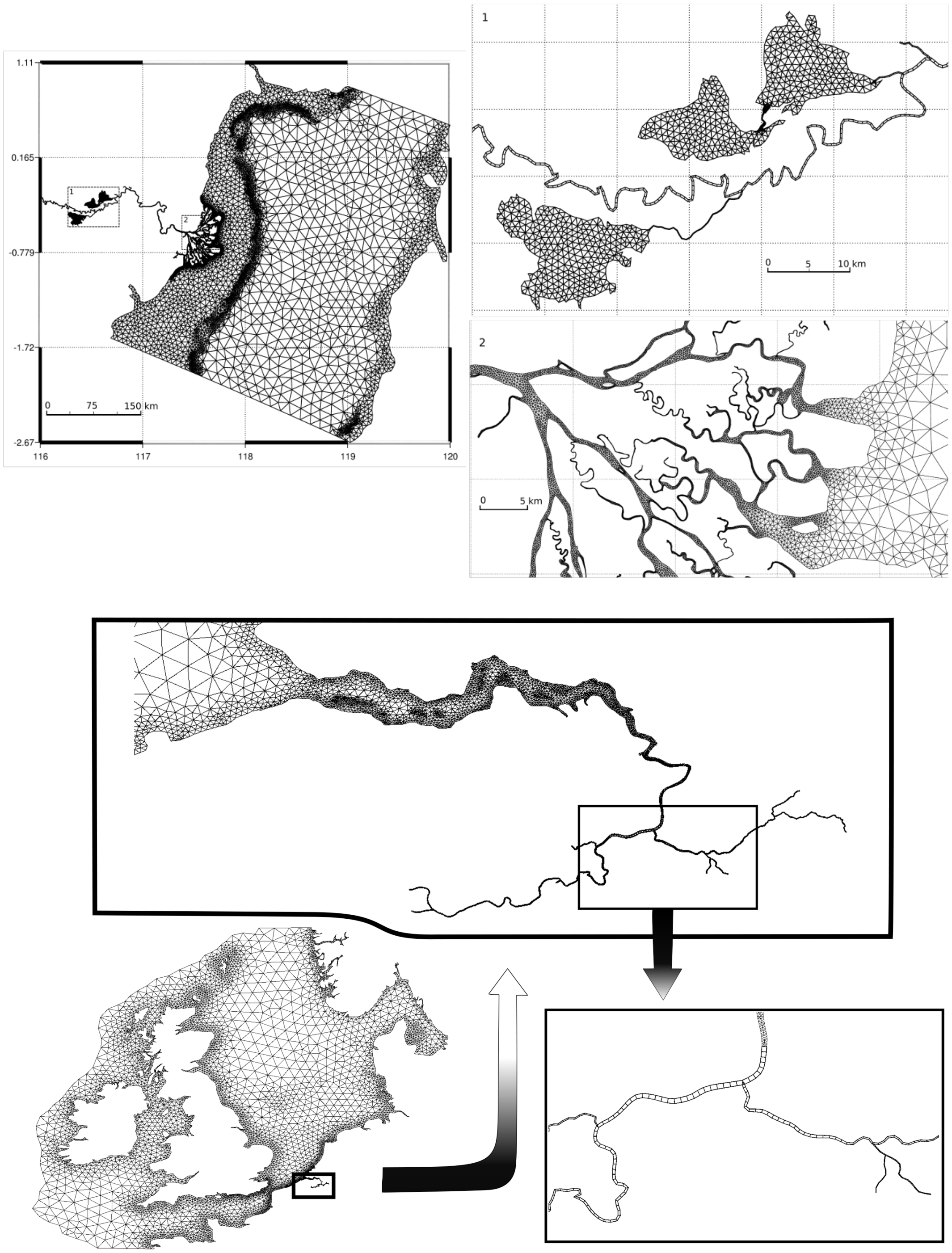


Figure 6b - Meshes of the Mahakam River and Delta (Indonesia) (top) and the Scheldt estuary and tidal river network (bottom).

The first dataset contains surfaces that represent discontinuities in the domain. Those surfaces are often “bad”, with holes and missing parts; bodies or salt bags can have holes where they should not, especially when they were created by gluing two horizons together. Horizons may intersect where they should not, or may coincide -- a horizon being a function *z(x,y)*, often created by an auto picker. Mesh generation will have to deal with those bad/noisy/incomplete data with the aim at producing high quality meshes in an automatic manner.

One of the key issues here the availability of a representation of the underground geometry that will be adapted to the mesh generation procedures. In the 90s, methods using level-sets [Osher-Sethian] gained a lot of momentum in somewhat similar settings. However, the issue here is that the primary information that is available (surfaces representing discontinuities in the domain) is of rather complex topology on one hand, and contains inaccuracies or noise on the other hand. WAVE's consortium has a strong experience in using level-set to represent arbitrary geometries (in fact including CAD geometries in a process of shape optimization as shown in figure 7). Those techniques are mature regarding the representation of topologically simple models with a complex geometry (e.g. a crack, or one single interface), or complex but clean topologies (e.g. CAD models). To combine both difficulties is still a challenge and have to be dealt with the objectives in mind for this project. The numerical technique dealt with here will be based on high order discontinuous Galerkin methods, so we have to devise a representation scheme that takes this particularity into account. One possibility here would be to represent the discontinuities element-wise and not globally, therefore avoiding completely topological issues. The fact that one does not need to tag regions globally (as in CAD models) also hints toward a more local approach.

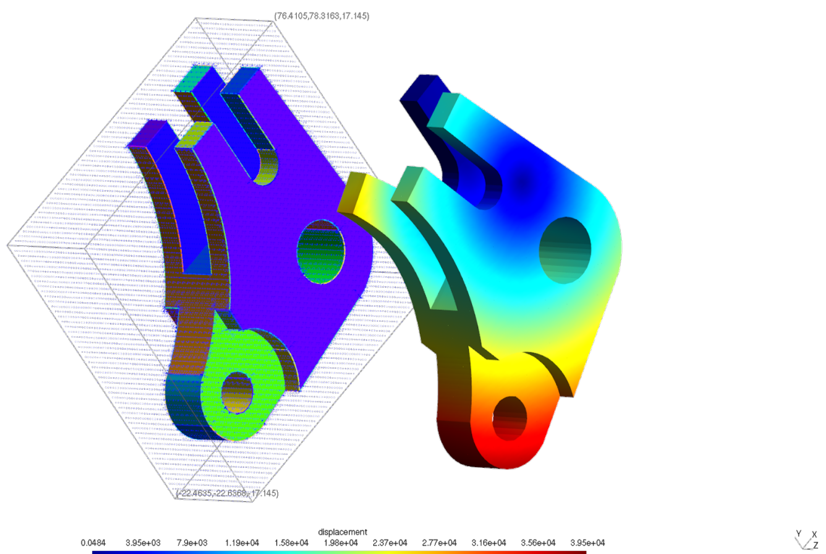


Figure 7 - 3D non-conforming structured mesh (nodes only) with level-set surfaces of a mechanical part (left) - Displacement field: a mechanical force is applied to the lower eye (right)

The second dataset contains pointwise "velocities" i.e. it characterizes wave speeds in the various materials contained in the underground. Those datasets are usually based on voxels and are usually very large (over one Terabyte).

An international consortium (GoCAD[8]) has proposed a standardized way of describing geophysical datas. GoCAD input contains raw data that are similar to Dicom inputs for medical imaging. We will use this standard as input in our meshing procedure.

[8] http://www.gocad.org/w4/index.php/consortium/why-join

Task 1.2: Generation of Hexaedral meshes in thin domains

A domain is said to be thin when one of its dimensions is much smaller than the others. In thin domains, surface meshes should be designed in such a way that meshes on surfaces that are close should be aligned in order to avoid the generation of degenerated elements. An initial tetrahedral mesh that is conforming to thin structures will be generated at first. Such an initial 3D mesh allow to compute relevant geometrical information's such as distances: if $d(\mathbf{x}_i)$ is the distance to point $\mathbf{x}_i$ to the closest surface and of h is the desired mesh size, then, if $d(\mathbf{x}_i) << h$, two sides of a thin region are detected. One of the sides will be considered as master and the trace of the master mesh will be computed on all surfaces that are close to it. A second tetrahedral mesh will be generated with the new surface mesh as input. The indirect algorithm presented in [Baudouin-et-al] will be used to build the final hex mesh. Issues related to non-manifold domains containing T-junctions or more complex bi- or tri-furcations will have to be addressed.

WP2 Domain decomposition techniques for time-harmonic waves

Using finite element methods for high-frequency problems implies the solution of wave equations on extremely large volume meshes, with a huge number of grid points—about 250 million for the rather simple example depicted on Figure 1. As explained in WP1, generating the grid is the first challenge. The second challenge is that no current time-harmonic (frequency domain) finite element technique scales on such problems. This is a major bottleneck for many applications, where currently only non-convergent (whose accuracy cannot be controlled) asymptotic techniques can be used. This is the second major challenge that we want to tackle.

To solve high-frequency FEM in a scalable way, domain decomposition methods (DDMs) are currently the only viable strategy, due to shortcomings in iterative linear solvers (preconditioned Krylov solvers or multigrid methods for indefinite matrices). In the family of DDMs, so-called Optimized Schwarz methods have proved to work well, but their convergence strongly depends on the choice of the transmission operators used to couple the sub-problems. It is well known that the optimal transmission operator is, in the case of linear acoustics, the non-local Dirichlet-to-Neumann (DtN) integral operator associated with the complement of the subdomain of interest. Scalability in the high-frequency regime requires localizing this operator while preserving key spectral properties of the original DtN map. To attain this goal the adapted mathematical framework is pseudo-differential operator theory and symbolic calculus. For homogeneous media, the construction of quasi-optimal DDMs has been successfully achieved in [Boubendir-Antoine-Geuzaine] for the Helmholtz equation. The non-homogeneous case remains an open problem, which we propose to address in this project (Task 2.1). The second challenge for time-harmonic domain decomposition methods is to achieve scalability with respect to the number of subdomains, i.e., to obtain algorithms that exhibit a number of iterations independent of the number of subdomains. We propose to investigate this issue in Task 2.2 through the development of sweeping-type preconditioners [Ying-Engquist] [Stolk] [Geuzaine-Vion].

Task 2.1: High-order local transmission conditions for elastodynamics

The efficient implementation of the transmission operators for the DDMs can be carried out in a finite element context using high-order rational approximations of the symbols of the transmission operators. Such approximations generalize common impedance-type transmission conditions used in the literature [Gander-Magoules-Nataf], and can lead to quasi-optimal domain decomposition methods (DDM), in the sense that their convergence rate is optimal for evanescent modes and improves on competing approaches in the rest of the spectrum (see Figure 8 and 9). This quasi-optimality is crucial for high-frequency scalability, i.e., to obtain algorithms which converge in a fixed number of iterations with respect to the frequency, as was proved for low order FEM in [Boubendir-Antoine-Geuzaine] (see Figure 10).

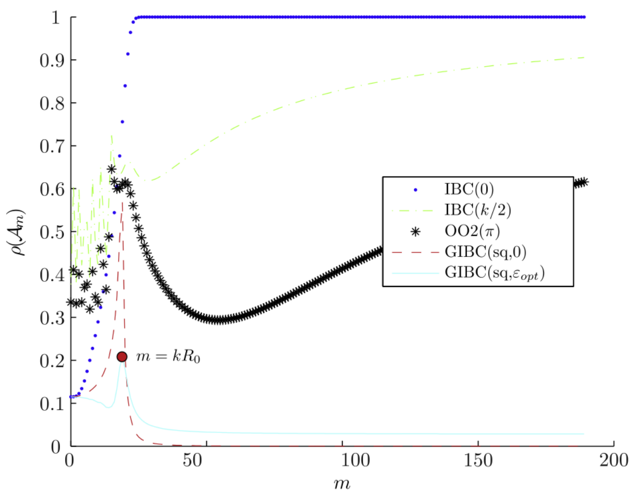


Figure 8 - Spectral radius of the model iteration operator for a DDM with 2 subdomains, with circular interface. GIBC denotes the novel high-order Padé-localized transmission condition [Boubendir-Antoine-Geuzaine].

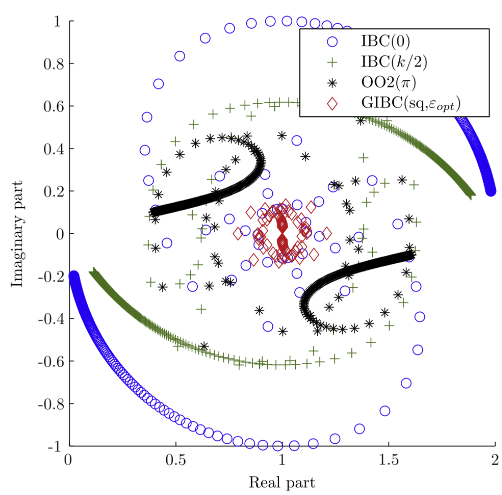


Figure 9 - Spectrum of (identity minus the) iteration operator; shows clustering of eigenvalues around (1,0) for the high-order Padé-localized condition [Boubendir-Antoine-Geuzaine].

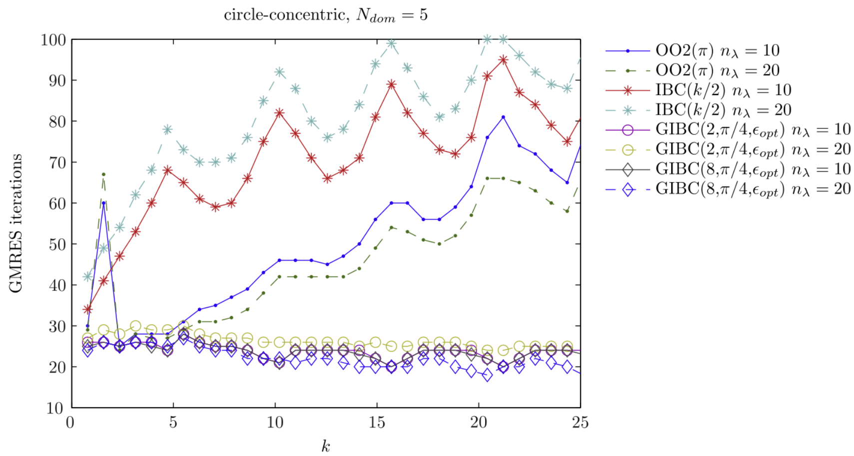


Figure 10 - Convergence of the DDM (# of GMRES iterations) vs. wavenumber, showing optimal high-frequency behavior of the high-order Padé-localized DDM [Boubendir-Antoine-Geuzaine].

In this task we will extend the results obtained in [Boubendir-Antoine-Geuzaine] in several ways. First, in order to reduce the number of degrees freedom for the local subproblems or to increase the accuracy of the solution for a given mesh, we will investigate high-order FEM discretizations on the hexahedral meshes developed in WP1. Second, we will extend the whole procedure, including the rational approximations and the high-order FEM, to elastodynamics for homogeneous media, based on the recent theoretical work of Darbas and Le Louer [Darbas-LeLouer]. For the solution of the (smaller size) subproblems in each subdomain we will exploit the locally cartesian character of the hexahedral meshes to construct efficient AILU-type preconditioners [Gander-Nataf], which will be compared with full direct sparse solvers [Amestoy-Duff-L'Excellent-Koster]. In a third step, we will apply the obtained DDMs to smoothly varying non-homogeneous media, before considering media with sharp discontinuities. In the latter cases, in addition to high-order Padé-localized rational approximations, we will consider high-order transmission conditions based on perfectly matched layers (PMLs). Indeed, promising results for acoustic waves [Engquist-Ying] [Stolk] [Vion-Geuzaine] tend to show that PMLs can be a compelling alternative for strongly heterogeneous and/or anisotropic media. In all cases, improvements of the current meshing technology (partitioning, generation of overlaps) will be necessary in order to preserve scalability of the algorithms. Finally, we will explore if and how some of the developed techniques could be applied to the nonlinear case. This last research direction is completely open, but could benefit from recent advances in the field of computational quantum mechanics [Antoine-Bao-Besse].

Task 2.2: Parallel sweeping preconditioners

Scalability with the number of subdomains will be investigated through the use of sweeping-type preconditioners, as recently proposed for time-harmonic acoustics in [Engquist-Ying] [Stolk] [Vion-Geuzaine]. Two main sub-tasks will be carried out. First, we will extend the double-sweep preconditioner proposed in [Vion-Geuzaine] to elastodynamics, using the transmission conditions developed in Task 2.1. Then, we will investigate the parallel application of this preconditioner by following a double-pronged strategy. Indeed, sweeping approaches introduce intrinsically sequential operations in the solution process, and their efficient use on large scale high performance computing clusters requires special attention. The first strategy is to introduce "cuts" in the decomposition, in order to apply the sweeping preconditioner on smaller groups of subdomains, which effectively amounts to applying a block-type preconditioner. As was shown in [Vion-Geuzaine-2], this block-type application can restore some parallel efficiency, albeit to the detriment of a degraded iteration count. A second strategy, particularly well suited to the inverse problems in seismic imaging, is the construction of a parallel, pipelined version of the preconditioner. The pipelining idea rests on the following observation: for inverse seismic problems, multiple artificial wave sources (up to several thousand independent sources for land-based exploration by e.g. BP[9]) are used to trigger waves, whose reflection are recorded by geophones in order to reconstruct the underground soil. As all these sources are independent, this amounts to solving a linear problem with multiple right-hand-sides. The sweeping preconditioner could then be applied in a pipelined fashion, i.e., each sequential phase starting with a one-subdomain offset, allowing to recapture almost perfect parallel scalability on as many CPUs as there are sources. To the best of our knowledge, this approach has never been tested in the literature, and could lead to a true breakthrough for practical large-scale computations.

WP3 High-order time-domain schemes on hexahedral meshes

Membres of WAVES consortium are renowned specialists in the domain of Discontinuous Galerkin Methods. The discontinuous Galerkin (DG) method is a compact finite element method that provides a practical framework for the development of high-order accurate methods for unstructured grids. The method is well suited for large-scale time-dependent computations in which high accuracy is required. High order DG methods have proven their numerical superiority with respect to second order scheme for wave applications in the time domain. Time domain computations are of course useful to solve unsteady problems, but they can also serve as an alternative to harmonic approaches for highly non-linear problems. Explicit time integration will be privileged with multirate time stepping schemes [Seny-et-al, Seny-et-al-1].

Task 3.1: Spectral Discontinuous Finite Elements on Hexaedral Grids

Hexahedral grids allow the use of finite element basis that are tensor products of one dimensional basis of P_n that are the set of Lagrangian interpolants $L_j(t)$, j=0,...,n, on the Gauss-Lobatto Legendre (GLL) quadrature points in the reference domain: t_i in [−1,+1], i = 0,...,n [Fisher]. The use of such tensor product basis is well adapted to modern CPU architectures such as GPUs or ARMs. We will develop our solvers on those new architectures using OCCA, the extensible multi-threading programming API [Medina]. OCCA is a C++ library focused on host-device interaction. Using run-time compilation and macro expansions, OCCA is a novel single kernel language that expands to multiple threading languages. Currently, OCCA supports device kernel expansions for the OpenMP, OpenCL, and CUDA platforms. Pr. Remacle is spending one year in a sabbatical leave in the group of Pr. Warburton where OCCA has been developed. In WAVES, we will strengthen our

[9] http://www.bp.com/en/global/corporate/about-bp/bp-and-technology/more-discovery/land-seismic-imaging.html

interactions with Pr. Warburton's group. As an example, we have developed a simple hex-based spectral finite element code using OCCA that solves a 3D diffusion problem implicitly using preconditioned conjugate gradients. The two more consuming kernels of the process (90% of the time) are the computation of the residual and the preconditioner. Figure 11 shows the performance (in GFlops) that was obtained with different polynomial orders using CUDA and using OpenCL on the CPU. GPU computations were made on one single GPU NVIDIA Tesla K40 and multi-threaded CPU computations were done on a 32-core Intel machine. We observe a speedup of over 30 for all polynomial orders.

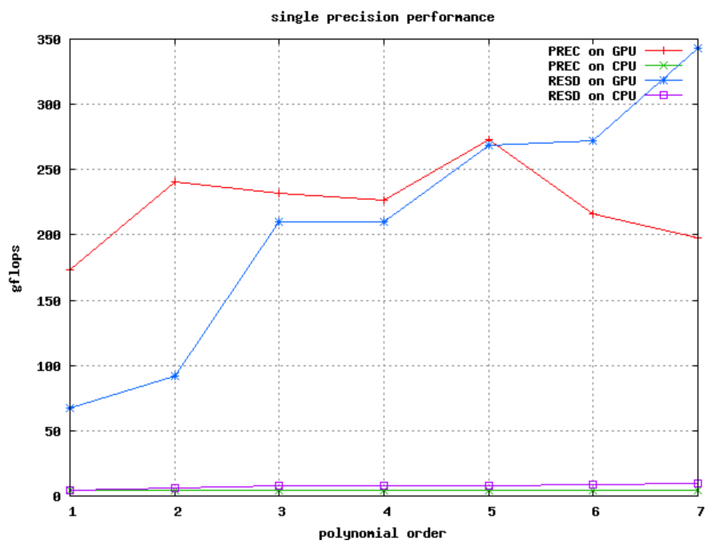


Figure 11 - Number crunching on a modern GPU vs. on CPU

Task 3.2: Absorbing Boundary Conditions in the Time Domain

This tasks aims at improving the numerical simulation of unbounded domains through artificial boundary treatments in the time domain [Modave-Deleersnijder-Delhez]. First, we plan to study the characteristics of existing high-order absorbing boundary conditions (ABCs) and perfectly matched layers (PMLs) for elastodynamic cases of increasing complexity (homogeneous/heterogeneous media, isotropic/anisotropic media) [Basu-Chopra] [Meza-Fajardo-Papageorgious] [Kucukcoban-Kallicokas] [Duru-Kreiss] [Sagiyama-Sanjay-Persson] [Ping-Zhang-Xu] [Rabinovich-Givoli-Hagstrom-Bielak] [Hagstrom-Warburton]. In particular, we plan to study the accuracy and the computational efficiency of the truncation for different elastic wave modes, and to study its long-time stability. The selected and/or proposed ABC/PML formulations will then be adapted to anisotropic and heterogeneous media. Supplementary systematic comparisons with numerical benchmarks will be done to evaluate the features of each formulation. Benchmarks with media of increasingly complexity will be considered: from homogeneous to heterogeneous and from isotropic to anisotropic (in particular: vertical transverse isotropic and tilted transverse isotropic). Depending on the results, the formulations could be derived and tested for truncated domains with different shapes (cuboidal or convex with a regular boundary), and the compatibility with different numerical schemes could be discussed. In addition, if no spurious oscillations appear in the numerical simulations, proofs of the stability of ABC/PML formulations could be investigated using classical energy-based methods. For the PMLs, the criterion of Bécache et al. [Becache-Fauqueux-Joly] will also be used.

WP4 Interface capturing techniques on non conformal hexahedral meshes

In an harmonic approach as well as when the numerical integration is made in time, the question of representing non mesh- conforming discontinuities often arises. In fact, it seems troublesome to represent these discontinuities in a conventional way (constraining mesh elements to share boundaries with the discontinuities), because this implies a precise representation of every internal boundary in a structured and sound way, e.g. in a B-Rep data structure. As stated in the introduction, such a representation is not always available, especially in the specific case of seismic underground waves. Here, we propose to use partition of unity / extended finite element (PUM/XFEM) techniques to tackle the accurate representation of sharp discontinuities that are often strong features of the underground structure.

In the case of an harmonic excitation, as stated before, the Helmholtz equation may be solved to accurately represent the spatial variations of the response of the media. To the best of our knowledge, no application of these techniques has been done to solve the harmonic wave propagation in geology using high order discontinuous Galerkin (DG) functional spaces, and this constitutes one of the deliverables of the research we propose in this work package. Now, in the case of non-harmonic excitations (e.g. impulses), the above techniques are not often used, as researchers usually favor explicit time integration in that case. There are however still numerous problems related to the stability of such numerical schemes in the case of perturbations in the domain of interest (here, we mean the very local change of functional space), and this is relatively unexplored in the case of high order DG finite elements. We propose here a second deliverable to this work package that is to explore this technique in the case of explicit time stepping DG method.

Task 4.1: Accurate representation of waves along sharp interfaces in an harmonic setting

The goal of this task is to develop a numerical scheme that allows to embed sharp interfaces into an arbitrary mesh for the Helmholtz equation, first for scalar problems (like acoustics and wave propagation in fluids) then for the more complex setting of elastic waves, where the interfaces may have a different behavior if one considers shear waves or compression waves. The interfaces considered here are sharp; it means that the thickness of the transition between media that differ in their mechanical properties is smaller than the elements that are used to model the rest of the domain. As stated in the introduction we plan to use PUM/XFEM-like methods and adapt those to the case of DG.

Using the PUM/XFEM techniques in the case of the Helmholtz equation is not entirely new, see for instance the works in [Strouboulis-Babuska-Hidajat] and [Strouboulis-Hidajat-Babuska]. In the latter case, the PUM was used to represent the wave in a plain 2D or 3D domain. For instance, a planar wave may be easily represented by a simple analytical function that is then embedded in the functional space used in the finite elements. The problem here is that while it works perfectly in the one dimensional case where waves have only two directions to propagate, it is definitely not so appealing in higher dimensions because of the complexity of the propagation patterns that increase significantly dispersion errors, even using enriched finite elements with additional propagation modes. In this task, rather than trying to embed new shape functions to enhance the solution in the 3D domain, we will concentrate on the discontinuities. The challenge here is to capture the peculiar behavior of waves around discontinuities (reflection, transmission, scattering if the discontinuity is not smooth).

First we will concentrate on the less demanding problem of an acoustic wave propagation to explore the numerical properties needed along the interface to get results that are similar to those obtained when the interface is conforming to the mesh. We expect here optimal h-convergence properties with respect to the size of the mesh - same rate as with a conforming approximation of the same order. There are different possible ways of coupling two media with different characteristics. In the literature, one can cite e.g. [Sukumar-et-al] and [Moes-Cloirec-Cartraud-Remacle], and many others following, for which the coupling is implicit through the use of additional enriched shape functions for the case of elastostatics. In [Béchet-Moes-Wohlmuth], the coupling is made explicit through the use of a specific Lagrange multiplier space. In this task, we will assess which method works best in the case of scalar wave propagation. These preliminary results will pave the way to extend the chosen algorithm to (i) elastodynamic wave propagation with dissimilar solid materials, and (ii) to the interface between materials having dissimilar propagation modes - e.g. from solid elastodynamic waves to fluid acoustic waves. There are of course applications for this coupling in marine seismic exploration (see e.g. [Lee-Lim-Min-Kwon-Park] in the case of finite differences).

Task 4.2: Development of stabilization schemes for the PUM/XFEM techniques in high order time domain DG methods

With non-harmonic solicitations, one have to resort to classical explicit time stepping in order to simulate the wave propagation in elastic media. Since a decade, there exist numerous applications of the PUM/XFEM techniques to represent discontinuities in this setting see e.g. [Rozycki-Moes-Bechet-Dubois] and many others e.g. see [Rhetore-Gravouil-Combescure] for dynamic crack propagation. In [Liu-Oswald-Belytschko], the application is more specific to wave propagation in media (composite structures) for which the interfaces between different materials are represented with level-sets. All these applications are made with standard low-order approximations. In the current literature, coupling between DG methods and the PUM/XFEM has been also investigated but mostly for (i) low order cases as in [Shen-Lew] and (ii) for higher order but static Poisson's equations as in [Brandstetter-Govindjee], therefore avoiding stabilization issues that are inherent to explicit schemes. In the case of high order time domain DG approximation, it is difficult to find any existing PUM/XFEM-like approach in the literature. In this projects, there is however a crucial need for such a technique because the mesh will be mostly structured (for an increased efficiency of solvers).
One of the most challenging issue here is the stability of the method with respect of the time step used in the simulation. It has been shown in [Rozycki-Moes-Bechet-Dubois] that if a consistent formulation is used for the discontinuities, the stability criterion for the time step may be well below the actual stability threshold in the bulk of the domain. This is especially true if material properties are very different on either side of the discontinuity (e.g. a void and a stiff material). This has been addressed in the low order case by using non-consistent

formulations (explicit formulations that have a mass matrix that is not computed the same way as the stiffness matrix). Now, for high order DG formulations, the questions remains open on what exactly should be done. Three possible ways of solving the problem of small time steps are envisioned: (i) extend the results that are working already for low order to high order DG methods, (ii) use a local time stepping strategy if the domains have wave speed that differ by at most an order of magnitude (i.e. will probably not work without adaptation on a void-material interface) and (iii) do some mesh fitting where possible. It should be noted that the optimal way to tackle the problem is probably a combination of all three methods.

4.5. Detailed work plan

In addition to the four main scientific work packages (WP1 to WP4) introduced in the previous section, two additional work packages (WP0 and WP5) are introduced in the work plan to handle respectively coordination tasks and the large scale testing of the integrated software on real datasets.

WP0: Coordination

Leader: ULg-ACE. *Participants: UCL-MECA, UCL-MEMA2, ULg-CGEO.*

Scientific and administrative coordination will be carried out by ULg-ACE. A general meeting of all the partners will be organized every 6 months.

ULg-ACE will also coordinate the common IT infrastructure required by the software development (web site, SVN version control, Trac development forge and CTest/CDash automated testing), as well as the distribution of the results as "building blocks" directly usable by the scientific community (e.g. via the ONELAB web site http://onelab.info/

WP1: Generation of hexahedral meshes on non-standard geometries

Leader: UCL-MEMA. *Participants: ULg-ACE, ULg-CGEO.*

Task 1.1: Mesh generation for Non-CAD systems

- **1.1.1.** Preparation of sub-terrain data for mesh generation purposes (M1 → M6). Extension of the reparametrization work of [Marchandise-et-al] and of [Remacle-Geuzaine-Compère-Marchandise] to sub terrain surfaces (M1 → M12). Representation of discontinuities using levelsets (M6 → M12). The first numerical experiments will be based on existing data, e.g. the ones available at http://geodus1.ta.tudelft.nl/seage3dm/.
- **1.1.2** Generation of tetrahedral meshes based on the results of Task 1.1.1. (M6 → M12). Generation of hex-dominant meshes (M6 → M12) and then generation of all-hex meshes (M12 → M36), possibly non-conforming.

Task 1.2: Generation of hex-meshes in thin domains

- **1.2.1** Extension of our work in 2D smooth frame fields [Remacle-et-al] to the 3D case (M12 → M24).
- **1.2.2** Automatic detection of thin regions in general 3D domains. A master-slave 1D and 2D mesh generation procedure will be set in order to enforce points that are on surfaces which are close are set in a structured way (M12 → M36).

- **1.2.3** The frontal approach of [Baudouin-et-al] will be extended to thin domains. This requires smooth frame fields (M18 → M42). This is the main part of the work in WP1.

These tasks will be carried out mainly by the PhD student hired by UCL-MEMA.

WP2: Domain decomposition techniques for time-harmonic waves

Leader: ULg-ACE. *Participants: UCL-MEMA, ULg-CGEO.*

Task 2.1: High-order local transmission conditions for elastodynamics

- **2.1.1** Extension of the results from [Boubendir-Antoine-Geuzaine] using high-order finite element discretizations (M1 → M6)
- **2.1.2** High-order rational approximation of exact transmission operators for elastodynamics with homogeneous media, based on [Darbas-LeLouer] (M6 → M18)
- **2.1.3** Extension of the resulting DDM to smoothly varying or piecewise continuous non homogeneous media, and comparison with Perfectly Matched Layer (PML) based transmission conditions (M6 → M18)
- **2.1.4** Construction of efficient AILU-type preconditioners using local cartesian nature of hexahedral grids, and comparison with classical direct sparse solvers (M24 → M36)
- **2.1.5** Exploration of applicability of developed DDM to the nonlinear case (M36 → M42)

Task 2.2: Parallel sweeping preconditioners

- **2.2.1** Extension of the double-sweep preconditioner proposed in [Vion-Geuzaine] to elastodynamics, using the transmission conditions developed in Tasks 2.1.1, 2.1.2 and 2.1.3 (M18 → M30)
- **2.2.2** Parallelization of the preconditioner using a block-type application strategy, by introducing cuts in the decomposition (M30 → M42)
- **2.2.3** Pipelining of the preconditioner for seismic imaging problems (M30 → M42)

These tasks will be carried out mainly by the PhD student hired by ULg-ACE.

WP3: High-order time-domain schemes on hexahedral meshes

Leader: UCL-MEMA2. *Participants: UCL-MEMA, ULg-ACE, ULg-CGEO.*

Task 3.1: Spectral Discontinuous Finite Elements on Hexahedral Grids

- **3.1.1.** Development of HEX/OCCA-based DGM formulations for the acoustic wave equation, for the elastic wave equation and for the 3D shallow water equations (M1 → M18).

- **3.1.2.** Extension of our work on parallel multirate time stepping schemes [Seny-et-al-2] to GPUs (M18 → M42).

Task 3.2: Absorbing Boundary Conditions in the Time Domain

- **3.2.1.** Study of accuracy, computational efficiency and long-term stability of the truncation for different elastic wave modes and selection of best ABC/PML (M1 → M18).
- **3.2.2.** Extension of the selected ABC/PML formulations to anisotropic and heterogeneous media (M18 → M36).

These tasks will be carried out mainly by the PhD student hired by UCL-MEMA2.

WP4: Interface capturing techniques on non conformal hexahedral meshes

Leader: ULg-CGEO. *Participants: UCL-MEMA, UCL-MEMA2, ULg-ACE.*

Task 4.1 Accurate representation of waves along sharp interfaces in an harmonic setting

- **4.1.1** Assessing the right numerical scheme for acoustic waves crossing an interface between dissimilar materials (enrichment functions, lagrange multiplier approach…) (M1 → M12)
- **4.1.2** Extension to the elastodynamic case (M12 → M24)
- **4.1.3** Fluid/Solid coupling between acoustic and elastodynamic waves (M24 → M36)

Task 4.2 Development of stabilization schemes for the PUM/XFEM techniques in high order time domain DG methods

- **4.2.1** Extension of current algorithms to the case of DG schemes for elastodynamics (M24 → M36)
- **4.2.2** Assessment of the technique and comparison with e.g. node matching algorithms, with inputs from task 1.2.2 (M36 → M42)

These two tasks will be carried out mainly by the PhD student hired by ULg-CGEO.

WP5: Large scale applications on real datasets

Leader: UCL-MEMA. *Participants: ULg-ACE, UCL-MEMA2, ULg-CGEO.*

The goal of this last work package is twofold: (i) Continuous integration of the results from WP1, WP2, WP3 and WP4 and (ii) application of the developed software to large scale test-cases. A rolling integration strategy will be adopted, thanks to the common development platform. The large-scale applications will concern both academic benchmarks (e.g. the Marmousi test-case) and industrial benchmarks (provided e.g. by Total or Shell, with whom ULg-ACE and UCL-MEMA already have existing collaborations).

Task 5.1 Application to complex cases (numerous interfaces and propagation media)

- **5.1.1** Integration 1 (frequency domain): Non-CAD meshes (1.1.1), high-order DDM (2.1.1, 2.1.2, 2.1.3), sharp interfaces (4.1.1) (M18 → M24)
- **5.1.2** Integration 2 (time domain): Non-CAD meshes (1.1.1, 1.1.2), ABCs (3.2.1, 3.2.2) (M36 → M42)

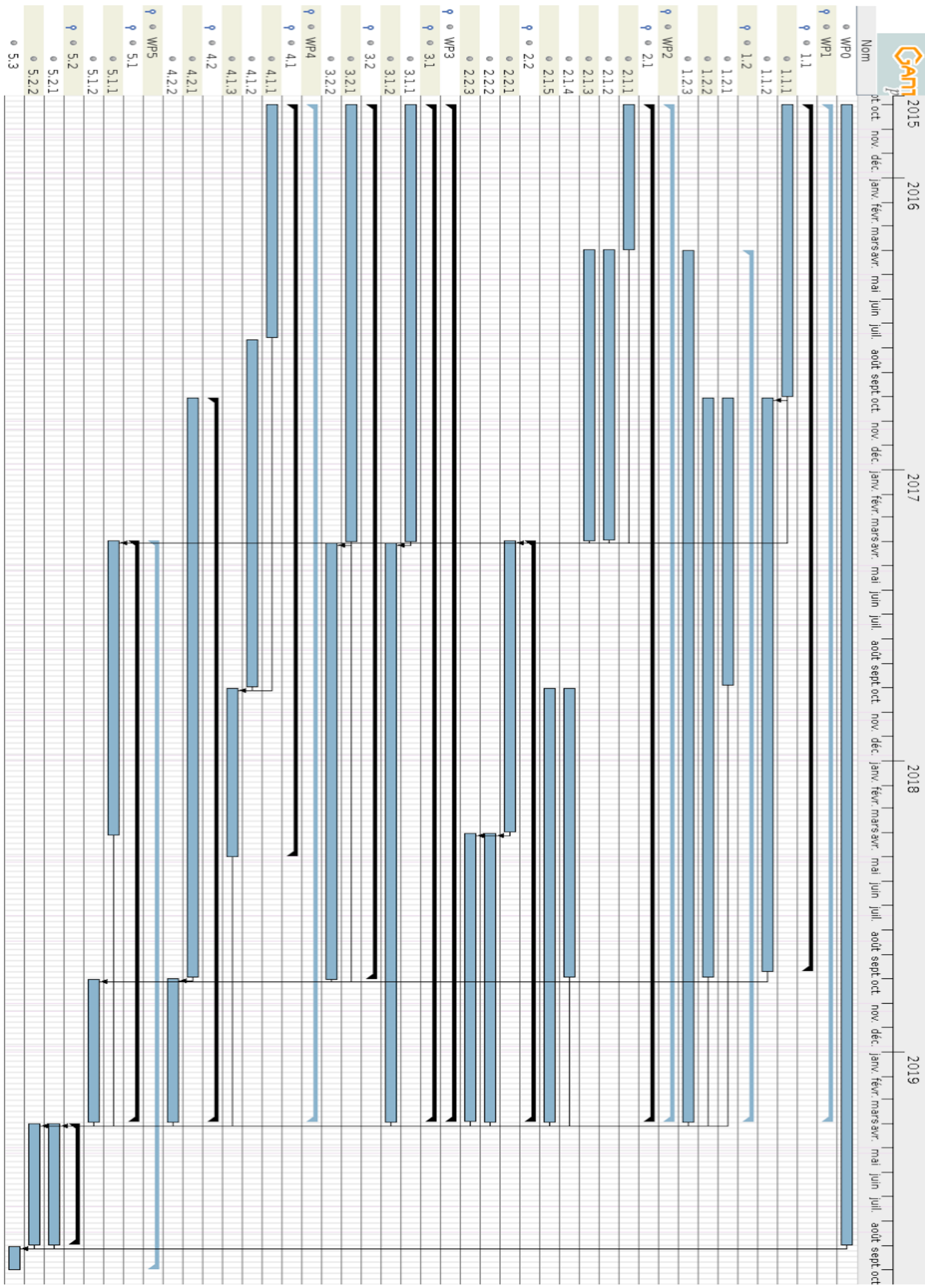
Task 5.2 Application to large-scale cases

- **5.2.1** Academic benchmarks (M42 → M47)
- **5.2.2** Industrial benchmarks (M42 → M47)

Task 5.3 Project evaluation and perspectives (M48)

Timetable

The timing and interactions between tasks are summarized in the following GANTT diagram.



Distribution of the work between the researchers and the partners

The total manpower supported by the project is 192 man-months, which corresponds to the four full-time PhD students supported for the duration of the project (4 x 48 man-months).

The distribution between the different tasks is summarized as follows:

- ULg-ACE PhD student: 36 man-months on WP1 and 6 man-months on WP5
- UCL-MEMA PhD student: 36 man-months on WP2 and 6 man-months on WP5
- ULg-MEMA2 PhD student: 36 man-months on WP3 and 6 man-months on WP5
- ULg-CGEO PhD student: 36 man-months on WP4 and 6 man-months on WP5

Six man-months for each PhD researcher will be devoted to the writing of the thesis manuscript and/or research papers.

In addition to the staff financed by the project, several junior and senior scientists (with research subjects related to WAVES) will also be involved - see list of personnel in Section 6.3.

For the whole length of the project the promoters will supervise the PhD students and contribute to the technical developments. The coordination (WP0) will be carried out exclusively by the promoters.

Interaction between partners

Due the very integrated character of the proposed research, a close cooperation between all the partners is necessary. This cooperation will be organized through bi-annual general meetings of the partners, and the use of adequate software engineering tools. All software developments will be carried out in open source environment Gmsh (http://gmsh.info), which is actively developed and used by all the partners of the ARC. Common promotion and dissemination of the results will be greatly encouraged and reinforced by common publications, attendance to scientific meetings, etc. A web site will be created to ensure the project visibility at the international level.

Risk mitigation

The proposed research is potentially high-impact, with possible novel theoretical and practical developments. It consequentially also contains a part of risk.

This risk is however relatively limited, as several mitigation approaches can be envisioned for each work package:

- **WP0:** no major risk.
- **WP1:** if the novel full-hex algorithms are not successful, the methods developed in WP2, **WP3 and WP4** can still be applied as-is on hex-dominant grids.
- **WP2:** if the high-order Padé-localized conditions cannot be derived for elastodynamics, appropriate PML-based conditions can be used.
- **WP3:** No major risk. Parallel multirate time steppers require efficient partitioning algorithms. Not a lot of those algorithms are available and the new constraints arising from the use of GPUs may slightly harm the optimality of the partitionings.
- **WP4:** In the frequency domain (task 4.1), if the direct application of PUM/XFEM methods does not work, a less optimal direct coupling of the domains with some smearing in the mechanical properties along the interface can be used instead.
- **WP4:** In the time domain (task 4.2), we could also use the same trick that will lead, in addition to the spatial smearing, to a time step that is suboptimal. However, in this case there are more options, which is a risk-reducing factor.
- **WP5:** no major risk once WP1-4 are done.

4.6. Bibliography

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5. Budget

5.1 Total budget

	Year 1 (3 months)	Year 2 (12 months)	Year 3 (12 months)	Year 4 (12 months)	Year 5 (9 months)	TOTAL
Staff	36.000,00 €	146.400,00 €	149.200,00 €	152.000,00 €	116.400,00 €	600.000,00 €
Operating costs	1.600,00 €	24.400,00 €	34.400,00 €	34.400,00 €	32.800,00 €	127.600,00 €
Equipment	12.000,00 €	0,00 €	12.000,00 €	0,00 €	0,00 €	24.000,00 €
Overhead (5%)	1.880,00 €	8.540,00 €	9.180,00 €	9.320,00 €	7.460,00 €	36.380,00 €
TOTAL	51.480,00 €	179.340,00 €	204.780,00 €	195.720,00 €	156.660,00 €	787.980,00 €

5.2 Budget by partner

Notes:

- Staff costs are for PhD student grants (1 per research group)
- Equipment is for 1 laptop and 1 GPU card per research group

ULg-ACE	Year 1 (3 months)	Year 2 (12 months)	Year 3 (12 months)	Year 4 (12 months)	Year 5 (9 months)	**TOTAL**
Staff	9.000,00 €	36.600,00 €	37.300,00 €	38.000,00 €	29.100,00 €	150.000,00 €
Operating costs	400,00 €	6.100,00 €	8.600,00 €	8.600,00 €	8.200,00 €	31.900,00 €
Consumables	200,00 €	800,00 €	800,00 €	800,00 €	600,00 €	3.200,00 €
Documentation	200,00 €	800,00 €	800,00 €	800,00 €	600,00 €	3.200,00 €
Travel	0,00 €	2.500,00 €	5.000,00 €	5.000,00 €	5.000,00 €	17.500,00 €
Foreign guests	0,00 €	2.000,00 €	2.000,00 €	2.000,00 €	2.000,00 €	8.000,00 €
Equipment	3.000,00 €	0,00 €	3.000,00 €	0,00 €	0,00 €	6.000,00 €
Overhead (5%)	470,00 €	2.135,00 €	2.295,00 €	2.330,00 €	1.865,00 €	9.095,00 €
TOTAL	**12.870,00 €**	**44.835,00 €**	**51.195,00 €**	**48.930,00 €**	**39.165,00 €**	**196.995,00 €**

UCL-MEMA	Year 1 (3 months)	Year 2 (12 months)	Year 3 (12 months)	Year 4 (12 months)	Year 5 (9 months)	**TOTAL**
Staff	9.000,00 €	36.600,00 €	37.300,00 €	38.000,00 €	29.100,00 €	150.000,00 €
Operating costs	400,00 €	6.100,00 €	8.600,00 €	8.600,00 €	8.200,00 €	31.900,00 €
Consumables	200,00 €	800,00 €	800,00 €	800,00 €	600,00 €	3.200,00 €
Documentation	200,00 €	800,00 €	800,00 €	800,00 €	600,00 €	3.200,00 €
Travel	0,00 €	2.500,00 €	5.000,00 €	5.000,00 €	5.000,00 €	17.500,00 €
Foreign guests	0,00 €	2.000,00 €	2.000,00 €	2.000,00 €	2.000,00 €	8.000,00 €
Equipment	3.000,00 €	0,00 €	3.000,00 €	0,00 €	0,00 €	6.000,00 €
Overhead (5%)	470,00 €	2.135,00 €	2.295,00 €	2.330,00 €	1.865,00 €	9.095,00 €
TOTAL	**12.870,00 €**	**44.835,00 €**	**51.195,00 €**	**48.930,00 €**	**39.165,00 €**	**196.995,00 €**

ULg-CGEO	Year 1 (3 months)	Year 2 (12 months)	Year 3 (12 months)	Year 4 (12 months)	Year 5 (9 months)	**TOTAL**
Staff	9.000,00 €	36.600,00 €	37.300,00 €	38.000,00 €	29.100,00 €	150.000,00 €
Operating costs	400,00 €	6.100,00 €	8.600,00 €	8.600,00 €	8.200,00 €	31.900,00 €
Consumables	200,00 €	800,00 €	800,00 €	800,00 €	600,00 €	3.200,00 €
Documentation	200,00 €	800,00 €	800,00 €	800,00 €	600,00 €	3.200,00 €
Travel	0,00 €	2.500,00 €	5.000,00 €	5.000,00 €	5.000,00 €	17.500,00 €
Foreign guests	0,00 €	2.000,00 €	2.000,00 €	2.000,00 €	2.000,00 €	8.000,00 €
Equipment	3.000,00 €	0,00 €	3.000,00 €	0,00 €	0,00 €	6.000,00 €
Overhead (5%)	470,00 €	2.135,00 €	2.295,00 €	2.330,00 €	1.865,00 €	9.095,00 €
TOTAL	**12.870,00 €**	**44.835,00 €**	**51.195,00 €**	**48.930,00 €**	**39.165,00 €**	**196.995,00 €**

UCL-MEMA2	Year 1 (3 months)	Year 2 (12 months)	Year 3 (12 months)	Year 4 (12 months)	Year 5 (9 months)	**TOTAL**
Staff	9.000,00 €	36.600,00 €	37.300,00 €	38.000,00 €	29.100,00 €	150.000,00 €
Operating costs	400,00 €	6.100,00 €	8.600,00 €	8.600,00 €	8.200,00 €	31.900,00 €
Consumables	200,00 €	800,00 €	800,00 €	800,00 €	600,00 €	3.200,00 €
Documentation	200,00 €	800,00 €	800,00 €	800,00 €	600,00 €	3.200,00 €
Travel	0,00 €	2.500,00 €	5.000,00 €	5.000,00 €	5.000,00 €	17.500,00 €
Foreign guests	0,00 €	2.000,00 €	2.000,00 €	2.000,00 €	2.000,00 €	8.000,00 €
Equipment	3.000,00 €	0,00 €	3.000,00 €	0,00 €	0,00 €	6.000,00 €
Overhead (5%)	470,00 €	2.135,00 €	2.295,00 €	2.330,00 €	1.865,00 €	9.095,00 €
TOTAL	**12.870,00 €**	**44.835,00 €**	**51.195,00 €**	**48.930,00 €**	**39.165,00 €**	**196.995,00 €**

5.3 List of the personnel (not paid by the project, but participating in the realization of the project)

ULg-ACE:

- Christophe Geuzaine
- Véronique Beauvois
- David Colignon
- Patrick Dular
- Maxime Graulich
- Alexandre Halbach
- Kevin Jacques
- Amaury Johnen
- Nicolas Marsic
- Axel Modave
- Jean de Dieu Nshimiyimana
- Yannick Paquay
- Maxime Spirlet
- Alexandre Vion

UCL-MEMA:

- Jean-François Remacle
- Vincent Legat
- Jonathan Lambrechts
- Sébastien Blaise
- Paul-Emile Bernard
- Thomas Toulorge
- Nicolas Kowalski
- Vincent Bertrand
- Guillaume Verheylewegen
- François Henrotte

ULg-CGEO:

- Eric Béchet
- Christophe Leblanc
- Frédéric Duboeuf

UCL-MEMA2:

- Eric Deleersnijder
- Philippe Delandmeter
- Yoann Lebars
- Valentin Vallaeys
- Christopher Thomas

6. Available equipment

Computational resources for solving large scale applications on high performance computing clusters will be provided by the Consortium des Équipements de Calcul Intensif (CÉCI), funded by the Fonds de la Recherche Scientifique de Belgique (F.R.S.-FNRS) under Grant No. 2.5020.11. See http://www.ceci-hpc.be for more information.

In addition, servers for testing GPU-intensive codes are available in the partners' labs:

- 3 nodes with 1 GPU NVIDIA Tesla M2075, 2 CPU Intel E5645 and 48GB of RAM at ULg-ACE
- 1 node ttec CUDA 4210 - 6-core Xeon X5690 - 24 GB Ram, with a NVIDIA TESLA C2075, 6Go Ram GPU computing unit at ULg-CGEO
- 32 core SMP machine with 128 GB of RAM at UCL-MEMA.

Appendix A. Presentation of the partners

A.1 Curriculum Vitae of the promoters

A.1.1 ULg-ACE

Short Curriculum Vitæ of Prof. Dr. Ir. Christophe Geuzaine

University of Liège (ULg)
Dept. of Electrical Engineering and Computer Science
Applied and Computational Electromagnetics (ACE)
Montefiore Institute, Sart-Tilman, Bldg. B28, Parking P32
B-4000 Liège, Belgium
Tel: +3243663730 – Fax: +3243662910
Email: cgeuzaine@ulg.ac.be – Web: http://www.montefiore.ulg.ac.be/~geuzaine

Biographical data

- Belgian citizen, born February 6, 1973. Married, 1 daughter.
- Electrical engineer (ULg, 1996) and Ph.D. in Applied Sciences (ULg, 2001).

Research interests

- Modeling, analysis, algorithm development, and simulation for problems arising in various areas of engineering and science, with current applications in computational electromagnetism and biomedical problems.

Academic positions

- Since Jan. 2013: Full Professor, Dept. of Electrical Engineering and Computer Science, ULg.
- Jan. 2009–Dec. 2012: Professor, Dept. of Electrical Engineering and Computer Science, ULg.
- Jan. 2007–Dec. 2008: Associate Professor, Dept. of Electrical Engineering and Computer Science, ULg.
- Aug. 2005–Dec. 2006: Tenure-Track Assistant Professor, Mathematics Department, Case Western Reserve University, USA.
- Oct. 2002–Sep. 2005: Postdoctoral Researcher, Belgian National Fund for Scientific Research (FNRS).
- Jan. 2002–Aug. 2005: Postdoctoral Scholar, Department of Applied and Computational Mathematics, California Institute of Technology, USA.

Visiting professor positions

- Université de Lorraine, France (Jun. 2012), Ecole Centrale de Nantes, France (Jul. 2010), Universidade Federal de Santa Catarina, Brazil (Jul. 2008), Institut Elie Cartan, University Henri Poincaré Nancy, France (Jun. 2006), Institut Fresnel, University of Aix-Marseille I, France (Jul. 2005).

Research experience

- Head of the ACE research group (23 members) and director of the EMC Laboratory (about 300k Eur/year revenue); vice-president of the Dept. of Electrical Engineering and Computer Science (since 2014); president of the high performance computing group of the University of Liège (since 2014).
- (Co-)principal investigator in various programmes, including ARC, PAI/IUAP, FP7 EU and Walloon Region (total about 5.5M Eur).
- (Co-)guest editor of 3 special issues in scientific journals.
- (Co-)author of about 100 peer-reviewed journal articles, cited about 2700 times (Google Scholar).
- 30 invited lectures and 5 best paper awards over the last five years.
- Co-author of two popular open source scientific computing software (http://gmsh.info and http://getdp.info).
- Supervisor of 4 PhD theses (8 ongoing).
- Main organizer of the EMF international conference.
- Reviewer of manuscripts for over 15 journals, and projects submitted to the Belgian National Fund for Scientific Research (FNRS), the French Research Agency (ANR), the US National Science Foundation (NSF), etc.

Teaching

- Subject matters: electromagnetics, scientific computing, modelling methods.
- Current ULg courses: APRI0007, ELEC0041, ELEC0431, ELEC0055, INFO0939, MATH0471.

Publication report

Google Scholar: http://scholar.google.be/citations?user=D8Wumi0AAAAJ&hl=fr

Orbi:
http://orbi.ulg.ac.be/orbireport?query=%28%28uid%3Au030291%29%29&model=a&format=apa&data=metric&data=pr&sort_by0=1&order0=DESC&sort_by1=3&order1=ASC&sort_by2=2&order2=ASC&output=html&language=en&title=Publications+and+communications+of+Christophe+Geuzaine+%5Bu030291%5D

The complete list is available in Appendix C.

A.1.2 UCL-MEMA

Short Curriculum Vitæ of Prof. Dr. Ir. Jean-François Remacle

Université catholique de Louvain (UCL/IMMC/MEMA, on leave) &
Rice University, Dept. of Computational and Applied Mathematics (CAAM).
Telephone: +32-(0) 473.90.99.30 or +1-832 648.0657
E-mail: jean-francois.remacle@uclouvain.be – Web: www.caam.rice.edu/~remacle

Biographical data

- Belgian citizen born on October 27 1969, in Namur, Belgium - Married - Three children
- *Ingénieur civil* (ULg, 1992) and *Docteur en sciences appliquées* (ULg, 1997)

Present employment

- Professor (*professeur ordinaire*), UCL, since 2012
- Professor, Rice University, 2014-2015 (sabbatical leave)

Research interests

- High order numerical methods for PDEs.
- Co-author of Gmsh, the open source mesh generator. Gmsh's paper (2009) is already cited more that 1000 times on Google Scholar.
- (Co-) principal investigator in various programs, including two ARCs, 4 european projects, 7 walloon region projects, bringing about 4 MEuros in research funds
- (Co-) author of around 80 peer-reviewed articles, cited more than 3,700 times (Google Scholar)
- Stays abroad: Ecole polytechnique de Montréal (1997-1999), Rensselaer Polytechnic Institute (1999-2002), Ecole Centrale de Nantes (2 months as invited professor in 2007 and 2009), Université de Montpellier II (3 months as a CNRS director in 2010 and 2011), Rice University (one year of sabbatical leave in 2014-2015).

Teaching

- Undergraduate: mathematics (PDEs, complex variables, numerical analysis), numerical methods (finite elements in solids, mesh generation), fluid mechanics, mechanics of structures.
- Graduate: Discontinuous Galerkin Methods (GrasMech), Topics in Computational Science and Parallel Computing.

Service

- Organiser/convener of various workshops, conference sessions or conferences
- Associate editor of SIAM journal on Scientific Computing
- Associate editor of Engineering With Computers
- Associate editor of SMAI journal of Computational Mathematics
- Reviewer of manuscripts for over 20 journals, and projects submitted to the Agence Nationale de Recherche, the US National Science Foundation, etc.
- Head of MEMA unit/pole from August 2012 until August 2014
- Vice-president for research of IMMC (2010-2013)

Publication reports

Google Scholar: http://scholar.google.be/citations?user=G6FECu8AAAAJ&hl=fr

Dial:
http://dial.academielouvain.be/DialExport/BibliographyForm?author=Remacle%2C+Jean-Fran%C3%A7ois&sort=documentType&sortType=asc&startDate=&endDate=&type=classic&site=BOREAL

The complete list is available in Appendix C.

A.1.3 ULg-CGEO

Short Curriculum Vitæ of Prof. Dr. Ir. Éric Béchet

University of Liège (Ulg), Aerospace and Mechanical engineering dept.
Chemin des chevreuils,1 B--4000 Liège
Tel : +32(0)43669265
E-mail: eric.bechet@ulg.ac.be – Web: http://cg-dev.ltas.ulg.ac.be/~bechet/?lang=fr

Biographical data

- born on January 25th 1974, married, two children
- Ph.D , 2002, École Polytechnique de Montréal, Canada.
- Diplôme d'ingénieur, 1997 - École Supérieure de Sciences et Techniques de l'Ingénieur de Nancy – ESSTIN, France.
- Diplôme d'Études Approfondies (DEA – 3ème cycle), 1997, École doctorale PROMEN, Nancy, France (with honours).

Employment

- Since sept. 2008 – *Chargé de cours*, Université de Liège, Belgium.
- Since sept. 2005 – Maître de Conférences, Université de Lorraine, Metz, France (On academic leave).
- 2003-2005 - Post doctoral fellow, Ecole Centrale de Nantes, France
- French military duty (1997-1998)

Research Interests

- Extended finite element method, CAD modeling, Mesh generation, Piezoelectric materials, fracture mechanics, Composites materials.

Research Experience

Funding

- Convention Région Wallonne WIST 3.0 218.775 € / total of 772.750 €
- WBI , 7ème commission mixte Wallonie-Bruxelles / Québec : 1.500€
- Post-doc “in” mobility AVERROES ~ 20.000 €
- Action de recherche concertée ARC 09/14-2 ~ 120.000 €/ Total of 1.249.156 €
- Starting grant Ulg : 55.300 €

55 articles cited more than 800 times (google scholar)

Stays abroad :

- Sept. 2005 – jan. 2006 and juil. 2006 – sept. 2008 : Université de Metz, France.
- Jan. 2006 – juil. 2006 : Technische Universität Bergakademie Freiberg, Allemagne.
- Jan. 2003 – août 2005 : École Centrale de Nantes, France.

Teaching

- Current teachings : Computer Aided Design, Technical drawing, Computational geometry, Computer graphics, Integrated projects, New numerical methods in computational mechanics.
- Formerly : Symbolic computation tools, Calculus, C language, strength of materials

Service

- Participation in various thesis committees and jurys, committee for undergraduate studies at ULG, reviewer for journals in engineering, local co-organization of one conference etc.

Publication reports

Google Scholar: http://scholar.google.be/citations?user=xpCv_W0AAAAJ&hl=fr

Orbi:
http://orbi.ulg.ac.be/orbireport?query=%28%28uid%3Au209626%29%29&model=a&format=apa&data=metric&data=pr&sort_by0=1&order0=DESC&sort_by1=3&order1=ASC&sort_by2=2&order2=ASC&output=html&language=fr&title=Publications+et+communications+de+Eric+B%C3%A9chet+[u209626]

The complete list is available in Appendix C.

A.1.4 UCL-MEMA2

Short Curriculum Vitæ of Prof. Dr. Ir. Eric Deleersnijder

Université catholique de Louvain (UCL)
Institute of Mechanics, Materials and Civil Engineering (IMMC)
4 Avenue G. Lemaître, Bte L4.05.02, B-1348 Louvain-la-Neuve, Belgium
Telephone: +32-(0)10.47.23.63 or +(32)-(0)10.47.23.50 - Mobile phone: +32-(0)493.248.829
E-mail: eric.deleersnijder@uclouvain.be - Web: www.ericd.be

Biographical data

- Belgian citizen born on 25 April 1961, in Liège, Belgium - Married - Two children
- *Ingénieur civil* (ULg, 1984) and *Docteur en sciences appliquées* (UCL, 1992)

Present employment

- Reader (professeur), UCL, since 2011
- Part-time professor, Delft University of Technology, 2014-2019
- Honorary Research associate with the Belgian Fund for Scientific Research (FNRS)

Research interests

- Multi-scale modeling of the hydrosphere (www.climate.be/slim)
- Tracer and timescale methods in fluid flows (www.climate.be/cart)

Research experience

- (Co-) principal investigator in various programs, including three ARCs and one PAI, bringing about 4 MEuros in research funds
- (Co-) guest editor of 6 special issues in scientific journals
- (Co-) author of ~ 150 peer-reviewed articles, cited ~ 3,900 times (Google Scholar)
- Stays abroad: Laboratoire de météorologie dynamique du CNRS (ENS, Paris, 8 months in 1993-1994), Institut de recherche mathématique de Rennes (chargé de recherche associé du CNRS, 3 months in 2001), Delft University of Technology (gastdocent, 6 months in 2003)

Teaching

- Subject matters: mechanics (introductory level), modeling methods, fluid mechanics
- Present UCL courses: LAUCE2157, LGEO2130, LMECA2853, LMAPR2510, LPHY1113, LPHY1352
- Part-time invited professor at *Universiteit Gent* (Ghent, Belgium) in 2001-2002

Service

- Organiser/convener of various workshops, conference sessions or conferences
- Associate editor of *Ocean Dynamics*
- Reviewer of manuscripts for over 20 journals, and projects submitted to the US National Science Foundation, the Australian Research Council, the Israel Science Foundation, etc.
- Expert for the International Atomic Energy Agency's assessment of the radiological situation at the atolls of Mururoa and Fangataufa (1996-1998)

- Participation in various committees (at UCL and elsewhere), including chairmanship of UCL's high performance computing committee (*Comité du calcul intensif*) for 3 years
- Head of MEMA unit/pole from October 2009 until August 2012
- Vice-president for research of IMMC (since January 2013)

Publication reports

Google Scholar: http://scholar.google.be/citations?user=C_d8G_8AAAAJ&hl=fr&oi=ao

Dial:
http://dial.academielouvain.be/DialExport/BibliographyForm?author=Deleersnijder%2C+Eric&sort=date&sortType=desc&startDate=&endDate=&type=classic&site=BOREAL

The complete list is available in Appendix C.

A.2 Funding

A.2.1 ULg-ACE

Programe “WBGreen”, “Free Software for Electric Drive Optimization” (FEDO), 2013-2017. [ULg-ACE funding: €383.820]

IUAP P7/02, “Multiscale modelling of electrical energy systems” (M2E2S), 2012–2017. [ULg-ACE funding: €500.000]

ELIA research programme on EMF–BBEMG “Software for Interactive Evaluation of ELF Electromagnetic Field Exposure”, 2013–2017. [ULg-ACE funding: €218.000]

FP7, “SECurity of Railways against Electromagnetic aTtacks” (Secret), 2012–2015. [ULg-ACE funding €120.880]

Plan Marshall - SPW - Logistics, “Temperature Traceability along the Biotech Pharma product Life Cycle” (Tem+p+Track), 2012–2015. [ULg-ACE funding: €258.399]

Plan Marshall - SPW - Skywin, “Smart Pod” (S-Pod), 2012–2016. [ULg-ACE funding: €158.000]

Plan Marshall - SPW - Mecatech, “Partenariat d’innovation technologique en électronique de puissance et matériaux” (ATAC-CONCEPT), 2010–2013. [ULg-ACE funding: € 203.000]

Programme “Wist 3”, “Technologies de génération de maillages hexaédriques dominants” (DOMHEX), 2010–2013. [ULg-ACE funding: €218.775]

Programme “Wist 3”, “Open Numerical Engineering LABoratory” (ONELAB), 2010–2013. [ULg-ACE funding: €273.825]

Programme “WIST 3”, “Angular Localization for Indoor positioning based on optimized Zigbee low Environmental Emissions Sensor networks” (ALIZEES), 2010–2013. [ULg-ACE funding: €172.602]

Fondation d’entreprise EADS, “Hybridisation de méthodes numériques standards et de l’analyse microlocale pour la diffraction acoustique électromagnétique à haute fréquence. Applications à la construction de formulations variationnelles adaptées et de préconditionneurs analytiques” (HIgh- BRID), 2010–2013. [ULg-ACE funding: €112.930]

FP7 ERA-Net MATERA+, “Advanced Numerical Simulations of Inter- and Intralaminar Failures in Composites” (SIMUCOMP), 2010–2012. [ULg-LTAS & ACE funding: €320.000]

SGS CEBEC convention, “LEP”, 2010–. [ULg-ACE funding: €30.000/year]

Projet d’action de recherche concertée (ARC), “From imaging to geometrical modelling of complex micro structured materials: Bridging computational engineering and material science”, 2009-2013. [ULg-ACE funding: €370.035]

ELIA research programme on EMF–BBEMG “Contact current, sensitivity to electricity & 50Hz electric and magnetic fields”, 2009–2013. [ULg-ACE funding: €120.348]

IUAP P6/21, “Inverse problems and optimization in low frequency electromagnetism” (IPOLFE), 2007–2011. [ULg-ACE funding: €400.000]

Subvention Région Wallonne, “Extension du laboratoire de Compatibilité Electromagnétique” (WalMag), 2009–2010. [ULg-ACE funding: €1.600.000]

Programme “FuturEnergy”, “Optimisation technico-économique de la production d’électricité verte par des systèmes hybrides (éoliens- photovoltaïques) de faible puissance” (OptiSHER), 2008–2012. [ULg-ACE funding: €319.630]

Programme “Wist 2”, projet 616420, “Logiciel prototype de nouvelle génération pour la simulation par éléments finis et l’optimisation en mécanique et en électromagnétisme” (EFCONIVO), 2007–2010. [ULg-ACE funding: €283,485]

Crédit d’impulsion “Simulation numérique de phénomènes de diffraction haute-fréquence”, Fonds spéciaux pour la recherche, 2007–2009. [ULg-ACE funding: €126.400]

A.2.2 UCL-MEMA

Actions de Recherche Concertées "A second-generation model of the ocean system" (with Thierry Fichefet, Vincent Legat and Jean-François Remacle), funded by the Communauté Française de Belgique, from 15 September 2004 until 15 September 2009 [UCL funding: €725,000]

MESSIAEN, 2003–2006 : Methods for Efficient Simulations of Aircraft Engine Noise, Projet Européen du 6ème programme cadre (STREP). Among partners of Messiaen were Rolls-Royce, Airbus, FFT et la TU Eindhoven. Messiaen was ranked 1stof all the projects of the first call (aeronautics and space). [UCL funding: €236,000]

PAMADA, Procédure d’adaptation de maillages parallèle appliqué à un large spectre d’applications de calcul scientifique. First Post-Doc funded by the Walloon Region. [UCL funding: €152,000].
Link: http://recherche-technologie.wallonie.be/projets/index.html?IDD=8344.

MERHEO, 2009–2013: First Doctorant Agréé International (First DOCA), in collaboration with CENAERO. [UCL funding: one Ph.D.].
Link: http://recherche-technologie.wallonie.be/projets/index.html?IDD=11615.

SINUS, 2008 – 2015: with G. Winckelmans, L. Delannay et T. Pardoen. Simulation numérique haute performance. FEDER project (Fonds européens de développement régionaux). [UCL funding: €650,000].
Link: http://recherche-technologie.wallonie.be/projets/index.html?IDD=12512.

MULTI-PHI, 2009 – 2012 : Recherches industrielles de base en prototypage virtuel multiphysique. SKYWIN project (3rd call), funded by the Walloon Region. [UCL funding: €223,000].

EFCONIVO, 2007–2011 : Logiciel prototype de nouvelle génération pour la simulation par éléments finis et l'optimisation en mécanique et en électromagnétisme. Projet WIST2 financé par la région wallonne. Les partenaires de EFCONIVO sont l'ULg et la société Samtech. EFCONIVO a été classé 2ème de l'appel WIST2. [Budget UCL : €210,000]. Link: http://recherche-technologie.wallonie.be/projets/index.html?IDD=8427.

Actions de Recherche Concertées "Taking up the Challenges of Multi-Scale Marine Modelling" (with Thierry Fichefet, Emmanuel Hanert, Vincent Legat, E. Deleersnijder and Sandra Soares Frazao), funded by the Communauté Française de Belgique, from 1 October 2010 until 30 September 2015 [UCL funding: €485,000].
Link: http://sites.uclouvain.be/slim/.

DOMHEX, 2010–2014 : Génération de maillages Hex-Dominants. Projet WIST3 financé par la région wallonne. Les partenaires de DOMHEX sont l'ULg et la société Samtech. DOMHEX a été classé 2ème de l'appel WIST3. [UCL funding: €350,000]. Link: http://recherche-technologie.wallonie.be/projets/index.html?IDD=17007.

ONELAB, 2010–2013 : Open Numerical Laboratory. Projet WIST3 financé par la région wallonne. Les partenaires de ONELAB sont l'ULg et la société GDTech. ONELAB a été classé 3ème de l'appel WIST3. [UCL funding: €437,550]. Link: www.onelab.info.

PARNAS, 2010–2014 : Partnership for Numerical Acoustic Simulation, Projet Européen Marie Curie Industry- Academia Parnerships and Pathways (IAPP). [UCL funding: 2 years of post-doc salary].

IDIHOM, 2010–2013: Industrialization of High Order Methods – A top-down approach, Projet Européen du 7ème programme cadre (STREP). Les partenaires d'IDIHOM sont, entre autres, l'Imperial College London, l'INRIA, le DLR et Airbus. [UCL funding: €200,000]. Link: http://www.idihom.de/.

FEDO, 2013-2017, Programe “WBGreen”, “Free Software for Electric Drive Optimization”. [UCL funding: €400,000].

HPC4WE, 2014-2017: High Performance Computing For Walloon Enterprises, SKYWIN project (9th call) funded by the walloon region. [UCL funding: €250,000].

HEXAFORM, 2014-2017: Generation of Conforming Hexahedral Meshes for Industrial Applications, Projet BEWARE ACADEMIA. [UCL funding: €230,000].

TILDA, 2014-2017, Towards Industrial LES/DNS in Aeronautics – Paving the Way for Future Accurate CFD, European Project (call H2020-MG-2014). [UCL funding: €265,000].

A.2.3 ULg-CGEO

DOMHEX, 2010–2014 : Génération de maillages Hex-Dominants. Projet WIST3 financé par la région wallonne. Les partenaires de DOMHEX sont l'ULg et la société Samtech. DOMHEX a été classé 2ème de l'appel WIST3. [ULG-CGEO funding: ~€220,000]. Link: http://recherche-technologie.wallonie.be/projets/index.html?IDD=17007.

Convention WBI , 7ème commission mixte Wallonie-Bruxelles / Québec : "Intégration de la méthode XFEM dans le processus de CAO/FAO" , avec l'Université du Québec à trois-Rivières, 1.500€

Post-doc "in" mobility AVERROES : "Mise à jour d'un modèle géométrique de pièces manufacturées suite à l'optimisation de forme à l'aide de la méthode des éléments finis étendus" ~ 20.000 €

Action de recherche concertée Université de Liège N° 09/14-02 "BRIDGING- From Imaging to geometrical modelling of complex micro structured materials: Bridging computational engineering and material science". ~ 120.000 €/ Total of 1.249.156 €

Starting grant Ulg "Une représentation alternative des frontières dans le cadre de simulations numériques", (2009-2011) 55.300 €

A.2.4 UCL-MEMA2

Modelling of the hydrodynamics of the Mururoa atoll lagoon, funded by France's Commissariat à l'Energie Atomique / Ministère de la Défense, from 1 Dec. 1993 until 30 Nov. 1997 [1,000,000 FF]

World Ocean modelling on a "small" parallel computer, funded by Digital Equipment Corporation N.V./S.A., from 1 Aug. 1994 until 31 July 1996 [1,044,054 BEF]

North Sea Model Advection Dispersion Study (NOMADS) (Coordinator: R. Proctor), funded by the European Union under MAST, from 1 Feb. 1995 until 31 Jan 1997 [11,210 ECU]

Actions de Recherche Concertées "Modéliser les variations du climat terrestre" (with A. Berger, main promoter), funded by the Communauté Française de Belgique (CFWB), from 1 Oct 1997 until 30 Sep. 2002 [20,000,000 BEF]

An integrated approach to assess carbon dynamics in the Southern Ocean (coordinator: F. Dehairs): One-dimensional modelling of sea-ice and the water column, funded by the Belgian Federal Office for Scientific, Technical and Cultural Affairs (OSTC), from 1 Dec 1996 until 30 Nov 2000 [4,370,000 BEF]

Global Ocean Storage of Anthropogenic Carbon (GOSAC) (Coordinator: J. Orr), sub-contractor to the Laboratory for Planetary and Atmospheric Physics of the University of Liège, funded by the European Union, from 1 Dec 1997 until 30 Nov 2000 [39,500 ECU]

Simulation numérique et traitement de données (with X. Gonze and B. Piraux, main promoter), funded by the Fonds Spéciaux de Recherche de l'Université catholique de Louvain, from 1 October 1998 until 30 September 2000 [5,000,000 BEF]

Simulation numérique et traitement de données (with X. Gonze, main promoter, and B. Piraux), funded by the Fonds pour la Recherche Fondamentale Collective de Belgique (FRFC), from 1 February 1999 until 31 January 2002 [24,000,000 BEF]

Développement d'un modèle de circulation générale océanique de seconde génération pour l'étude du climat terrestre (with V. Legat), funded by the Fonds Spéciaux de Recherche de l'Université catholique de Louvain, from 1 October 2000 until 30 September 2002 [1,325,000 BEF]

Climate variability as recorded in Lake Tanganyika (CLIMLAKE) (Coordinator: J.-P. Descy), funded by the Belgian Federal Office for Scientific, Technical and Cultural Affairs (OSTC), from 1 Dec 2000 until 28 February 2005 [217,402.62 EURO]

Assessing the sensitivity of the Southern Ocean's biological pump to climate change (Coordinator: F. Dehairs), funded by the Belgian Federal Office for Scientific, Technical and Cultural Affairs (OSTC), from 1 Dec 2000 until 28 February 2005 [264,105.76 EURO]

Northern Ocean-Atmosphere Carbon Exchange Study (NOCES) (Coordinator: J. Orr), sub-contractor to the Laboratory for Planetary and Atmospheric Physics of the University of Liège, funded by the European Union, from 1 April 2002 until 31 March 2005 [30,557 EURO]

Implementation in Earth Tech's CALMET of a new divergence minimization algorithm (subcontract), funded by Earth Tech, Inc., from 1 May 2002 until 31 August 2002 [10,000 USD]

Développement d'un modèle de circulation générale océanique de seconde génération pour l'étude du climat terrestre (suite) (with V. Legat), funded by the Fonds Spéciaux de Recherche de l'Université catholique de Louvain, from 1 October 2002 until 30 September 2004 [15,000 EURO]

Apport de l'assimilation des données satellitaires à la modélisation de la glace de mer (with T. Fichefet, main promoter), funded by the Fonds Spéciaux de Recherche de l'Université catholique de Louvain, from 1 October 2002 until 30 September 2004 [44,750 EURO]

Impact des Changements Climatiques sur l'Utilisation Durable des Pêcheries du Lac Tanganyika (CLIMFISH), funded by the Belgian Science Policy, from 1 July 2004 until 31 December 2006 [74,550 EURO]

Actions de Recherche Concertées "A second-generation model of the ocean system"[1] (with Thierry Fichefet, Vincent Legat and Jean-François Remacle), funded by the Communauté Française de Belgique, from 15 September 2004 until 15 September 2009 [725,000 EURO]

Crédit aux Chercheurs "Numerical Modelling of Geophysical Flows: Idealizations, Stability of Solutions and Interpretations of the Results", funded by the FNRS, from 1 October 2004 until 30 September 2007 [6,000 EURO]

Numerical Simulation: Application in Solid State Physics, Physical Oceanography and Fluid Dynamics (with Xavier Gonze, main promoter, and Grégoire Winckelmans), funded by the Fonds pour la Recherche Fondamentale Collective de Belgique (FRFC), from 1 February 2005 until 31 January 2009 [450,000 EURO]

Interuniversity Attraction Pole (IAP) "Tracing and Integrated Modelling of Natural and Anthropogenic Effects on Hydrosystems: The Scheldt River Basin and Adjacent Coastal North Sea" (TIMOTHY) (Coordinator: C. Lancelot), funded by the Belgian Science Policy (BELSPO), from 1 January 2007 until 31 December 2011 [400,000 EURO]

Actions de Recherche Concertées "Taking up the Challenges of Multi-Scale Marine Modelling"[2] (with Thierry Fichefet, Emmanuel Hanert, Vincent Legat, Jean-François Remacle and Sandra Soares Frazao), funded by the Communauté Française de Belgique, from 1 October 2010 until 30 September 2015 [485,000 EURO]

Cholera outbreaks at Lake Tanganyika induced by climate change? (CHOLTIC) (Coordinator: Pierre-Denis Plisnier), funded by the Belgian Science Policy (BELSPO), from 15 December 2010 until 31 March 2015 [121,125 EURO]

Modélisation du système fleuve Congo/golfe de Guinée (with Emmanuel Hanert), funded by CLS (www.cls.fr), from 1 June 2013 until 31 May 2015 [189,750 EURO]

Oceans of icy satellites, with Véronique Dehant (main promoter), funded by the Fonds Spéciaux de Recherche de l'Université catholique de Louvain, 2014-2015 (15 months) [52,000 EURO, 1st phase]

A. 3 Previous ARCs obtained by WAVES co-promoters

All the four PIs of WAVES have obtained ARCs in the last 10 years. We split this appendix in two parts, one for UCL, one for ULg.

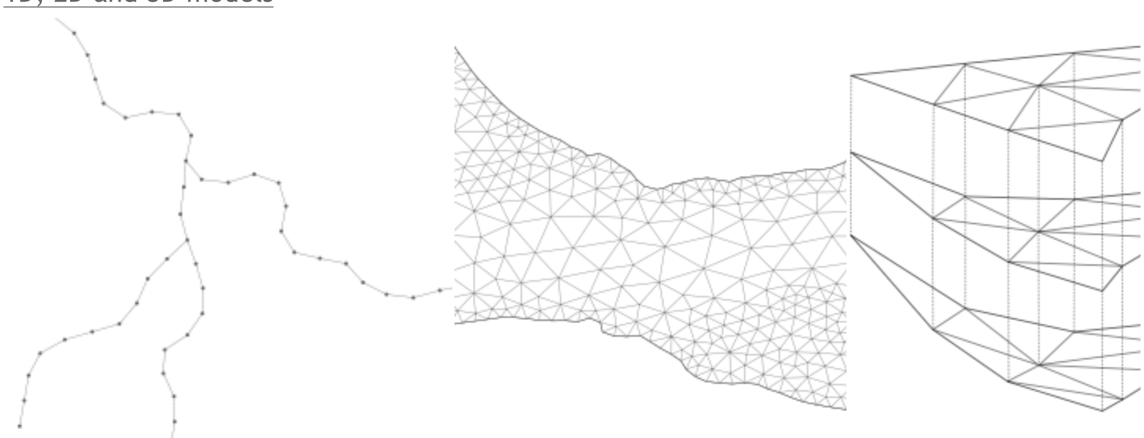
A.3.1 UCL

Both UCL promoters were involved in the development and use of SLIM, the Second generation Louvain-la-Neuve Ice-ocean Model. SLIM's ARC ends in 2015. Extensive information on the SLIM project can be found at the SLIM website http://sites.uclouvain.be/slim/. More specifically, 13 Ph.D. theses were successfully achieved in SLIM and over 70 peer-review papers were published.

Summary

SLIM is a hydrodynamical model based on finite element method (FEM). The main advantage of FEM formulation is that it allows the use of unstructured grids. The computational grid can therefore be refined arbitrarily in the areas of interest thus focusing the computational power where it is needed, without having recourse to nested grids that are unfeasible in a number of marine domains such as the Great Barrier Reef (Australia), whose topography/bathymetry is much too complex. This gives rise to *multi-scale modeling* as the spatial resolution may vary greatly within the same grid and a single model is able to resolve both the large-scale features, such as in the open sea, but also small-scale phenomena in shallow areas, coasts, estuaries and rivers. Moreover, coast lines can be represented as piecewise linear curves in contrast to staircase-like boundaries of the structured grids. In global scale applications the poles have traditionally posed a problem as they represent a singularity in the coordinate system. Such difficulties are absent with unstructured grids.

1D, 2D and 3D models



1D mesh 2D mesh 3D mesh

SLIM consists of a 1D river model, a 2D depth-averaged model and 3D barotropic/baroclinic model. It therefore can be applied on a wide range of problems. Currently the 1D and 2D models can be coupled to simulate an entire sea - estuary - river network continuum in one model. SLIM utilizes a generic 3D coordinate system where the curvature of Earth can easily be taken into account, which renders it suitable for large geophysical applications.

The 1D river model consists of linear river segments where variable river width and cross-section are taken into account. River segments can be joined to model a river network with accurate computation of bifurcation by the means of a Riemann solver.

In the 2D model the domain is divided into triangular elements allowing accurate representation of complex topography. The meshes are generated with GMSH software.

The 3D model uses triangular prismatic elements that are formed by extruding the 2D mesh in the vertical direction. The governing equations are solved using the mode-splitting technique, i.e. the 2D depth-averaged system is solved first and the vertical structure is updated afterwards.

Discontinuous Galerkin formulation

The spatial derivative operators are discretized with the Discontinuous Galerkin (DG) finite element method for both the free surface elevation and the velocity field. The numerical solution is thus a piecewise polynomial function that is discontinuous at the element interfaces. The inter-element fluxes are solved with an approximate Riemann solver. The DG-FEM approach can be seen as a mixture of finite volume and finite element methods and it has several advantages: Because characteristic variables are up-winded across the element interfaces, DG-FEM well-suited for advection dominated problems and does not suffer from oscillations or excessive numerical dissipation. Moreover, due to the completely discontinuous elements, DG-FEM is highly parallelizable and local mass conservation is ensured. DG-FEM is also very flexible in terms of mesh topologies and element types, which makes it an attractive approach for hp-adaptivity (adaptation of the mesh resolution and/or the polynomial degree of the solution).

Time stepping

Currently available time-marching schemes are explicit and semi-explicit Runge-Kutta schemes as well as diagonally implicit Runge-Kutta using Newton-Raphson iteration. The latter is very advantageous for large multi-scale simulations as it allows taking long time steps independently of the spatial resolution.

Remarkable achievements

SLIM has been applied to various domains, including the river-sea continuum of the Scheldt (Belgium-Netherlands) and the Mahakam (Indonesia), Lake Tanganyika, the Great Barrier Reef (GBR) (Australia) and various sub-domains of it. Beside hydrodynamics simulations, a a number of environmental issues have been addressed such as the determination of the rate of water renewal in semi-enclosed domains, the simulation of fine sediment transport, the study of the fate of heavy metals, microbiological pollution studies and connectivity assessment in the GBR using network science tools.

Further information

The subsequent links offer more in-depth information on the following topics:

- Mesh Generation
- Mesh adaptivity

- Three-dimensional component of SLIM

PhD theses

- **Hanert E.**, 2004, Towards a Finite Element Ocean Circulation Model (pdf)
- **Legrand S.**, 2006, Maillages non-structurés en modélisation marine (pdf)
- **White L.**, 2007, Accuracy and Consistency in Finite Element Ocean Modeling (pdf)
- **Bernard P.-E.**, 2008, Discontinuous Galerkin methods for geophysical flow modeling (pdf)
- **Blaise S.,** 2009, Development of a Finite Element marine model (pdf)
- **Comblen R.,** 2010, Discontinuous finite element methods for two- and three-dimensional marine flows (pdf)
- **Lambrechts J.,** 2011, Finite elements methods for coastal flows: application to the Great Barrier Reef (pdf)
- **Lietaer O.**, 2011, Finite element methods for sea ice modeling (pdf)
- **de Brye B.,** 2011, Multiscale finite-element modelling of river-sea continua (pdf)
- **Gourgue O.**, 2011, Finite element modeling of sediment dynamics in the Scheldt (pdf)
- **Kärnä T.,** 2012, Development of a baroclinic discontinuous Galerkin finite element model for estuarine and coastal flows (pdf)
- **Bouillon S.,** 2013, Sea ice rheologies for large-scale models (pdf)
- **Seny B.,** 2014, Development and implementation of a parallel explicit multirate time stepping strategy for accelerating discontinuous Galerkin computations (pdf)
- **Pham Van C.,** 2014, Development of a finite element model simulating flow and sediment dynamics: Application to the Mahakam land-sea continuum (Indonesia), (public defense on November 28th, 2014)

Journal articles

More than 70 journal articles were published in the context of SLIM. The following link (http://sites.uclouvain.be/slim/index.php?id=6) gives an extensive list of those papers.

A.3.2 ULg

Both ULg promoters were involved in ARC N° 09/14-02 BRIDGING "From Imaging to geometrical modelling of complex micro structured materials: Bridging computational engineering and material science", which ended in 2014.

Summary

The development of artificially synthesized materials has exploded over the last years. These multifunctional materials exhibit remarkable physical properties (mechanical, electromagnetic, acoustic, ...) thanks to their particular micro-structure and their potential applications span almost all areas of the industrial fields: aeronautics, electronics, automotive, bio-medical, ... Up to now it is in most cases impossible to determine the macroscopic (i.e. homogenised) properties of these complex materials without expensive and time-consuming experiments, which in turn, constraint material tailoring to trial and error tests.

This ARC project focused on the theoretical study, the computational implementation and the experimental validation of homogenization techniques, based on the resolution of a finite-element boundary value problem defined on a Representative Volume Element (RVE), which allows to predict the macroscopic behavior of complex micro-structured materials. It resulted in the development of an integrated tool dedicated to the design of new micro- and meso-structured materials. Both mechanical and electromagnetic properties were investigated using these innovative modeling tools. An additional challenges has been tackled: the need of high quality geometrical models as input for the numerical models. This ARC led to novel techniques to construct such models directly from imaging techniques.

The numerical techniques developed by the engineering teams (teams of the Dept. of Aerospace and Mechanical Engineering and of the Dept. Electrical Engineering and Computer Science) have been validated on geometries constructed from images of actual nanocomposites with nanofillers (manufactured by the Centre for Education and Research on Macromolecules, CERM). The raw images were obtained by X-ray micro-tomography (Laboratory of Chemical Engineering, LGC) or by electronic tomography (Centre for Applied Technology in Microscopy, CATµ) depending on the scale of the composites at hand.

PhD theses

- **Phuong Minh Tran** (2009-2014), "Determination of the relationship between foam morphology and electrical conductivity of polymer/carbon nanotube nanocomposite foams",Université de Liège, defended February 2014
- **Van Dung Nguyen** (2009-2014) , "Computational homogenization of cellular materials capturing micro-buckling, macro-localization and size effects",Université de Liège, defended March 2014.
- **Innocent Niyonzima** (2009-2014) "Multiscale Finite Element Modeling of Nonlinear Quasistatic Electromagnetic Problems'',Université de Liège, defended September 2014
- **Christophe Leblanc** (2012-expected 2015) "Finite element computations based on tomographic 3D images",Université de Liège, planned defense in 2015.

Journal articles

- Niyonzima, Innocent; Sabariego, Ruth Vazquez; Dular, Patrick et al "Nonlinear Computational Homogenization Method for the Evaluation of Eddy Currents in Soft Magnetic Composites" in IEEE Transactions on Magnetics (2014), 50(02).
- Boubekeur, Mohamed; Kameni, Abelin; Pichon, Lionel, Modave, Axel, Geuzaine, Christophe. "Analysis of transient scattering problems using a discontinuous Galerkin method: application to the shielding effectiveness of enclosures with heterogeneous walls" in International Journal of Numerical Modelling: Electronic Networks, Devices and Fields (2014), 27(3), 626-635
- Niyonzima, Innocent; V Sabariego, Ruth; Dular, Patrick et al "Finite Element Computational Homogenization of Nonlinear Multiscale Materials in Magnetostatics" in IEEE Transactions on Magnetics (2012), 48(2), 587-590.

- Niyonzima, Innocent; V Sabariego, Ruth; Dular, Patrick et al, “Computational Homogenization for Laminated Ferromagnetic Cores in Magnetodynamics” in IEEE Transactions on Magnetics (2013), 49(5), 2049-2052.
- V. D. Nguyen and L. Noels. "Computational homogenization of cellular materials." International Journal of Solids and Structures 51, no. 11-12 (juin 2014): 2183-2203.
- V. D. Nguyen, G. Becker, and L. Noels. "Multiscale computational homogenization methods with a gradient enhanced scheme based on the discontinuous Galerkin formulation." Computer Methods in Applied Mechanics & Engineering 260 (juin 15, 2013): 63-77.
- V. D. Nguyen, E. Béchet, C. Geuzaine, and L. Noels. "Imposing periodic boundary condition on arbitrary meshes by polynomial interpolation." Computational Materials Science 55 (avril 2012): 390-406.
- Henrotte, François; Steentjes, Simon; Hameyer, Kay; Geuzaine, Christophe. “Iron loss calculation in steel laminations at high frequencies” in IEEE Transactions on Magnetics (2014), 50(2), 333-336.
- Steentjes, S.; Henrotte, F.; Geuzaine, Christophe; Hamayer, Kay. “A dynamical energy-based hysteresis model for iron loss calculation in laminated cores” in *International Journal of Numerical Modelling* (2014), 27(3), 433-443.
- Kameni, Abelin; Modave, Axel ; Boubekeur, Mohamed; Preault, Valentin; Pichon, Lionel; Geuzaine, Christophe. “Evaluation of shielding effectiveness of composite wall with a time domain discontinuous Galerkin method” in European Physical Journal : Applied physics (2013), 64(2), 24508.
- François-Lavet, Vincent ; Henrotte, François; Stainier, Laurent; Noels, Ludovic; Geuzaine, Christophe. “An Energy-Based Variational Model of Ferromagnetic Hysteresis for Finite Element Computations” in Journal of Computational & Applied Mathematics (2013), 246
- Fangyi Wan; Minh Phuong Tran; Christophe Leblanc; Eric Bechet; Christophe Detrembleur; Ludovic Noels, Jean-Michel Thomassin; Van-Dung Nguyen “Experimental and computational micro-mechanical investigations of compressive properties of polypropylene/multi-walled carbon nanotubes nanocomposite foams.” Submitted to Mechanics of Materials (2014).
- Tran, Minh Phuong, Detrembleur, Christophe, Alexandre, Michaël et al. , “The influence of foam morphology of multi-walled carbon nanotubes/poly(methyl methacrylate) nanocomposites on electrical conductivity” in Polymer (2013), 54(13), 3261-3270.

A. 4 Important publications

A.4.1 List of relevant publications

Pr. J.-F. Remacle.

- Geuzaine, C., & Remacle, J. F. (2009). Gmsh: A 3-D finite element mesh generator with built-in pre-and post-processing facilities. *International Journal for Numerical Methods in Engineering*, *79*(11), 1309-1331.
- Seny, B., Lambrechts, J., Toulorge, T., Legat, V., & Remacle, J. F. (2014). An efficient parallel implementation of explicit multirate Runge–Kutta schemes for discontinuous Galerkin computations. *Journal of Computational Physics*, *256*, 135-160.
- Remacle, J. F., Geuzaine, C., Compère, G., & Marchandise, E. (2010). High-quality surface remeshing using harmonic maps. *International Journal for Numerical Methods in Engineering*, *83*(4), 403-425.
- Baudouin, T. C., Remacle, J. F., Marchandise, E., Henrotte, F., & Geuzaine, C. (2014). A frontal approach to hex-dominant mesh generation. *Advanced Modeling and Simulation in Engineering Sciences*, *1*(1), 1-30.
- Chevaugeon, N., Remacle, J. F., Gallez, X., Ploumhans, P., & Caro, S. (2005, May). Efficient discontinuous Galerkin methods for solving acoustic problems. In *11th AIAA/CEAS Aeroacoustics Conference*.

Pr. E. Béchet.

- Béchet, E., Moes, N., & Wohlmuth, B. (2009). A stable Lagrange multiplier space for stiff interface conditions within the extended finite element method. International Journal for Numerical Methods in Engineering, 78(8), 931-954
- Béchet, E., Cuilliere, J.-C., & Trochu, F. (2002). Generation of a finite element MESH from stereolithography (STL) files. Computer-Aided Design, 34(1), 1-17.
- Moumnassi, M., Belouettar, S., Béchet, E., Bordas, S., Quoirin, D., & Potier-Ferry, M. (2011). Finite element analysis on implicitly defined domains: An accurate representation based on arbitrary parametric surfaces. Computer Methods in Applied Mechanics & Engineering, 200(5-8), 774-796.
- Rozycki, P., Moes, N., Béchet, E., & Dubois, C. (2008). X-FEM explicit dynamics for constant strain elements to alleviate mesh constraints on internal or external boundaries. Computer Methods in Applied Mechanics & Engineering, 197(5).
- Béchet, E., Minnebol, H., Moes, N., & Burgardt, B. (2005). Improved implementation and robustness study of the X-FEM for stress analysis around cracks. International Journal for Numerical Methods in Engineering, 64(8), 1033-1056.

Pr. C. Geuzaine.

- O. Bruno, C. Geuzaine, J. Monro, F. Reitich. Prescribed error tolerances within fixed computational times for scattering problems of arbitrarily high frequency: the convex case. Philosophical Transactions of the Royal Society (Series A: Mathematical, Physical and Engineering Sciences), 362(1816):629–645, 2004.

- C. Geuzaine, O. Bruno, and F. Reitich. On the O(1) solution of multiple-scattering problems. IEEE Trans. Magn., 41(5):1488–1491, 2005.
- C. Geuzaine, J.-F. Remacle. Gmsh: A 3-D finite element mesh generator with built-in pre-and post-processing facilities. International Journal for Numerical Methods in Engineering 79 (11), 1309-1331, 2009.
- Y. Boubendir, X. Antoine, C. Geuzaine. A quasi-optimal non-overlapping domain decomposition algorithm for the Helmholtz equation. Journal of Computational Physics 231 (2), 262-280, 2012.
- M. El Bouajaji, X. Antoine, C. Geuzaine. Approximate local magnetic-to-electric surface operators for time-harmonic Maxwell's equations. Journal of Computational Physics, in press, 2014.

Pr. E. Deleersnijder

- Lambrechts, J., Hanert, E., Deleersnijder, E., Bernard, P. E., Legat, V., Remacle, J. F., & Wolanski, E. (2008). A multi-scale model of the hydrodynamics of the whole Great Barrier Reef. *Estuarine, Coastal and Shelf Science*, *79*(1), 143-151.
- Brinkman, R., Wolanski, E., Deleersnijder, E., McAllister, F., & Skirving, W. (2002). Oceanic inflow from the coral sea into the great barrier reef. *Estuarine, Coastal and Shelf Science*, *54*(4), 655-668.
- Modave, A., Deleersnijder, É., & Delhez, É. J. (2010). On the parameters of absorbing layers for shallow water models. *Ocean Dynamics*, *60*(1), 65-79.
- Hanert, E., Roux, D. Y. L., Legat, V., & Deleersnijder, E. (2005). An efficient Eulerian finite element method for the shallow water equations. *Ocean Modelling*, *10*(1), 115-136.
- Legrand, S., Deleersnijder, E., Hanert, E., Legat, V., & Wolanski, E. (2006). High-resolution, unstructured meshes for hydrodynamic models of the Great Barrier Reef, Australia. *Estuarine, coastal and shelf science*, *68*(1), 36-46.

A.4.2 List of important publications in the last 5 years

Pr. J.-F. Remacle.

- Geuzaine, C., & Remacle, J. F. (2009). Gmsh: A 3-D finite element mesh generator with built-in pre-and post-processing facilities. International Journal for Numerical Methods in Engineering, 79(11), 1309-1331.
- Remacle, J. F., Geuzaine, C., Compère, G., & Marchandise, E. (2010). High-quality surface remeshing using harmonic maps. International Journal for Numerical Methods in Engineering, 83(4), 403-425.
- Remacle, J. F., Lambrechts, J., Seny, B., Marchandise, E., Johnen, A., & Geuzaine, C. (2012). Blossom-Quad: A non-uniform quadrilateral mesh generator using a minimum-cost perfect-matching algorithm. International Journal for Numerical Methods in Engineering, 89(9), 1102-1119.
- Comblen, R., Lambrechts, J., Remacle, J. F., & Legat, V. (2010). Practical evaluation of five partly discontinuous finite element pairs for the non-conservative shallow water equations. International Journal for Numerical Methods in Fluids, 63(6), 701-724.

- Johnen, A., Remacle, J. F., & Geuzaine, C. (2013). Geometrical validity of curvilinear finite elements. Journal of Computational Physics, 233, 359-372.

Pr. E. Béchet.

- Béchet, E., Moes, N., & Wohlmuth, B. (2009). A stable Lagrange multiplier space for stiff interface conditions within the extended finite element method. International Journal for Numerical Methods in Engineering, 78(8), 931-954.
- Béchet, E., Scherzer, M., & Kuna, M. (2009). Application of the X-FEM to the fracture of piezoelectric materials. International Journal for Numerical Methods in Engineering, 77(11), 1535-1565.
- Moumnassi, M., Belouettar, S., Béchet, E., Bordas, S., Quoirin, D., & Potier-Ferry, M. (2011). Finite element analysis on implicitly defined domains: An accurate representation based on arbitrary parametric surfaces. Computer Methods in Applied Mechanics & Engineering, 200(5-8), 774-796.
- Nguyen, V. D., Béchet, E., Geuzaine, C., & Noels, L. (2012). Imposing periodic boundary condition on arbitrary meshes by polynomial interpolation. Computational Materials Science, 55, 390-406.
- Remacle, J.-F., Henrotte, F., Carrier-Baudouin, T., Béchet, E., Marchandise, E., Geuzaine, C., & Mouton, T. (2013). A Frontal Delaunay Quad Mesh Generator Using the L^∞ Norm. International Journal for Numerical Methods in Engineering, 94(5), 494-512.

Pr. C. Geuzaine.

- C. Geuzaine, J.-F. Remacle. Gmsh: A 3-D finite element mesh generator with built-in pre-and post-processing facilities. International Journal for Numerical Methods in Engineering 79 (11), 1309-1331, 2009.
- Y. Boubendir, X. Antoine, C. Geuzaine. A quasi-optimal non-overlapping domain decomposition algorithm for the Helmholtz equation. Journal of Computational Physics 231 (2), 262-280, 2012.
- M. Pellikka, S. Suuriniemi, L. Kettunen, C. Geuzaine. Homology and cohomology computation in finite element modeling. SIAM Journal on Scientific Computing 35 (5), B1195-B1214, 2013.
- A Vion, C Geuzaine. Double sweep preconditioner for optimized Schwarz methods applied to the Helmholtz problem. Journal of Computational Physics 266, 171-190, 2014.
- M. El Bouajaji, X. Antoine, C. Geuzaine. Approximate local magnetic-to-electric surface operators for time-harmonic Maxwell's equations. Journal of Computational Physics, in press, 2014.

Pr. E. Deleersnijder

- de Brye, B., de Brauwere, A., Gourgue, O., Kärnä, T., Lambrechts, J., Comblen, R., & Deleersnijder, E. (2010). A finite-element, multi-scale model of the Scheldt tributaries, river, estuary and ROFI. *Coastal Engineering*, *57*(9), 850-863.

- Kärnä, T., De Brye, B., Gourgue, O., Lambrechts, J., Comblen, R., Legat, V., & Deleersnijder, E. (2011). A fully implicit wetting–drying method for DG-FEM shallow water models, with an application to the Scheldt Estuary. *Computer Methods in Applied Mechanics and Engineering*, *200*(5), 509-524.
- Comblen, R., Legrand, S., Deleersnijder, E., & Legat, V. (2009). A finite element method for solving the shallow water equations on the sphere. *Ocean Modelling*, *28*(1), 12-23.
- de Brye, B., de Brauwere, A., Gourgue, O., Delhez, E. J., & Deleersnijder, E. (2012). Water renewal timescales in the Scheldt Estuary. *Journal of Marine Systems*, *94*, 74-86.
- Gourgue, O., Comblen, R., Lambrechts, J., Kärnä, T., Legat, V., & Deleersnijder, E. (2009). A flux-limiting wetting–drying method for finite-element shallow-water models, with application to the Scheldt Estuary. *Advances in Water Resources*, *32*(12), 1726-1739.

Appendix B. Reviewers

B.1 List of reviewers with potential conflicts of interest

- Prof. Xavier Antoine, Université de Lorraine, France (time-harmonic domain decomposition, high-order transmission conditions). Frequent collaborator of C. Geuzaine.
- Prof. Nicolas Moës, Ecole Centrale de Nantes, France (interface capturing techniques, XFEM). Frequent collaborator of J.-F. Remacle and E. Bechet.
- Prof. Tim Warburton, Rice University, U.S.A. Collaborator of J.-F. Remacle.

B.2 List of suggested reviewers

- Dr. Amik St Cyr, Shell Global Solutions International BV, The Netherlands, Email: Amik.St-Cyr@shell.com (numerical methods for geophysical prospection, elastodynamics).
- Prof. Victorita Dolean, Mathematics And Statistics, Strathclyde University, Livingstone Tower, 26 Richmond Street G1-1XH, Glasgow, U.K., Phone: +44-(0)141-548-4536, Email: victorita.dolean@strath.ac.uk (time-harmonic domain decomposition techniques).
- Dr. Marion Darbas, LAMFA CNRS UMR 7352, 33, rue Saint-Leu, 80039 AMIENS Cedex 1 France, Phone: +33-(0)3-22-82-75-16, Email: marion.darbas@u-picardie.fr (mathematical foundations for local transmission conditions in elastodynamics).
- Dr. Stéphane Lanteri, INRIA, NACHOS project-team, 2004 Route des Lucioles, B.P. 93, 06902 Sophia Antipolis Cedex France, Phone: +33-(0)4-92-38-77-34, Email: Stephane.Lanteri@inria.fr (numerical techniques for time-domain waves).
- Prof. John E. Dolbow, Civil and Environmental Engineering, Duke University, 121 Hudson Hall, Durham, NC 27708-0287 U.S.A., Phone: +1-919-660-5202, Email: jdolbow@duke.edu (interface capturing, XFEM).

Appendix C. Complete list of publications

Université de Liège

Publications and communications of Christophe Geuzaine [u030291]

Legend

Bibliometric indicators linked to the journal *(for those whose ISSN has been indicated by the author)*
- ***IF = Impact factor*** *Thomson ISI. Are indicated : IF of the year of publication and IF of the last edition of JCR* ***(last)****, « ? » if not known by ORBi yet ; « - » if non-existent.*
- ***IF5 :*** *idem as IF but for a 5 year period (new indicator since 2009).*
- ***EigenF = EigenFactor*** *(see : http://www.eigenfactor.org/).*
- ***Article Infl. = Article Influence :*** *EigenFactor divided by the number of articles published in the journal.*

➔ More information ? http://orbi.ulg.ac.be/rpt#rev

Bibliometric indicators linked to the article
- ***ORBi viewed*** *= total number of visualizations of a reference on ORBi (of which X internally within the ULg).*
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➔ More information ? http://orbi.ulg.ac.be/rpt#art

(Warning : According to disciplines, some bibliometric indicators may not be relevant)

, etc: full text of the document available in Open Access
, etc: full text of the document available in restricted access
Peer reviewed (verified by ORBi) : *the information is available in the ORBi journals database*

1. Dissertations and Theses

1.b. Doctoral thesis

Geuzaine, C. (2001). *High order hybrid finite element schemes for Maxwell's equations taking thin structures and global quantities into account*.
http://hdl.handle.net/2268/22803
ORBi viewed: **82** (27 ULg) ; downloaded: **15** (8 ULg)

1.c. Second cycle dissertations (licence, master, DES, DEA)

Geuzaine, C. (1996). *Développement d'éléments finis nodaux et d'arête hiérarchiques 2D et 3D appliqués au problème des courants induits*.
http://hdl.handle.net/2268/22945
ORBi viewed: **75** (15 ULg) ; downloaded: **8** (4 ULg)

3. Articles in peer reviewed academic journals

3.a. With an international target audience

As first or last author

Johnen, A., Ernst, D., & Geuzaine, C. (in press). Sequential decision-making approach for quadrangular mesh generation. *Engineering with Computers*.
http://hdl.handle.net/2268/173826
Peer reviewed ✓
ORBi viewed: **110** (16 ULg) ; downloaded: **24** (6 ULg)
IF: ? — EigenF: ? — Article Infl.: ?

Modave, A., Delhez, E., & Geuzaine, C. (2014). Optimizing Perfectly Matched Layers in Discrete Contexts. *International Journal for Numerical Methods in Engineering, 99*(6), 410–437.
http://hdl.handle.net/2268/165708
Peer reviewed (verified by ORBi) ✓
ORBi viewed: **40** (10 ULg) ; downloaded: **2** (2 ULg) — SCOPUS®: **0**
IF 2014: **?**; last: **1.961**; IF5: **2.509** — EigenF 2014: **?**; last: **0.0285** — Article Infl. 2014: **?**; last: **1.0545**

Boubekeur, M., Kameni, A., Pichon, L., Modave, A., & Geuzaine, C. (2014). Analysis of transient scattering problems using a discontinuous Galerkin method: application to the shielding effectiveness of enclosures with heterogeneous walls. *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields, 27*(3), 626-635.

http://hdl.handle.net/2268/157222

Peer reviewed ✓

ORBi viewed: **34** (11 ULg) ; downloaded: **1** — SCOPUS®: **0**

Dular, P., Péron, V., Perrussel, R., Krähenbühl, L., & Geuzaine, C. (2014). Perfect Conductor and Impedance Boundary Condition Corrections via a Finite Element Subproblem Method. *IEEE Transactions on Magnetics, 50*(2).

http://hdl.handle.net/2268/173505

Peer reviewed (verified by ORBi) ✓

ORBi viewed: **6** (1 ULg) ; downloaded: **1** (1 ULg) — SCOPUS®: **0**

IF 2014: **?**; last: **1.213**; IF5: **1.301** — EigenF 2014: **?**; last: **0.0338** — Article Infl. 2014: **?**; last: **0.387**

Niyonzima, I., Sabariego, R. V., Dular, P., & Geuzaine, C. (2014). Nonlinear Computational Homogenization Method for the Evaluation of Eddy Currents in Soft Magnetic Composites. *IEEE Transactions on Magnetics, 50*(02).

http://hdl.handle.net/2268/171504

Peer reviewed (verified by ORBi) ✓

ORBi viewed: **27** (8 ULg) ; downloaded: **3** (3 ULg) — SCOPUS®: **0**

IF 2014: **?**; last: **1.213**; IF5: **1.301** — EigenF 2014: **?**; last: **0.0338** — Article Infl. 2014: **?**; last: **0.387**

Baudouin, T. C., Remacle, J.-F., Marchandise, E., Henrotte, F., & Geuzaine, C. (2014). A frontal approach to hex-dominant mesh generation. *Advanced Modeling and Simulation in Engineering Sciences, 1*(1), 1-30.

http://hdl.handle.net/2268/171468

Peer reviewed (verified by ORBi) ✓

ORBi viewed: **15** (3 ULg) ; downloaded: **1** (1 ULg) — SCOPUS®: **-**

Henrotte, F., Steentjes, S., Hameyer, K., & Geuzaine, C. (2014). Iron loss calculation in steel laminations at high frequencies. *IEEE Transactions on Magnetics, 50*(2), 333-336.

http://hdl.handle.net/2268/171467

Peer reviewed (verified by ORBi) ✓

ORBi viewed: **8** (3 ULg) ; downloaded: **0** — SCOPUS®: **0**

IF 2014: **?**; last: **1.213**; IF5: **1.301** — EigenF 2014: **?**; last: **0.0338** — Article Infl. 2014: **?**; last: **0.387**

Kameni, A., Boubekeur, M., Alloui, L., Bouillault, F., Lambretchs, J., & Geuzaine, C. (2014). A 3-D Semi-Implicit Method for Computing the Current Density in Bulk Superconductors. *IEEE Transactions on Magnetics, 50*(2), 377--380.

http://hdl.handle.net/2268/171469

Peer reviewed (verified by ORBi) ✓

ORBi viewed: **13** (6 ULg) ; downloaded: **3** (3 ULg) — SCOPUS®: **0**

IF 2014: **?**; last: **1.213**; IF5: **1.301** — EigenF 2014: **?**; last: **0.0338** — Article Infl. 2014: **?**; last: **0.387**

Vion, A., & Geuzaine, C. (2014). Double sweep preconditioner for optimized Schwarz methods applied to the Helmholtz problem. *Journal of Computational Physics, 266*, 171--190.

http://hdl.handle.net/2268/171464

Peer reviewed ✓

ORBi viewed: **10** ; downloaded: **0** — SCOPUS®: **0**

Kameni, A., Modave, A., Boubekeur, M., Preault, V., Pichon, L., & Geuzaine, C. (2013). Evaluation of shielding effectiveness of composite wall with a time domain discontinuous Galerkin method. *European Physical Journal : Applied physics, 64*(2), 24508.

http://hdl.handle.net/2268/154299

Peer reviewed (verified by ORBi) ✓

ORBi viewed: **59** (10 ULg) ; downloaded: **0** — SCOPUS®: **0**

IF 2013: **0.789**; last: **0.789**; IF5: **0.801** — EigenF 2013: **?**; last: **0.0043** — Article Infl. 2013: **?**; last: **0.2649**

Modave, A., Kameni, A., Lambrechts, J., Delhez, E., Pichon, L., & Geuzaine, C. (2013). An optimum PML for scattering problems in the time domain. *European Physical Journal : Applied physics, 64*(2), 24502.

http://hdl.handle.net/2268/149904

Peer reviewed (verified by ORBi) ✓

ORBi viewed: **76** (28 ULg) ; downloaded: **6** (6 ULg) — SCOPUS®: **1**

IF 2013: **0.789**; last: **0.789**; IF5: **0.801** — EigenF 2013: **?**; last: **0.0043** — Article Infl. 2013: **?**; last: **0.2649**

Dang, Q. V., Dular, P., Vazquez Sabariego, R., Krähenbühl, L., & Geuzaine, C. (2013). Subproblem Approach for Modeling Multiply Connected Thin Regions with an h-Conformal Magnetodynamic Finite Element Formulation. *European Physical Journal : Applied physics, in press*.

http://hdl.handle.net/2268/153046

Peer reviewed (verified by ORBi) ✓
ORBi viewed: **91** (20 ULg) ; downloaded: **7** (6 ULg) — SCOPUS®: **0**
IF 2013: **0.789**; last: **0.789**; IF5: **0.801** — EigenF 2013: **?**; last: **0.0043** — Article Infl. 2013: **?**; last: **0.2649**

François-Lavet, V., Henrotte, F., Stainier, L., Noels, L., & Geuzaine, C. (2013). An Energy-Based Variational Model of Ferromagnetic Hysteresis for Finite Element Computations. *Journal of Computational & Applied Mathematics, 246*, 243–250.

http://hdl.handle.net/2268/124340

Peer reviewed (verified by ORBi) ✓
ORBi viewed: **144** (39 ULg) ; downloaded: **149** (13 ULg) — SCOPUS®: **0**
IF 2013: **1.077**; last: **1.077**; IF5: **1.245** — EigenF 2013: **?**; last: **0.0308** — Article Infl. 2013: **?**; last: **0.601**

Niyonzima, I., V Sabariego, R., Dular, P., Henrotte, F., & Geuzaine, C. (2013). Computational Homogenization for Laminated Ferromagnetic Cores in Magnetodynamics. *IEEE Transactions on Magnetics, 49*(5), 2049-2052.

http://hdl.handle.net/2268/148782

Peer reviewed (verified by ORBi) ✓
ORBi viewed: **114** (36 ULg) ; downloaded: **14** (14 ULg) — SCOPUS®: **4**
IF 2013: **1.213**; last: **1.213**; IF5: **1.301** — EigenF 2013: **?**; last: **0.0338** — Article Infl. 2013: **?**; last: **0.387**

Johnen, A., Remacle, J.-F., & Geuzaine, C. (2013). Geometrical Validity of Curvilinear Finite Elements. *Journal of Computational Physics, 233*, 359-372.

http://hdl.handle.net/2268/128340

Peer reviewed (verified by ORBi) ✓
ORBi viewed: **88** (29 ULg) ; downloaded: **78** (7 ULg) — SCOPUS®: **3**
IF 2013: **2.485**; last: **2.485**; IF5: **3.184** — EigenF 2013: **?**; last: **0.0580** — Article Infl. 2013: **?**; last: **1.3692**

Pellikka, M., Suuriniemi, S., Kettunen, L., & Geuzaine, C. (2013). Homology and Cohomology Computation in Finite Element Modeling. *SIAM Journal on Scientific Computing, 35*(5), 1195--B1214.

http://hdl.handle.net/2268/171459

Peer reviewed ✓
ORBi viewed: **5** ; downloaded: **0** — SCOPUS®: **1**

Johnen, A., Remacle, J.-F., & Geuzaine, C. (2012, December 07). Geometrical Validity of High-Order Triangular Finite Elements. *Engineering with Computers*.

http://hdl.handle.net/2268/129806

Peer reviewed (verified by ORBi) ✓
ORBi viewed: **102** (27 ULg) ; downloaded: **103** (3 ULg) — SCOPUS®: **-**
IF 2012: **0.600**; last: **1.088**; IF5: **0.832** — EigenF 2012: **?**; last: **0.0014** — Article Infl. 2012: **?**; last: **0.5059**

Vion, A., Thierry, B., & Geuzaine, C. (2012, December). Acceleration of the convergence of a non-overlapping domain decomposition method by an approximate deflation technique for high-frequency wave propagation. *Proceedings of the 15th Biennial IEEE Conference on Electromagnetic Field Computation (CEFC2012)*.

http://hdl.handle.net/2268/171500

Peer reviewed ✓
ORBi viewed: **5** (2 ULg) ; downloaded: **2** — SCOPUS®: **-**

Dang, Q. V., Dular, P., Vazquez Sabariego, R., Krahenbuhl, L., & Geuzaine, C. (2012). Subproblem Approach for Thin Shell Dual Finite Element Formulations. *IEEE Transactions on Magnetics, 48*(2), 407-410.

http://hdl.handle.net/2268/112753

Peer reviewed (verified by ORBi) ✓
ORBi viewed: **69** (25 ULg) ; downloaded: **5** (5 ULg) — SCOPUS®: **3**
IF 2012: **1.422**; last: **1.213**; IF5: **1.301** — EigenF 2012: **?**; last: **0.0338** — Article Infl. 2012: **?**; last: **0.387**

Dular, P., Krähenbühl, L., Vazquez Sabariego, R., V. Ferreira da Luz, M., Kuo-Peng, P., & Geuzaine, C. (2012). A Finite Element Subproblem Method for Position Change Conductor Systems. *IEEE Transactions on Magnetics, 48*(2), 403-406.

http://hdl.handle.net/2268/113663

Peer reviewed (verified by ORBi) ✓
ORBi viewed: **32** (10 ULg) ; downloaded: **4** (3 ULg) — SCOPUS®: **1**
IF 2012: **1.422**; last: **1.213**; IF5: **1.301** — EigenF 2012: **?**; last: **0.0337** — Article Infl. 2012: **?**; last: **0.3494**

Boubendir, Y., Antoine, X., & Geuzaine, C. (2012). A Quasi-Optimal Non-Overlapping Domain Decomposition Algorithm for the Helmholtz Equation. *Journal of Computational Physics, 231*(2), 262-280.

http://hdl.handle.net/2268/113150

Peer reviewed (verified by ORBi)
ORBi viewed: **23** (6 ULg) ; downloaded: **2** (2 ULg) — SCOPUS®: **8**
IF 2012: **2.138**; last: **2.485**; IF5: **3.184** — EigenF 2012: **?**; last: **0.0573** — Article Infl. 2012: **?**; last: **1.3934**

Gaignaire, R., Scorretti, R., Vazquez Sabariego, R., & Geuzaine, C. (2012). Stochastic uncertainty quantification of eddy currents in the human body by polynomial chaos decomposition. *IEEE Transactions on Magnetics, 48*(2), 451-454.

http://hdl.handle.net/2268/113660

Peer reviewed (verified by ORBi)
ORBi viewed: **19** (11 ULg) ; downloaded: **5** (5 ULg) — SCOPUS®: **2**
IF 2012: **1.422**; last: **1.213**; IF5: **1.301** — EigenF 2012: **?**; last: **0.0337** — Article Infl. 2012: **?**; last: **0.3494**

Kameni, A., Lambrechts, J., Remacle, J.-F., Mezani, S., Bouillaut, F., & Geuzaine, C. (2012). Discontinuous Galerkin Method for Computing Induced Fields in Superconducting Materials. *IEEE Transactions on Magnetics, 48*(2), 591-594.

http://hdl.handle.net/2268/113659

Peer reviewed (verified by ORBi)
ORBi viewed: **18** (4 ULg) ; downloaded: **0** — SCOPUS®: **2**
IF 2012: **1.422**; last: **1.213**; IF5: **1.301** — EigenF 2012: **?**; last: **0.0337** — Article Infl. 2012: **?**; last: **0.3494**

Marchandise, E., Remacle, J.-F., & Geuzaine, C. (2012). Optimal parametrizations for surface remeshing. *Engineering with Computers*, 1-20.

http://hdl.handle.net/2268/171450

Peer reviewed
ORBi viewed: **4** ; downloaded: **0** — SCOPUS®: **-**

Niyonzima, I., V Sabariego, R., Dular, P., & Geuzaine, C. (2012). Finite Element Computational Homogenization of Nonlinear Multiscale Materials in Magnetostatics. *IEEE Transactions on Magnetics, 48*(2), 587-590.

http://hdl.handle.net/2268/104001

Peer reviewed (verified by ORBi)
ORBi viewed: **110** (31 ULg) ; downloaded: **6** (6 ULg) — SCOPUS®: **4**
IF 2012: **1.422**; last: **1.213**; IF5: **1.301** — EigenF 2012: **?**; last: **0.0337** — Article Infl. 2012: **?**; last: **0.3494**

Remacle, J.-F., Lambrechts, J., Seny, B., Marchandise, E., Johnen, A., & Geuzaine, C. (2012). Blossom-Quad: a non-uniform quadrilateral mesh generator using a minimum cost perfect matching algorithm. *International Journal for Numerical Methods in Engineering, 89*, 1102-1119.

http://hdl.handle.net/2268/113152

Peer reviewed (verified by ORBi)
ORBi viewed: **100** (13 ULg) ; downloaded: **3** (2 ULg) — SCOPUS®: **8**
IF 2012: **2.056**; last: **1.961**; IF5: **2.509** — EigenF 2012: **?**; last: **0.0283** — Article Infl. 2012: **?**; last: **0.99**

Rochus, V., & Geuzaine, C. (2012). A Primal/Dual Approach for the Accurate Evaluation of the Electromechanical Coupling in MEMS. *Finite Elements in Analysis & Design, 49*(1), 19-27.

http://hdl.handle.net/2268/113151

Peer reviewed (verified by ORBi)
ORBi viewed: **15** (6 ULg) ; downloaded: **1** (1 ULg) — SCOPUS®: **1**
IF 2012: **1.389**; last: **1.595**; IF5: **1.679** — EigenF 2012: **?**; last: **0.0048** — Article Infl. 2012: **?**; last: **0.5961**

Rochus, V., Gutschmidt, S., Cardona, A., & Geuzaine, C. (2012). Electro-Mechano-Fluidic Modelling of Microsystems using Finite Elements. *IEEE Transactions on Magnetics, 48*(2), 355-358.

http://hdl.handle.net/2268/113658

Peer reviewed (verified by ORBi)
ORBi viewed: **15** (3 ULg) ; downloaded: **1** (1 ULg) — SCOPUS®: **1**
IF 2012: **1.422**; last: **1.213**; IF5: **1.301** — EigenF 2012: **?**; last: **0.0337** — Article Infl. 2012: **?**; last: **0.3494**

Dular, P., Dang, Q. V., Vazquez Sabariego, R., Krahenbuhl, L., & Geuzaine, C. (2011). Correction of Thin Shell Finite Element Magnetic Models via a Subproblem Method. *IEEE Transactions on Magnetics, 47*(5), 1158-1161.

http://hdl.handle.net/2268/113675

Peer reviewed (verified by ORBi)
ORBi viewed: **29** (11 ULg) ; downloaded: **3** (3 ULg) — SCOPUS®: **3**
IF 2011: **1.363**; last: **1.213**; IF5: **1.301** — EigenF 2011: **0.0338**; last: **0.0338** — Article Infl. 2011: **0.387**; last: **0.387**

Vion, A., Vazquez Sabariego, R., & Geuzaine, C. (2011). A Model Reduction Algorithm for Solving Multiple Scattering Problems Using Iterative Methods. *IEEE Transactions on Magnetics, 47*(5), 1470-1473.

http://hdl.handle.net/2268/113656

Peer reviewed (verified by ORBi) ✓
ORBi viewed: **21** (6 ULg) ; downloaded: **4** (4 ULg) — SCOPUS®: **2**
IF 2011: **1.363**; last: **1.213**; IF5: **1.301** — EigenF 2011: **?**; last: **0.0337** — Article Infl. 2011: **?**; last: **0.3494**

Gaignaire, R., Crevecoeur, G., Dupré, L., V Sabariego, R., Dular, P., & Geuzaine, C. (2010). Stochastic Uncertainty Quantification of the Conductivity in EEG Source Analysis by Using Polynomial Chaos Decomposition. *IEEE Transactions on Magnetics, 46*(8), 3457-3460.

http://hdl.handle.net/2268/83234

Peer reviewed (verified by ORBi) ✓
ORBi viewed: **64** (12 ULg) ; downloaded: **3** (3 ULg) — SCOPUS®: **9**
IF 2010: **1.053**; last: **1.213**; IF5: **1.301** — EigenF 2010: **0.0337**; last: **0.0337** — Article Infl. 2010: **0.3494**; last: **0.3494**

Geuzaine, C., Vion, A., Gaignaire, R., Dular, P., & V Sabariego, R. (2010). An Amplitude Finite Element Formulation for Multiple-Scattering by a Collection of Convex Obstacles. *IEEE Transactions on Magnetics, 46*(8), 2963-2966.

http://hdl.handle.net/2268/35709

Peer reviewed (verified by ORBi) ✓
ORBi viewed: **81** (21 ULg) ; downloaded: **3** (1 ULg) — SCOPUS®: **3**
IF 2010: **1.053**; last: **1.213**; IF5: **1.301** — EigenF 2010: **0.0337**; last: **0.0337** — Article Infl. 2010: **0.3494**; last: **0.3494**

Nicolet, A., Zolla, F., & Geuzaine, C. (2010). Transformation Optics, Generalized Cloaking and Superlenses. *IEEE Transactions on Magnetics, 46*.

http://hdl.handle.net/2268/35763

Peer reviewed ✓
ORBi viewed: **43** (7 ULg) ; downloaded: **2** (1 ULg) — SCOPUS®: **7**

V Sabariego, R., Sergeant, P., Gyselinck, J., Dular, P., Dupré, L., & Geuzaine, C. (2010). Finite-Element Analysis of a Shielded Pulsed-Current Induction Heater -- Experimental Validation of a Time-Domain Thin-Shell Approach. *COMPEL, 29*(6), 1585-1595.

http://hdl.handle.net/2268/35702

Peer reviewed (verified by ORBi) ✓
ORBi viewed: **35** (2 ULg) ; downloaded: **1** (1 ULg) — SCOPUS®: **0**
IF 2010: **0.394**; last: **0.440**; IF5: **0.364** — EigenF 2010: **0.0017**; last: **0.0017** — Article Infl. 2010: **0.1628**; last: **0.1628**

Antoine, X., & Geuzaine, C. (2009). Phase Reduction Models for Improving the Accuracy of the Finite Element Solution of Time-Harmonic Scattering Problems I: General Approach and Low-Order Models. *Journal of Computational Physics, 228*, 3114--3136.

http://hdl.handle.net/2268/21865

Peer reviewed (verified by ORBi) ✓
ORBi viewed: **58** (11 ULg) ; downloaded: **3** (2 ULg) — SCOPUS®: **3**
IF 2009: **2.369**; last: **2.485**; IF5: **3.184** — EigenF 2009: **0.0561**; last: **0.0573** — Article Infl. 2009: **1.3881**; last: **1.3934**

Geuzaine, C., & Remacle, J.-F. (2009). Gmsh: a three-dimensional finite element mesh generator with built-in pre- and post-processing facilities. *International Journal for Numerical Methods in Engineering, 79*(11), 1309-1331.

http://hdl.handle.net/2268/22742

Peer reviewed (verified by ORBi) ✓
ORBi viewed: **197** (14 ULg) ; downloaded: **11** (3 ULg) — SCOPUS®: **560**
IF 2009: **2.025**; last: **1.961**; IF5: **2.509** — EigenF 2009: **0.0340**; last: **0.0283** — Article Infl. 2009: **1.0841**; last: **0.99**

Jacqmaer, P., Driesen, J., & Geuzaine, C. (2009). Modelling earthing systems and cables with moment methods. *International Journal for Computation and Mathematics in Electrical and Electronic Engineering, 28*(4), 989--1004.

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ORBi viewed: **121** (35 ULg) ; downloaded: **65** (21 ULg)

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IF 2009: **1.212**; last: **1.307**; IF5: **1.592** — EigenF 2009: **0.0009**; last: **0.0020** — Article Infl. 2009: **0.3259**; last: **0.5564**

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IF 2008: **1.129**; last: **1.213**; IF5: **1.301** — EigenF 2008: **0.0387**; last: **0.0337** — Article Infl. 2008: **0.3843**; last: **0.3494**

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ORBi viewed: **20** (1 ULg) ; downloaded: **0** — SCOPUS®: **2**
IF 2008: **1.742**; last: **-**; IF5: **-** — EigenF 2008: **0.0142**; last: **0.0149** — Article Infl. 2008: **0.609**; last: **0.6157**

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IF 2008: **1.129**; last: **1.213**; IF5: **1.301** — EigenF 2008: **0.0387**; last: **0.0337** — Article Infl. 2008: **0.3843**; last: **0.3494**

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IF 2007: **0.943**; last: **1.077**; IF5: **1.245** — EigenF 2007: **0.0239**; last: **0.0282** — Article Infl. 2007: **0.5651**; last: **0.5711**

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IF 2007: **0.226**; last: **0.440**; IF5: **0.364** — EigenF 2007: **-**; last: **0.0017** — Article Infl. 2007: **-**; last: **0.1628**

Remacle, J.-F., Chevaugeon, N., Marchandise, E., & Geuzaine, C. (2007). Efficient Visualization of High-Order Finite Elements. *International Journal for Numerical Methods in Engineering, 69*(4), 750--771.

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ORBi viewed: **16** (1 ULg) ; downloaded: **1** — SCOPUS®: **17**
IF 2007: **1.612**; last: **1.961**; IF5: **2.509** — EigenF 2007: **0.0335**; last: **0.0283** — Article Infl. 2007: **0.995**; last: **0.99**

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IF 2005: **1.014**; last: **1.213**; IF5: **1.301** — EigenF 2005: **0.0504**; last: **0.0337** — Article Infl. 2005: **0.459**; last: **0.3494**

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IF 2003: **1.006**; last: **1.213**; IF5: **1.301** — EigenF 2003: **0.0630**; last: **0.0337** — Article Infl. 2003: **0.5032**; last: **0.3494**

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IF 2002: **1.016**; last: **1.213**; IF5: **1.301** — EigenF 2002: **0.0651**; last: **0.0337** — Article Infl. 2002: **0.4942**; last: **0.3494**

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IF 2001: **?**; last: **1.213**; IF5: **1.301** — EigenF 2001: **0.0599**; last: **0.0337** — Article Infl. 2001: **0.4238**; last: **0.3494**

Geuzaine, C., Dular, P., & Legros, W. (2000). Dual Formulations for the Modeling of Thin Electromagnetic Shells using Edge Elements. *IEEE Transactions on Magnetics, 36*(4), 799-803.
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IF 2000: **0.72**; last: **1.213**; IF5: **1.301** — EigenF 2000: **0.0785**; last: **0.0337** — Article Infl. 2000: **0.5346**; last: **0.3494**

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IF 2000: **0.72**; last: **1.213**; IF5: **1.301** — EigenF 2000: **0.0785**; last: **0.0338** — Article Infl. 2000: **0.5346**; last: **0.387**

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IF 2000: **0.72**; last: **1.213**; IF5: **1.301** — EigenF 2000: **0.0785**; last: **0.0337** — Article Infl. 2000: **0.5346**; last: **0.3494**

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IF 1999: **-**; last: **0.440**; IF5: **0.364** — EigenF 1999: **-**; last: **0.0017** — Article Infl. 1999: **-**; last: **0.1628**

Geuzaine, C., Meys, B., Dular, P., Henrotte, F., & Legros, W. (1999). A Galerkin projection method for mixed finite elements. *IEEE Transactions on Magnetics, 35*(3), 1438--1441.
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Peer reviewed (verified by ORBi) ✓
ORBi viewed: **22** (4 ULg) ; downloaded: **2** (1 ULg) — SCOPUS®: **34**
IF 1999: **1.061**; last: **1.213**; IF5: **1.301** — EigenF 1999: **0.0762**; last: **0.0337** — Article Infl. 1999: **0.4901**; last: **0.3494**

Geuzaine, C., Meys, B., Dular, P., & Legros, W. (1999). Convergence of High Order Curl-Conforming Finite Elements. *IEEE Transactions on Magnetics, 35*(3), 1442--1445.
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Peer reviewed (verified by ORBi) ✓
ORBi viewed: **12** ; downloaded: **0** — SCOPUS®: **8**
IF 1999: **1.061**; last: **1.213**; IF5: **1.301** — EigenF 1999: **0.0762**; last: **0.0337** — Article Infl. 1999: **0.4901**; last: **0.3494**

As co-author

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ORBi viewed: **8** (3 ULg) ; downloaded: **0** — SCOPUS®: **0**
IF 2014: **?**; last: **0.629**; IF5: **0.577** — EigenF 2014: **?**; last: **0.0004** — Article Infl. 2014: **?**; last: **0.1683**

Marchandise, E., Geuzaine, C., & Remacle, J.-F. (2013). Cardiovascular and lung mesh generation based on centerlines. *International journal for numerical methods in biomedical engineering, 29*(6), 665-682.

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Remacle, J.-F., Henrotte, F., Carrier-Baudouin, T., Béchet, E., Marchandise, E., Geuzaine, C., & Mouton, T. (2013). A Frontal Delaunay Quad Mesh Generator Using the L_∞ Norm. *International Journal for Numerical Methods in Engineering, 94*(5), 494-512.

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ORBi viewed: **102** (35 ULg) ; downloaded: **6** (5 ULg) — SCOPUS®: **3**
IF 2013: **1.961**; last: **1.961**; IF5: **2.509** — EigenF 2013: **?**; last: **0.0285** — Article Infl. 2013: **?**; last: **1.0545**

Toulorge, T., Geuzaine, C., Remacle, J.-F., & Lambrechts, J. (2013). Robust untangling of curvilinear meshes. *Journal of Computational Physics, 254*, 8--26.

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ORBi viewed: **6** ; downloaded: **0** — SCOPUS®: **0**

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ORBi viewed: **563** (297 ULg) ; downloaded: **1313** (55 ULg) — SCOPUS®: **11**
IF 2012: **1.878**; last: **1.879**; IF5: **1.973** — EigenF 2012: **?**; last: **0.0225** — Article Infl. 2012: **?**; last: **0.6477**

Vazquez Sabariego, R., Geuzaine, C., Dular, P., & Gyselinck, J. (2012). Time-domain surface impedance boundary conditions enhanced by coarse volume finite-element discretisation. *IEEE Transactions on Magnetics, 48*(2), 631-634.

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ORBi viewed: **36** (7 ULg) ; downloaded: **3** (3 ULg) — SCOPUS®: **2**
IF 2012: **1.422**; last: **1.213**; IF5: **1.301** — EigenF 2012: **?**; last: **0.0337** — Article Infl. 2012: **?**; last: **0.3494**

Scorretti, R., Vazquez Sabariego, R., Morel, L., Geuzaine, C., Burais, N., & Nicolas, L. (2012). Computation of induced fields into the human body by dual Finite Element formulations. *IEEE Transactions on Magnetics, 48*(2), 783-786.

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ORBi viewed: **18** (5 ULg) ; downloaded: **3** (3 ULg) — SCOPUS®: **3**
IF 2012: **1.422**; last: **1.213**; IF5: **1.301** — EigenF 2012: **?**; last: **0.0337** — Article Infl. 2012: **?**; last: **0.3494**

Becker, G., Geuzaine, C., & Noels, L. (2011). A one Field Full Discontinuous Galerkin Method for Kirchhoff-Love Shells Applied to Fracture Mechanics. *Computer Methods in Applied Mechanics & Engineering, 200*(45-46), 3223-3241.

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ORBi viewed: **157** (62 ULg) ; downloaded: **130** (18 ULg) — SCOPUS®: **9**
IF 2011: **2.651**; last: **2.626**; IF5: **3.049** — EigenF 2011: **0.0401**; last: **0.0401** — Article Infl. 2011: **1.327**; last: **1.327**

Marchandise, E., Carton de Wiart, C., Vos, W., Geuzaine, C., & Remacle, J.-F. (2011). High Quality Surface Remeshing Using Harmonic Maps. Part II: Surfaces with High Genus and of Large Aspect Ratio. *International Journal for Numerical Methods in Engineering, 86*(11), 1303-1321.

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ORBi viewed: **28** (1 ULg) ; downloaded: **5** — SCOPUS®: **14**
IF 2011: **2.009**; last: **1.961**; IF5: **2.509** — EigenF 2011: **?**; last: **0.0283** — Article Infl. 2011: **?**; last: **0.99**

Dular, P., V Sabariego, R., Geuzaine, C., Luz, M. V. F. D., Kuo-Peng, P., & Krähenbühl, L. (2010). Finite Element Magnetic Models via a Coupling of Subproblems of Lower Dimensions. *IEEE Transactions on Magnetics, 46*(8), 2827-2830.

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ORBi viewed: **40** (6 ULg) ; downloaded: **2** (1 ULg) — SCOPUS®: **9**
IF 2010: **1.053**; last: **1.213**; IF5: **1.301** — EigenF 2010: **0.0337**; last: **0.0337** — Article Infl. 2010: **0.3494**; last: **0.3494**

V Sabariego, R., Dular, P., Geuzaine, C., & Gyselinck, J. (2010). Surface-Impedance Boundary Conditions in Dual Time-Domain Finite-Element Formulations. *IEEE Transactions on Magnetics, 46*(8), 3524-3531.

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ORBi viewed: **88** (14 ULg) ; downloaded: **4** (3 ULg) — SCOPUS®: **5**
IF 2010: **1.053**; last: **1.213**; IF5: **1.301** — EigenF 2010: **0.0337**; last: **0.0337** — Article Infl. 2010: **0.3494**; last: **0.3494**

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ORBi viewed: **33** (5 ULg) ; downloaded: **1** (1 ULg) — SCOPUS®: **12**
IF 2010: **-**; last: **1.542**; IF5: **1.447** — EigenF 2010: **1.1E-5**; last: **1.1E-5** — Article Infl. 2010: **0**; last: **0**

Remacle, J.-F., Geuzaine, C., Compère, G., & Marchandise, E. (2010). High-Quality Surface Remeshing Using Harmonic Maps. *International Journal for Numerical Methods in Engineering, 83*(4), 403-425.

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Lousberg, G., Ausloos, M., Geuzaine, C., Dular, P., Vanderbemden, P., & Vanderheyden, B. (2009). Numerical simulation of the magnetization of high-temperature superconductors: a 3D finite element method using a single time-step iteration. *Superconductor Science and Technology, 22*, 055005.

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ORBi viewed: **148** (54 ULg) ; downloaded: **186** (19 ULg) — SCOPUS®: **9**
IF 2009: **2.694**; last: **2.796**; IF5: **2.455** — EigenF 2009: **0.0202**; last: **0.0203** — Article Infl. 2009: **0.5869**; last: **0.6731**

Gyselinck, J., Geuzaine, C., Dular, P., & V Sabariego, R. (2009). Surface-impedance boundary conditions in time-domain finite-element calculations. *IEEE Transactions on Magnetics, 45*(3), 1280-1283.

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ORBi viewed: **78** (6 ULg) ; downloaded: **4** (1 ULg) — SCOPUS®: **6**
IF 2009: **1.061**; last: **1.213**; IF5: **1.301** — EigenF 2009: **0.0347**; last: **0.0337** — Article Infl. 2009: **0.3564**; last: **0.3494**

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ORBi viewed: **50** (8 ULg) ; downloaded: **0** — SCOPUS®: **0**
IF 2009: **1.061**; last: **1.213**; IF5: **1.301** — EigenF 2009: **0.0347**; last: **0.0337** — Article Infl. 2009: **0.3564**; last: **0.3494**

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ORBi viewed: **24** (1 ULg) ; downloaded: **1** (1 ULg) — SCOPUS®: **2**
IF 2008: **0.596**; last: **0.592**; IF5: **0.772** — EigenF 2008: **0.0002**; last: **0.0007** — Article Infl. 2008: **0.1873**; last: **0.2408**

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IF 2008: **2.468**; last: **1.683**; IF5: **1.867** — EigenF 2008: **0.0053**; last: **0.0038** — Article Infl. 2008: **1.5223**; last: **0.9538**

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ORBi viewed: **14** (2 ULg) ; downloaded: **0** — SCOPUS®: **5**
IF 2007: **0.751**; last: **1.276**; IF5: **1.133** — EigenF 2007: **0.0481**; last: **0.0371** — Article Infl. 2007: **0.3186**; last: **0.3228**

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IF 2004: **0.348**; last: **0.737**; IF5: **0.675** — EigenF 2004: **0.0011**; last: **0.0007** — Article Infl. 2004: **0.1174**; last: **0.0667**

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IF 2004: **0.180**; last: **0.440**; IF5: **0.364** — EigenF 2004: **-**; last: **0.0017** — Article Infl. 2004: **-**; last: **0.1628**

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IF 2004: **0.180**; last: **0.440**; IF5: **0.364** — EigenF 2004: **-**; last: **0.0017** — Article Infl. 2004: **-**; last: **0.1628**

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IF 2004: **0.486**; last: **1.077**; IF5: **1.245** — EigenF 2004: **0.0233**; last: **0.0282** — Article Infl. 2004: **0.5763**; last: **0.5711**

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Peer reviewed (verified by ORBi) ✓
ORBi viewed: **36** (4 ULg) ; downloaded: **3** (3 ULg) — SCOPUS®: **33**
IF 2004: **0.486**; last: **1.077**; IF5: **1.245** — EigenF 2004: **0.0233**; last: **0.0282** — Article Infl. 2004: **0.5763**; last: **0.5711**

V Sabariego, R., Gyselinck, J., Dular, P., Geuzaine, C., & Legros, W. (2004). Fast multipole acceleration of the hybrid finite-element/boundary-element analysis of 3-D eddy-current problems. *IEEE Transactions on Magnetics, 40*(2), 1278-1281.

http://hdl.handle.net/2268/22756

Peer reviewed (verified by ORBi) ✓
ORBi viewed: **19** (4 ULg) ; downloaded: **1** (1 ULg) — SCOPUS®: **11**
IF 2004: **0.837**; last: **1.213**; IF5: **1.301** — EigenF 2004: **0.0503**; last: **0.0337** — Article Infl. 2004: **0.4202**; last: **0.3494**

V Sabariego, R., Gyselinck, J., Geuzaine, C., Dular, P., & Legros, W. (2004). Application of the fast multipole method to hybrid finite element-boundary element models. *Journal of Computational & Applied Mathematics, 168*(1-2), 403-412.

http://hdl.handle.net/2268/2117

Peer reviewed (verified by ORBi) ✓
ORBi viewed: **44** (9 ULg) ; downloaded: **4** (3 ULg) — SCOPUS®: **1**
IF 2004: **0.486**; last: **1.077**; IF5: **1.245** — EigenF 2004: **0.0233**; last: **0.0282** — Article Infl. 2004: **0.5763**; last: **0.5711**

Dular, P., Gyselinck, J., Geuzaine, C., Sadowski, N., & Bastos, J. P. A. (2003). A 3-D Magnetic Vector Potential Formulation Taking Eddy Currents in Lamination Stacks Into Account. *IEEE Transactions on Magnetics, 39*(3), 1424--1427.

http://hdl.handle.net/2268/22768

Peer reviewed (verified by ORBi) ✓

ORBi viewed: **45** (2 ULg) ; downloaded: **2** — SCOPUS®: **37**

IF 2003: **1.006**; last: **1.213**; IF5: **1.301** — EigenF 2003: **0.0630**; last: **0.0337** — Article Infl. 2003: **0.5032**; last: **0.3494**

Gyselinck, J., Vandevelde, L., Dular, P., Geuzaine, C., & Legros, W. (2003). A General Method for the Frequency Domain FE Modelling of Rotating Electromagnetic Devices. *IEEE Transactions on Magnetics, 39*(3), 1147--1150.

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Peer reviewed (verified by ORBi) ✓

ORBi viewed: **19** (3 ULg) ; downloaded: **1** (1 ULg) — SCOPUS®: **9**

IF 2003: **1.006**; last: **1.213**; IF5: **1.301** — EigenF 2003: **0.0630**; last: **0.0337** — Article Infl. 2003: **0.5032**; last: **0.3494**

V Sabariego, R., Gyselinck, J., Geuzaine, C., Dular, P., & Legros, W. (2003). Application of the fast multipole method to the 2D finite element-boundary element analysis of electromechanical devices. *COMPEL, 22*(3), 659-673.

http://hdl.handle.net/2268/22765

Peer reviewed (verified by ORBi) ✓

ORBi viewed: **89** (20 ULg) ; downloaded: **4** (3 ULg) — SCOPUS®: **3**

IF 2003: **0.336**; last: **0.440**; IF5: **0.364** — EigenF 2003: **-**; last: **0.0017** — Article Infl. 2003: **-**; last: **0.1628**

Gyselinck, J., Dular, P., Geuzaine, C., & Legros, W. (2002). Harmonic-Balance Finite-Element Modelling of Electromagnetic Devices: A Novel Approach. *IEEE Transactions on Magnetics, 38*(2), 521--524.

http://hdl.handle.net/2268/22770

Peer reviewed (verified by ORBi) ✓

ORBi viewed: **20** (2 ULg) ; downloaded: **1** (1 ULg) — SCOPUS®: **28**

IF 2002: **1.016**; last: **1.213**; IF5: **1.301** — EigenF 2002: **0.0651**; last: **0.0337** — Article Infl. 2002: **0.4942**; last: **0.3494**

Luz, M. V. F. D., Dular, P., Sadowski, N., Geuzaine, C., & Bastos, J. P. A. (2002). Analysis of a Permanent Magnet Generator With Dual Formulations Using Periodicity Conditions and Moving Band. *IEEE Transactions on Magnetics, 38*(2), 961--964.

http://hdl.handle.net/2268/22771

Peer reviewed (verified by ORBi) ✓

ORBi viewed: **113** (12 ULg) ; downloaded: **2** (1 ULg) — SCOPUS®: **16**

IF 2002: **1.016**; last: **1.213**; IF5: **1.301** — EigenF 2002: **0.0651**; last: **0.0337** — Article Infl. 2002: **0.4942**; last: **0.3494**

Dular, P., Geuzaine, C., Luz, M. V. F. D., Sadowski, N., & Bastos, J. P. A. (2001). Connection boundary conditions with different types of finite elements applied to periodicity conditions and to the moving band. *COMPEL, 20*(1), 109--119.

http://hdl.handle.net/2268/22773

Peer reviewed (verified by ORBi) ✓

ORBi viewed: **20** (2 ULg) ; downloaded: **0** — SCOPUS®: **6**

IF 2001: **?**; last: **0.440**; IF5: **0.364** — EigenF 2001: **-**; last: **0.0017** — Article Infl. 2001: **-**; last: **0.1628**

Guenneau, S., Nicolet, A., Zolla, F., Geuzaine, C., & Meys, B. (2001). A finite element formulation for spectral problems in optical fibers. *COMPEL, 20*(1), 120--131.

http://hdl.handle.net/2268/22774

Peer reviewed (verified by ORBi) ✓

ORBi viewed: **7** (2 ULg) ; downloaded: **0** — SCOPUS®: **14**

IF 2001: **?**; last: **0.440**; IF5: **0.364** — EigenF 2001: **-**; last: **0.0017** — Article Infl. 2001: **-**; last: **0.1628**

Dular, P., Kuo-Peng, P., Geuzaine, C., Sadowski, N., & Bastos, J. P. A. (2000). Dual Magnetodynamic Formulations and Their Source Fields Associated with Massive and Stranded Inductors. *IEEE Transactions on Magnetics, 36*(4), 1293--1299.

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Peer reviewed (verified by ORBi) ✓

ORBi viewed: **26** (1 ULg) ; downloaded: **1** (1 ULg) — SCOPUS®: **2**

IF 2000: **0.72**; last: **1.213**; IF5: **1.301** — EigenF 2000: **0.0785**; last: **0.0338** — Article Infl. 2000: **0.5346**; last: **0.387**

Dular, P., Geuzaine, C., Genon, A., & Legros, W. (1999). An Evolutive Software Environment for Teaching the Finite Element Method in Electromagnetism. *IEEE Transactions on Magnetics, 35*(3), 1682--1685.

http://hdl.handle.net/2268/22781

Peer reviewed (verified by ORBi) ✓

ORBi viewed: **33** ; downloaded: **0** — SCOPUS®: **4**

IF 1999: **1.061**; last: **1.213**; IF5: **1.301** — EigenF 1999: **0.0762**; last: **0.0337** — Article Infl. 1999: **0.4901**; last: **0.3494**

Dular, P., Geuzaine, C., & Legros, W. (1999). A Natural Method for Coupling Magnetodynamic H-Formulations and Circuit Equations. *IEEE Transactions on Magnetics, 35*(3), 1626--1629.

http://hdl.handle.net/2268/22786

Peer reviewed (verified by ORBi) ✔
ORBi viewed: **23** (4 ULg) ; downloaded: **3** (2 ULg) — SCOPUS®: **15**
IF 1999: **1.061**; last: **1.213**; IF5: **1.301** — EigenF 1999: **0.0762**; last: **0.0337** — Article Infl. 1999: **0.4901**; last: **0.3494**

Meys, B., Geuzaine, C., Henrotte, F., Dular, P., & Legros, W. (1999). Dual Harmonic and Time Approaches for the Design of Microwave Devices. *IEEE Transactions on Magnetics, 35*(3), 1829--1832.

http://hdl.handle.net/2268/22782

Peer reviewed (verified by ORBi) ✔
ORBi viewed: **8** ; downloaded: **0** — SCOPUS®: **0**
IF 1999: **1.061**; last: **1.213**; IF5: **1.301** — EigenF 1999: **0.0762**; last: **0.0337** — Article Infl. 1999: **0.4901**; last: **0.3494**

Meys, B., Henrotte, F., Geuzaine, C., Hedia, H., & Legros, W. (1999). An Optimization Method for the Design of Physical and Maxwellian Absorbers. *IEEE Transactions on Magnetics, 35*(3), 1430--1433.

http://hdl.handle.net/2268/22783

Peer reviewed (verified by ORBi) ✔
ORBi viewed: **11** ; downloaded: **0** — SCOPUS®: **0**
IF 1999: **1.061**; last: **1.213**; IF5: **1.301** — EigenF 1999: **0.0762**; last: **0.0337** — Article Infl. 1999: **0.4901**; last: **0.3494**

Dular, P., Geuzaine, C., Henrotte, F., & Legros, W. (1998). A General Environment for the Treatment of Discrete Problems and its Application to the Finite Element Method. *IEEE Transactions on Magnetics, 34*(5), 3395--3398.

http://hdl.handle.net/2268/22789

Peer reviewed (verified by ORBi) ✔
ORBi viewed: **21** (1 ULg) ; downloaded: **1** — SCOPUS®: **50**
IF 1998: **0.704**; last: **1.213**; IF5: **1.301** — EigenF 1998: **0.0614**; last: **0.0337** — Article Infl. 1998: **0.3808**; last: **0.3494**

Remacle, J.-F., Geuzaine, C., Dular, P., Hedia, H., & Legros, W. (1998). Error estimation based on a new principle of projection and reconstruction. *IEEE Transactions on Magnetics, 34*(5), 3264--3267.

http://hdl.handle.net/2268/22796

Peer reviewed (verified by ORBi) ✔
ORBi viewed: **30** (1 ULg) ; downloaded: **1** — SCOPUS®: **5**
IF 1998: **0.704**; last: **1.213**; IF5: **1.301** — EigenF 1998: **0.0614**; last: **0.0337** — Article Infl. 1998: **0.3808**; last: **0.3494**

Others

Béchet, E., Dick, E., Geuzaine, C., Hogge, M., Malengier, B., Noels, L., Remacle, J.-F., Slodicka, M., & Van Keer (Eds.). (2013). Fifth International Conference on Advanced COmputational Methods in ENgineering (ACOMEN 2011). *International Journal of Computational & Applied Mathematics, 246*, 1-334.

http://hdl.handle.net/2268/144589

Peer reviewed (verified by ORBi) ✔
ORBi viewed: **107** (23 ULg) ; downloaded: **4** (4 ULg) — SCOPUS®: **-**

3.b. With a national target audience

As first or last author

Dular, P., Péron, V., Krähenbühl, L., & Geuzaine, C. (2013). Progressive Eddy Current modeling via a finite element subproblem method. *International Journal of Applied Electromagnetics and Mechanics.*

http://hdl.handle.net/2268/171457

Peer reviewed (verified by ORBi) ✔
ORBi viewed: **10** (1 ULg) ; downloaded: **0** — SCOPUS®: **-**
IF 2013: **0.737**; last: **0.737**; IF5: **0.675** — EigenF 2013: **?**; last: **0.0007** — Article Infl. 2013: **?**; last: **0.0667**

5. Books

5.b. As editor or publication director

Dupre, L., & Geuzaine, C. (Eds.). (2014). *Special Issue: The 9th International Symposium on Electric and Magnetic Fields (EMF 2013)*. Wiley & Sons.

http://hdl.handle.net/2268/171463

ORBi viewed: **9** (2 ULg) ; downloaded: **0** — SCOPUS®: **0**

Hogge, M., Van Keer, R., Dick, E., Malengier, B., Slodicka, M., Béchet, E., Geuzaine, C., Noels, L., & Remacle, J.-F. (Eds.). (2011). *Proceedings of the 5th International Conference on Advanded COmputational Methods in Engineering (ACOMEN2011)* (Dépôt légal: D/2011/0480/31). Liège, Belgium: Université de Liège.

http://hdl.handle.net/2268/106357
ORBi viewed: **42** (7 ULg)

6. Chapters and parts of collective works

6.a. Chapters

Boubendir, Y., Antoine, X., & Geuzaine, C. (2013). A non-overlapping quasi-optimal optimized Schwarz domain decomposition algorithm for the Helmholtz equation. *Proceedings of Domain Decomposition Methods in Science and Engineering XX* (pp. 519-526). Springer Berlin Heidelberg.

http://hdl.handle.net/2268/171452
Peer reviewed ✓
ORBi viewed: **5** — SCOPUS®: **-**

Marchandise, E., Crosetto, P., Geuzaine, C., Remacle, J.-F., & Sauvage, E. (2012). Quality open source mesh generation for cardiovascular flow simulations. In D., Ambrosi, A., Quarteroni, & G., Rozza (Eds.), *Modelling Physiological Flow* (pp. 395-414). Milan: Springer-Verlag.

http://hdl.handle.net/2268/83286
Peer reviewed ✓
ORBi viewed: **95** (3 ULg) ; downloaded: **6** — SCOPUS®: **-**

Antoine, X., Geuzaine, C., & Ramdani, K. (2010). Computational Methods for Multiple Scattering at High Frequency with Applications to Periodic Structure Calculations. In M., Ehrhardt (Ed.), *Wave Propagation in Periodic Media - Analysis, Numerical Techniques and practical Applications* (pp. 73-107). Bentham.

http://hdl.handle.net/2268/14982
ORBi viewed: **98** (16 ULg) ; downloaded: **5** (3 ULg)

Remacle, J.-F., Geuzaine, C., Compère, J., & Helenbrook, B. T. (2010). Adaptive Mesh Generation and Visualisation. In R., Blockley & W., Shyy (Eds.), *Encyclopedia of Aerospace Engineering* (pp. 1735-1746). Wiley.

http://hdl.handle.net/2268/22961
ORBi viewed: **286** (31 ULg) ; downloaded: **9** (1 ULg)

8. Scientific conferences at universities and research centers

Vion, A., & Geuzaine, C. (2014, May). *Parallel Double Sweep Preconditioner for the Optimized Schwarz Algorithm Applied to High Frequency Helmholtz and Maxwell Equations*. Paper presented at ICMS Workshop on Challenges in medical imaging: numerics, high performance computing, inverse problems, Strathclyde University Glasgow.

http://hdl.handle.net/2268/171490
ORBi viewed: **7** (1 ULg) — SCOPUS®: **-**

Aristidou, P., Plumier, F., Van Cutsem, T., & Geuzaine, C. (2013, March 05). *Power System Simulation Challenges*. Paper presented at 8th IntelliCIS Workshop, Aachen, Germany.

http://hdl.handle.net/2268/150191
ORBi viewed: **109** (10 ULg) ; downloaded: **96** (10 ULg) — SCOPUS®: **-**

Geuzaine, C. (2012, June 05). *Le monde à l'envers : résoudre des EDPs pour construire des maillages*. Paper presented at Séminaire de Mathématiques - EDP, Nancy, France.

http://hdl.handle.net/2268/125318
ORBi viewed: **48** (4 ULg)

Geuzaine, C. (2012, March 29). *Improved Finite Element Solvers for the Helmholtz Equation at High Frequencies*. Paper presented at Recent Advances in Modeling, Analysis and Simulation of Wave Propagation, Metz, France.

http://hdl.handle.net/2268/113827
ORBi viewed: **31** (2 ULg)

Antoine, X., Boubendir, Y., & Geuzaine, C. (2012, February 10). *Deux méthodes numériques pour la résolution de problèmes de diffraction multiple à haute fréquence*. Paper presented at Séminaire d'Analyse Appliquée, Paris, France.

http://hdl.handle.net/2268/113798
ORBi viewed: **15** (1 ULg)

Geuzaine, C., Antoine, X., Boubendir, Y., & Thierry, B. (2012, January 23). *Improved Domain Decomposition Method for the Helmholtz Equation*". Paper presented at Invited lecture, Delft, Netherlands.

http://hdl.handle.net/2268/113824
ORBi viewed: **40** (2 ULg)

Geuzaine, C. (2011, November). *Partial Differential Equations and Meshing*. Paper presented at Systems and Modelling Seminar, Liège, Belgium.

http://hdl.handle.net/2268/125317
ORBi viewed: **27** (2 ULg)

Antoine, X., Boubendir, Y., & Geuzaine, C. (2011, October 24). *Conditions aux limites de transmission robustes en decomposition de domaines pour l'acoustique*. Paper presented at GDR Ondes, Nice, France.

http://hdl.handle.net/2268/113799
ORBi viewed: **9** (1 ULg)

Antoine, X., Boubendir, Y., & Geuzaine, C. (2011, October 04). *Two numerical methods for solving high frequency multiple scattering problems*. Paper presented at Invited lecture, Genève, Suisse.

http://hdl.handle.net/2268/113796
ORBi viewed: **10** (1 ULg)

Gaignaire, R., Scorretti, R., Vazquez Sabariego, R., & Geuzaine, C. (2011, July 07). *Stochastic Uncertainty Quantification of Eddy Currents in the Human Body by Polynomial Chaos Decomposition*. Paper presented at Welisa seminar, Rostock, Germany.

http://hdl.handle.net/2268/113720
ORBi viewed: **14** (4 ULg)

Geuzaine, C. (2010, July 15). *Toward Convergent Methods for High-Frequency Wave Problems*. Paper presented at Invited Lecture, Nantes, France.

http://hdl.handle.net/2268/83290
ORBi viewed: **13** (7 ULg)

Geuzaine, C. (2010, June 16). *GetDP et Gmsh*. Paper presented at Journée Thématique FMM, ANR Microwave, Nancy, France.

http://hdl.handle.net/2268/83268
ORBi viewed: **58** (6 ULg)

Geuzaine, C. (2010, June 09). *High Quality Surface Meshing using Harmonic Maps*. Paper presented at Journée Thématique "Maillages et Equations aux Dérivées Partielles'' de la Fédération Charles Hermite, Nancy, France.

http://hdl.handle.net/2268/83336
ORBi viewed: **8** (1 ULg)

Geuzaine, C. (2010, April 28). *High Performance Algorithms for High-Order High-Frequency Electromagnetic Scattering*. Paper presented at Groupe de contact calcul intensif, Mons, Belgium.

http://hdl.handle.net/2268/83339
ORBi viewed: **18** (2 ULg)

Geuzaine, C. (2010, March 31). *Numerical methods for Electromagnetic Field Modeling, from quasistatic to high-frequency problems*. Paper presented at Invited Lecture, Santa Fe, Argentina.

http://hdl.handle.net/2268/83341
ORBi viewed: **33** (4 ULg)

Geuzaine, C. (2010, March 30). *High-Quality Remeshing using Harmonic Maps*. Paper presented at Invited Lecture, Santa Fe, Argentina.

http://hdl.handle.net/2268/83342
ORBi viewed: **7**

Geuzaine, C., & Remacle, J.-F. (2009, June 09). *Gmsh*. Paper presented at Trophées du Libre 2009, Soissons, France.

http://hdl.handle.net/2268/113781
ORBi viewed: **32**

Geuzaine, C. (2009, April 02). *Advances in Convergent High-Frequency Scattering Solvers*. Paper presented at Invited Lecture, Louvain-la-Neuve, Belgium.

http://hdl.handle.net/2268/83343
ORBi viewed: **3**

Geuzaine, C., & Remacle, J.-F. (2008, December 04). *Reparametrization and mesh generation of triangulated surfaces using Gmsh*. Paper presented at Invited Lecture, Berlin, Germany.

http://hdl.handle.net/2268/83352
ORBi viewed: **16**

Geuzaine, C. (2008, March 27). *High-Frequency Integral Equation Solvers for Acoustic and Electromagnetic Scattering Problems*. Paper presented at Invited Lecture, Lille, France.

http://hdl.handle.net/2268/83353

Geuzaine, C. (2008, February 29). *High-Frequency Integral Equation Solvers for Acoustic and Electromagnetic Scattering Problems*. Paper presented at - Reading, UK.

http://hdl.handle.net/2268/83357

Geuzaine, C. (2008, February 14). *High-Frequency Integral Equation Solvers for Acoustic and Electromagnetic Scattering Problems*. Paper presented at Invited Lecture, Rennes, France.

http://hdl.handle.net/2268/83359

Geuzaine, C. (2007, December 12). *High-Frequency Integral Equation Solvers for Acoustic and Electromagnetic Scattering Problems*. Paper presented at Invited Lecture, Leuven, Belgium.

http://hdl.handle.net/2268/83385

Geuzaine, C. (2006, December 08). *High-Order Discrete Geometrical Models*. Paper presented at Mathematics Colloquium, Cleveland, USA.

http://hdl.handle.net/2268/83411

Geuzaine, C. (2006, June 13). *Convergent Numerical Solution of Wave Scattering Problems at High Frequencies*. Paper presented at Invited Lecture, Nancy, France.

http://hdl.handle.net/2268/83412

Geuzaine, C. (2005, November 07). *High-Order, High-Frequency Methods for Wave Scattering I, II and III*. Paper presented at Applied Mathematics Seminar, Cleveland, USA.

http://hdl.handle.net/2268/83421

Geuzaine, C. (2005, November 04). *An O(1) Solver for the Helmholtz Equation*. Paper presented at Invited Lecture, Cleveland, USA.

http://hdl.handle.net/2268/83419

Geuzaine, C. (2005, October 04). *An O(1) Algorithm for Wave Scattering*. Paper presented at Invited Lecture, Zurich, Switzerland.

http://hdl.handle.net/2268/83423

Geuzaine, C. (2005, July). *High-order, high-frequency methods in computational electromagnetism. Part I: Fast, high-order discretization schemes. Part II: Extension to arbitrary high frequencies*. Paper presented at Invited Lectures, Marseille, France.

http://hdl.handle.net/2268/83424

Geuzaine, C. (2005, February 09). *An O(1) Solver for the Helmholtz Equation*. Paper presented at Invited Lecture, Cleveland, USA.

http://hdl.handle.net/2268/83425

Geuzaine, C. (2005, January 31). *An O(1) Solver for the Helmholtz Equation*. Paper presented at Invited Lecture, South Bend, IN, USA.

http://hdl.handle.net/2268/83426

Geuzaine, C. (2004, April 29). *An O(1) Solver for the Helmholtz Equation*. Paper presented at Applied Mathematics and Numerical Analysis Seminar, Minneapolis, MN, USA.

http://hdl.handle.net/2268/83427

Geuzaine, C. (2004, March 26). *An O(1) Method for Wave Scattering Problems*. Paper presented at Invited Lecture, Houston, TX, USA.

http://hdl.handle.net/2268/83428
ORBi viewed: **7**

Geuzaine, C. (2004, February 26). *An O(1) Solver for Electromagnetic Scattering*. Paper presented at IEEE APS/MTT Columbus Chapter Seminar, Columbus, OH, USA.

http://hdl.handle.net/2268/83430
ORBi viewed: **10**

Geuzaine, C. (2004, February 18). *Toward an O(1) Solver for Electromagnetic Scattering*. Paper presented at Invited Lecture, Ames, IA, USA.

http://hdl.handle.net/2268/83429
ORBi viewed: **5**

Geuzaine, C. (2002, July 23). *High-order, high-frequency methods for surface scattering problems*. Paper presented at - Troy, NY, USA.

http://hdl.handle.net/2268/83431
ORBi viewed: **10** (2 ULg)

Geuzaine, C. (2001, June 20). *Benefits of an open software environment for the modeling of coupled electromagnetic problems*. Paper presented at Invited Lecture, Grenoble, France.

http://hdl.handle.net/2268/83432
ORBi viewed: **7** (2 ULg)

9. Scientific congresses and symposia

9.a. On invitation

With an international target audience

Geuzaine, C., Henrotte, F., Remacle, J.-F., Marchandise, E., & Sabariego, R. (2013). ONELAB: Open Numerical Engineering LABoratory. *Actes du 11e Colloque National en Calcul des Structures (CSMA 2013), Giens, France*.

http://hdl.handle.net/2268/171456
Peer reviewed ✓
ORBi viewed: **4** (1 ULg) ; downloaded: **0** — SCOPUS®: **-**

Remacle, J.-F., Johnen, A., Lambrechts, J., Toulorge, T., Carrier-Baudouin, T., Marchandise, E., & Geuzaine, C. (2013). New mesh generation developments in GMSH. *Actes du 11e Colloque National en Calcul des Structures (CSMA 2013), Giens, France*.

http://hdl.handle.net/2268/171455
Peer reviewed ✓
ORBi viewed: **11** (1 ULg) — SCOPUS®: **-**

Vion, A., Bélanger-Rioux, R., Demanet, L., & Geuzaine, C. (2013). A DDM double sweep preconditioner for the Helmholtz equation with matrix probing of the DtN map. *Proceedings of the 11th International Conference on Mathematical and Numerical Aspects of Waves (WAVES 2013)*.

http://hdl.handle.net/2268/171451
Peer reviewed ✓
ORBi viewed: **7** (1 ULg) — SCOPUS®: **-**

Geuzaine, C., Antoine, X., Boubendir, Y., & Thierry, B. (2012). Improved Domain Decomposition Method for the Wave Equation in Harmonic Regime. *Proceedings of the 6th Advanced Computational Electromagnetics workshop (ACE 2012)*.

http://hdl.handle.net/2268/113823
Peer reviewed ✓
ORBi viewed: **30** (2 ULg)

Gorissen, B., Remacle, J.-F., Hillewaert, K., & Geuzaine, C. (2011). Robust generation of curvilinear hybrid meshes for CFD. *Proceedings of the 5th international conference on Advanced COmputational Methods in ENgineering (ACOMEN 2011)*.

http://hdl.handle.net/2268/113773
Peer reviewed ✓
ORBi viewed: **15**

Boubendir, Y., Antoine, X., & Geuzaine, C. (2010). Quasi-Optimal Convergence of Non Overlapping Domain Decomposition Method: the Helmholtz Equation. *Proceedings of the AMS 2010 Fall Central Section Meeting*.

http://hdl.handle.net/2268/83288

Peer reviewed ✓
ORBi viewed: **25** (2 ULg)

Remacle, J.-F., Geuzaine, C., & Marchandise, E. (2010). High Quality Surface Remeshing Using Harmonic Maps: Surfaces with High Genus and of Large Aspect Ratio. *Proceedings of the Third Workshop on Grid Generation for Numerical Computations, Tetrahedron III*.

http://hdl.handle.net/2268/83283

Peer reviewed ✓
ORBi viewed: **27** (1 ULg)

Geuzaine, C., Marchandise, E., & Remacle, J.-F. (2010). High-quality remeshing using harmonic maps. *Proceedings of the 5th Advanced Computational Electromagnetics workshop*.

http://hdl.handle.net/2268/83335

Peer reviewed ✓
ORBi viewed: **8** (1 ULg)

Dular, P., V Sabariego, R., Krähenbühl, L., & Geuzaine, C. (2010). Magnetic model refinement via a coupling of finite element subproblems. *Proceedings of Scientific Computing in Electrical Engineering (SCEE 2010)*.

http://hdl.handle.net/2268/83253

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Publications et communications de Eric Béchet [u209626]

Legend

Bibliometric indicators linked to the journal *(for those whose ISSN has been indicated by the author)*

*• **IF = Impact factor** Thomson ISI. Are indicated : IF of the year of publication and IF of the last edition of JCR **(last)**, « **?** » if not known by ORBi yet ; « **-** » if non-existent.*

*• **IF5 :** idem as IF but for a 5 year period (new indicator since 2009).*

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*• **Article Infl. = Article Influence :** EigenFactor divided by the number of articles published in the journal.*

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***Peer reviewed (verified by ORBi) :** the information is available in the ORBi journals database*

1. Dissertations and Theses

1.b. Doctoral thesis

Béchet, E. (2002). *Résolution d'un problème aux limites à frontières libres au moyen d'un algorithme de remaillage adaptatif et anisotrope*. Unpublished doctoral thesis, École Polytechnique de Montréal, Montréal, Canada.

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ORBi viewed: **6** (3 ULg) — SCOPUS®: **-**

3. Articles in peer reviewed academic journals

3.a. With an international target audience

As first or last author

Béchet, E., Moes, N., & Wohlmuth, B. (2009). A stable Lagrange multiplier space for stiff interface conditions within the extended finite element method. *International Journal for Numerical Methods in Engineering, 78*(8), 931-954.

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ORBi viewed: **125** (7 ULg) ; downloaded: **1** — SCOPUS®: **49**

IF 2009: **2.025**; last: **1.961**; IF5: **2.509** — EigenF 2009: **0.0340**; last: **0.0283** — Article Infl. 2009: **1.0841**; last: **0.99**

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Peer reviewed (verified by ORBi) ✔

ORBi viewed: **32** (8 ULg) ; downloaded: **1** (1 ULg) — SCOPUS®: **32**

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Peer reviewed ✔

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ORBi viewed: **55** (6 ULg) ; downloaded: **1** — SCOPUS®: **153**

IF 2005: **1.203**; last: **1.961**; IF5: **2.509** — EigenF 2005: **0.0406**; last: **0.0283** — Article Infl. 2005: **1.1917**; last: **0.99**

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ORBi viewed: **38** (5 ULg) ; downloaded: **1** (1 ULg) — SCOPUS®: **12**

IF 2004: **0.337**; last: **1.188**; IF5: **1.201** — EigenF 2004: **0.0023**; last: **0.0036** — Article Infl. 2004: **0.1795**; last: **0.2432**

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IF 2003: **1.131**; last: **3.012**; IF5: **3.946** — EigenF 2003: **0.0164**; last: **0.0184** — Article Infl. 2003: **0.8195**; last: **0.8623**

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IF 2002: **0.965**; last: **1.515**; IF5: **1.929** — EigenF 2002: **0.0095**; last: **0.0072** — Article Infl. 2002: **0.9327**; last: **0.7468**

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As co-author

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IF 2012: **1.878**; last: **1.879**; IF5: **1.973** — EigenF 2012: **?**; last: **0.0225** — Article Infl. 2012: **?**; last: **0.6477**

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IF 2011: **2.651**; last: **2.626**; IF5: **3.049** — EigenF 2011: **0.0401**; last: **0.0401** — Article Infl. 2011: **1.327**; last: **1.327**

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IF 2008: **2.129**; last: **2.626**; IF5: **3.049** — EigenF 2008: **0.0369**; last: **0.0403** — Article Infl. 2008: **1.1333**; last: **1.2625**

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IF 2008: **2.229**; last: **1.961**; IF5: **2.509** — EigenF 2008: **0.0327**; last: **0.0283** — Article Infl. 2008: **0.9979**; last: **0.99**

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IF 2006: **1.497**; last: **1.961**; IF5: **2.509** — EigenF 2006: **0.0403**; last: **0.0283** — Article Infl. 2006: **1.1761**; last: **0.99**

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5. Books

5.b. As editor or publication director

Hogge, M., Van Keer, R., Dick, E., Malengier, B., Slodicka, M., Béchet, E., Geuzaine, C., Noels, L., & Remacle, J.-F. (Eds.). (2011). *Proceedings of the 5th International Conference on Advanded COmputational Methods in Engineering (ACOMEN2011)* (Dépôt légal: D/2011/0480/31). Liège, Belgium: Université de Liège.

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ORBi viewed: **42** (7 ULg)

6. Chapters and parts of collective works

6.a. Chapters

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Peer reviewed ✓

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8. Scientific conferences at universities and research centers

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ORBi viewed: **8** (2 ULg)

9. Scientific congresses and symposia

9.a. On invitation

With an international target audience

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Peer reviewed ✓
ORBi viewed: **19** (2 ULg) ; downloaded: **0**

9.b. On a personal proposal

Published

With an international target audience

With peer reviewing

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Peer reviewed ✓
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http://hdl.handle.net/2268/99053
Peer reviewed ✓
ORBi viewed: **111** (57 ULg) ; downloaded: **5** (4 ULg)

Remacle, J.-F., Henrotte, F., Carrier Baudoin, T., Geuzaine, C., Béchet, E., Mouton, T., & Marchandise, E. (2011). A Frontal Delaunay Quad Mesh Generator Using the L∞ Norm. *Proceedings of the 20th International Meshing Roundtable*. Springer.
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Peer reviewed (verified by ORBi) ✓

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IF 2004: **0.764**; last: **2.044**; IF5: **2.329** — EigenF 2004: **0.0084**; last: **0.0098** — Article Infl. 2004: **0.6384**; last: **0.944**

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Oral presentations only or conference poster

With an international target audience

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Critères de recherche	
Auteur(s)	: Deleersnijder, Eric

Article de périodique (Journal article)

2014

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