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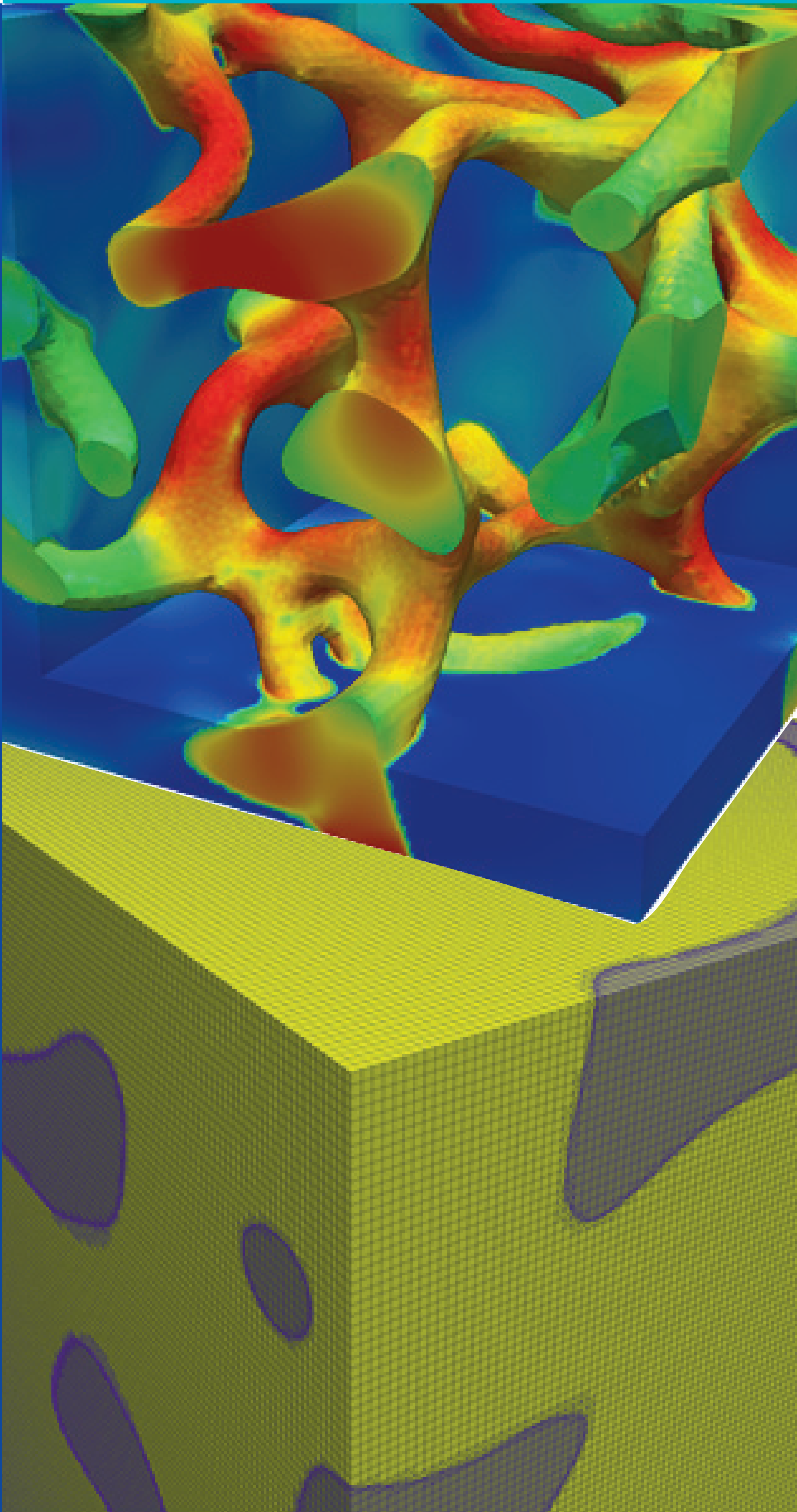

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IACM members are invited to send their contributions to the editors.

contents

editorial

How can IACM contribute to improving the global economy?

Before we can answer this question we have to realize that IACM is viewed by many as just a scientific organization whose mission is simply to foster the advances in an (apparently) narrow field.

The fact is that scope of computational mechanics encompasses all theoretical and applied areas in engineering and applied sciences. All products and processes that are designed and manufactured by industry, in the broad sense, make use of simulation technology emanating from computational mechanics disciplines. The same applies for the methods used for assessing the safety of constructions, vehicles and infrastructure, and the techniques for predicting the evolution of social and economical models, or the methods and devices for studying the behavior of the human body and other bio-systems, just to name a few.

It is therefore obvious that the knowledge emanating from computational mechanics can have a big impact on the procedures and tools that will be used for obtaining better, safer and more economical products and systems in the next decades.

Computational mechanics techniques can also be applied as a key ingredient in decision support systems, helping the definition of urban and rural areas which are sustainable from the point of view of energy, water resources and social-economic balance. Studies of this kind are essential in the development of many cities, regions and countries in the world.

A non-negligible contribution of the IACM to the world economy are the many conferences, workshops and workshops organized yearly by its members around the world. Indeed IACM is, at the same time, a global and a local organization. It has 41 affiliated associations representing 53 countries worldwide. Each of these associations is active in promoting national conferences covering general and specialized topics in computational mechanics. This adds to the larger conferences on computational solid and fluid mechanics organized by regional organizations such as ECCOMAS, APCOM and USACM. It is remarkable that all together over fifty meetings related to computational mechanics were organized worldwide in 2011.

The summit meeting of the IACM is the World Congress for Computational Mechanics (WCCM) which 10th edition will be held in the city of Sao Paulo on 8-13 July 2013. Some 2500 participants are expected to attend the WCCM2012.

These reunions play an important role towards increasing the cohesion of the IACM community, as well as being a forum for technical discussions fostering the advances in the different scientific fields and creating opportunities for RTD projects in different areas of engineering and applied sciences, with the participation of multidisciplinary groups from different countries.

The IACM community has therefore many opportunities for influencing the development of the global economy. It is now more important than ever that we take good advantage of them.

Eugenio Oñate
Editor of IACM Expressions

Multi-scale XFEM

in Hannover

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The eXtended Finite Element Method (XFEM) – a substantial generalization of FEM within the concept of partition of unity methods (PUM) using fixed, usually regular meshes – has long proven to be an excellent tool to simulate cracks. Due to its success the XFEM was also applied to problems with heterogenities, to fluid-structure interactions, cutting simulations and other applications. Interesting new applications are in the area of multi-scale methods. A major demand is understand microstructural effects leading to damage. For this one has to model and to compute the initiation of microvoids, their coalescence and nucleation with the appearance of microcracks. In the path of a growing macrocrack new microcracks can evolve due to changing material response caused by a progressing macrocrack. These problems can be modeled by a multi-scale XFEM.

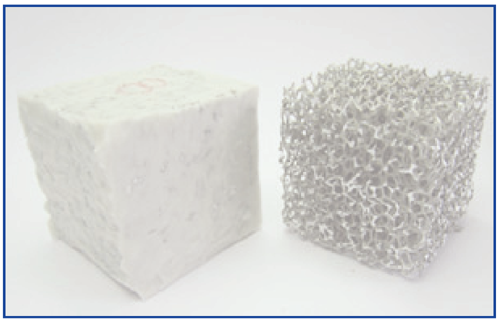


Figure 1:
Aluminum foam sample with and without silicone filler

XFEM for static crack propagation and heterogeneities

The XFEM is a tool to simulate cracks, heterogeneities and complex microstructures in two and three dimensions. In addition to its main advantage, the fact that cracks and heterogeneities can be modeled independent of the mesh, the basic concept of the XFEM does not have limitations regarding small or finite deformations or arbitrary material models. Usually only the displacement field is enriched with additional degrees of freedom associated with so-called enrichment functions

$$\boldsymbol{u}_h = \sum_{I=1}^{n_n} N_I \left(\boldsymbol{u}_I + H \boldsymbol{a}_I + \sum_{j=1}^{n_{enr}} q\, f_j \boldsymbol{b}_{jI} \right) \qquad \textbf{\textit{(1)}}$$

with N_I being the standard shape functions, H is the modified Heaviside function, f_j are crack tip enrichment functions and $\boldsymbol{u}_I$, $\boldsymbol{a}_I$ and $\boldsymbol{b}_{jI}$ are the corresponding nodal unknowns. The enrichment functions are chosen according to the in general non-smooth properties the displacement field is supposed to show in the subdomain where the enrichment functions have an effect *(figure 4)*. This way arbitrary discontinuities as well as special displacement fields, leading to specific strain and stress fields

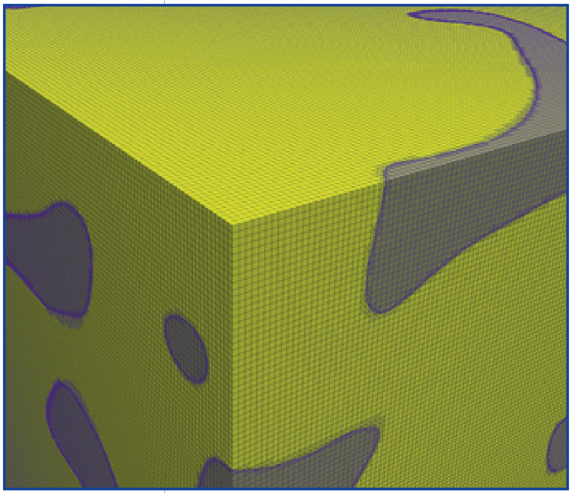


Figure 2:
XFEM discretization of the aluminum foam with silicone filler

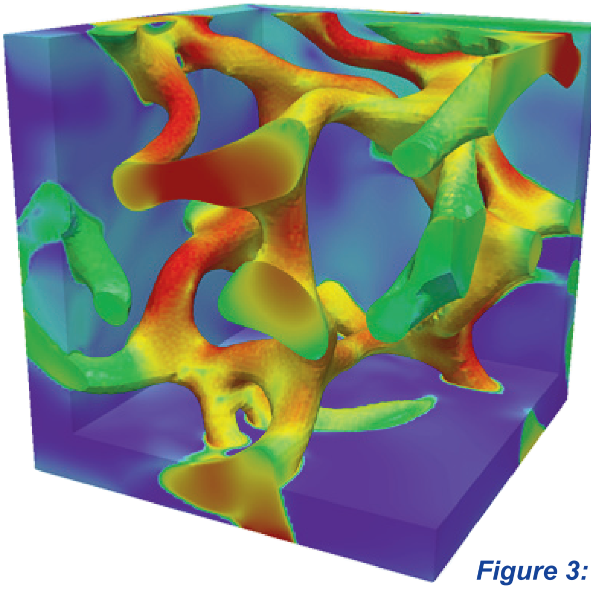


Figure 3:
Cut into the microstructure and von Mises stress distribution under vertical compression

containing e.g. singularities of a certain magnitude and order, can be represented. In linear elastic fracture mechanics the analytic asymptotic solution for the stress field including the singularity at the crack tip in 2D or the crack front in 3D can be approximated accurately by means of a specific set of basis functions with which the analytic solution of the near tip field can be built exactly. This classical approach was published in the first XFEM paper [1]. However, as will be pointed out later, equilibrated enrichment functions (according to the requested fracture modes) lead to more accurate solutions especially in the crack tip elements *(figure 11)*. In case of more complex material models within the fracture process zone like elasto-plasticity and non-local damage leading to physically more correct non-singular stress fields, an adequate modification of the enrichment functions concerning the order of the singularity is sufficient to obtain very good approximations with coarse meshes that do not impose a stress singularity. Similar modifications of the enrichment functions can be applied for cohesive crack models.

In case of material and structural heterogeneities enrichment functions reflecting the kinks in the displacement field are used. Thus complex microstructures such as foams including filler materials *(figures 1 to 3)* can easily be modeled with regular meshes containing only nicely shaped elements without the need for advanced three dimensional meshing algorithms. Also here, all classical material models including finite deformation theory can be applied without even changing the enrichment functions.

One flaw of the standard XFEM however is the fact that in elements connected to enriched nodes and non-enriched nodes (so-called blending elements) the partition of unity is not fulfilled. In these elements, despite the completeness of the finite element approximation space built by the standard shape functions, spurious jumps in the displacement field can occur that have a significantly bad influence on the convergence and error of the calculated XFEM solution. One possible and simple remedy to that problem is the application of a ramp function blending out the enrichment functions towards the non-enriched domains [2]. *(figure 4)* This technique has been extended to three dimensions in Hannover [3].

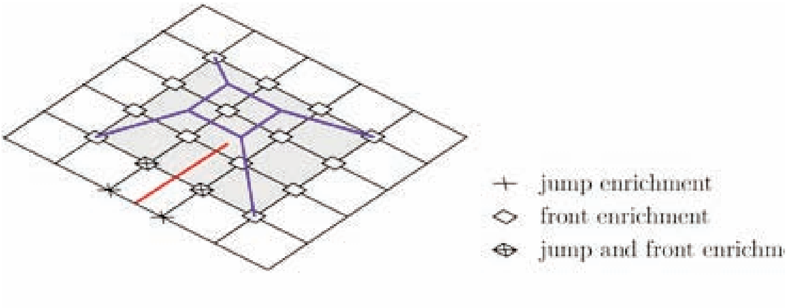
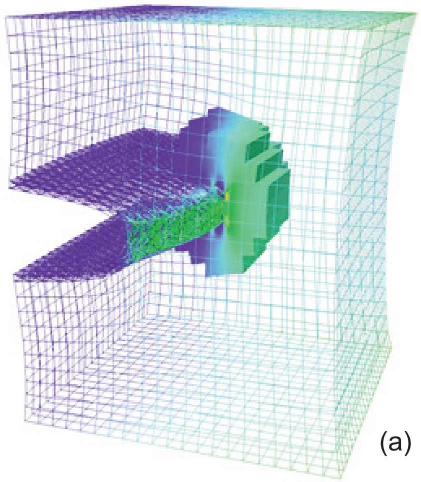


Figure 4:
Ramp function and enrichment pattern for the corrected XFEM



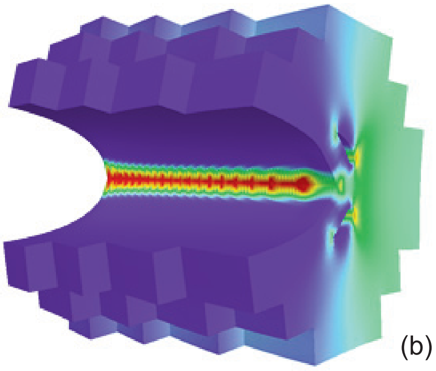


Figure 5:
(a) Stress distribution within a coarse scale mesh and cut through the fine scale domain of a specimen with one macrocrack and two microcracks under uniaxial tension;
(b) Deformed fine scale domain showing crack shielding effects

Multiscale coupling of crack initiation and propagation

In general, crack propagation is strongly influenced by microstructural behavior. Microcracks and microheterogeneities lead to complex microstructural stress fields resulting in crack amplification or crack shielding as well as in complex crack propagation paths. These mechanisms are important to consider in many industrial applications, mainly if more complex and modern materials are involved. The first important goal is the prediction of crack nucleation with the formation of one or several microcracks at an appropriate micro scale. The second goal is the simulation of the propagation and the determination of fracture patterns in macroscopic structures and engineering parts. Since crack propagation mechanisms are intrinsically connected to the material microstructure on a much finer scale, scale transition methods need to be applied to accurately capture microstructural behavior within a macrostructural computation. Especially for crack initiation and propagation analyses homogenization techniques based on the representative volume element concept cannot successfully be applied because

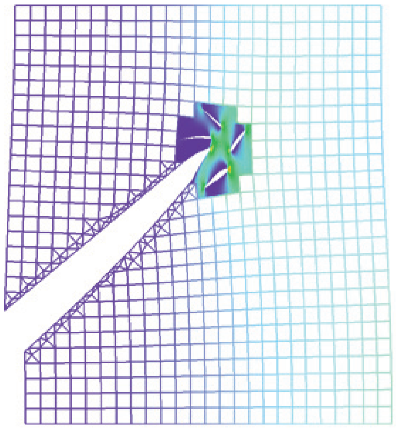


Figure 6:
Stress distribution in the deformed coarse scale mesh and the fine scale domain

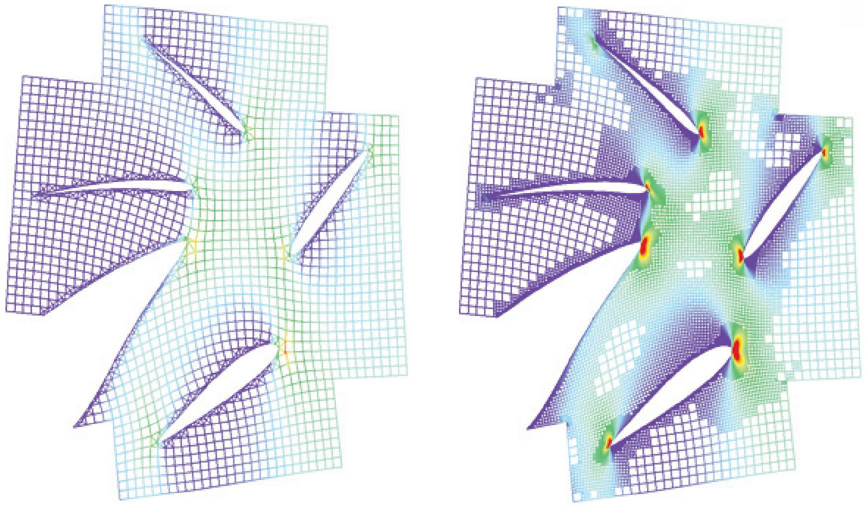


Figure 7:
Stress distribution in the deformed fine scale mesh before and after adaptive mesh refinement

crack propagation always leads to localization and thus to an indeterminable size of the representative volume element. In other words, the representative volume element automatically loses its representativeness. As long as cracks do not propagate however, homogenization techniques are applicable.

In case of crack propagation, multiscale techniques capable of handling localization phenomena need to be employed. One of these techniques is the multiscale projection method [4]. This method represents a direct mapping of the microstructural stress field onto the coarse scale mesh as well as a projection of the coarse scale displacement field onto the boundary of the chosen fine scale domain *(figure 5)*. The weak form of the coarse scale problem

$$\sum_{I=1}^{n_n^0}\sum_{k=1}^{n_{\mathrm{enr}}+1}\left(\hat{\boldsymbol{\eta}}^0_{kI}\right)^T\cdot\left(\int_{\Omega^0}{\boldsymbol{B}^0_{kI}}^T:\boldsymbol{\sigma}\,\mathrm{d}\Omega^0 - \int_{\Omega^0}\hat{N}^0_{kI}\left(\boldsymbol{f}_h-\rho\ddot{\boldsymbol{u}}^0_h\right)\mathrm{d}\Omega^0 - \int_{\partial\Omega^0}\hat{N}^0_{kI}\boldsymbol{t}_h\,\mathrm{d}\partial\Omega^0\right)=0 \qquad \textbf{(2)}$$

in which only coarse scale features are considered explicitly, contains the stresses of the fine scale solution. Here, η^0_{kI} denotes the nodal value of the test function. The superscript 0 indicates the coarse scale. All other quantities are according to standard notation in finite element literature. The fine scale problem

$$\sum_{I=1}^{n_n^1}\sum_{k=1}^{n_{\mathrm{enr}}+1}\left(\hat{\boldsymbol{\eta}}^1_{kI}\right)^T\cdot\left(\int_{\Omega^1}{\boldsymbol{B}^1_{kI}}^T:\boldsymbol{\sigma}(\varepsilon^1_h)\,\mathrm{d}\Omega^1 - \int_{\Omega^1}\hat{N}^1_{kI}\left(\boldsymbol{f}_h-\rho\ddot{\boldsymbol{u}}^1_h\right)\mathrm{d}\Omega^1\right)=0 \qquad \textbf{(3)}$$

is solved independently of the coarse scale problem. Here all fine scale features as well as coarse scale features are considered explicitly. On the boundary of the fine scale domain pure displacement boundary conditions are prescribed. These displacements come from the coarse scale solution. This method was developed for the two dimensional case by Loehnert & Belytschko [4] and extended to three dimensions by the XFEM research group in Hannover [5,6]. It has proven useful, accurate and efficient, especially if microstructural features need to be considered that are some orders of magnitude smaller than the typical coarse scale characteristics. In three dimensions the multiscale projection method enables the prediction of microcrack / macrocrack interaction where single scale computations would either not be feasible or computationally very expensive and potentially inaccurate.

Gradient smoothing and residual error estimation with adaptivity

Due to the fact that the complexity of the problems that can be solved using the XFEM increases, it is desirable to estimate the errors. These stem from the numerical approximation as well as from model assumptions. Recently different types of error estimators have been developed for XFEM simulation. In Hannover we extend the commonly known error estimation techniques to the multiscale projection method such that the strongly coupled discretization errors on all scales can be controlled and optimally decreased by means of mesh adaptation. Since efficiency becomes even more important, these methods are developed for three dimensional problems. Recovery based error estimators following the works of Zienkiewicz and Zhu as well as goal oriented error estimation techniques for quantities of interest such as the energy release rate are developed. *Figure 6* shows the σ_{yy} stress distribution of a mixed mode multiple crack in the deformed coarse scale and in the fine scale domain with several microcracks. In *figure 7* the original as well as the refined fine scale mesh is displayed. One can clearly see that the adaptive mesh refinement significantly improves the accuracy of the solution. Within the multi-scale projection method the influence of the model error turns out to be of great importance. The choice of the fine scale domain shape and size significantly changes the quality of the result as well as the required numerical effort. It is important to choose the fine scale domain such that the fine scale features, strongly influencing the near tip field of a propagating macrocrack, are taken into account appropriately. The fine scale domain should be selected such that the fluctuations on the boundary of the fine scale are negligible and have almost no effect on the near tip stress field of the macrocrack.

Residual error estimation analysis

The basic step of error controlled adaptivity is to assess the accuracy of the finite element solution u_h of a problem at hand. Computable upper bounds on discretization errors $u - u_h$ are typically measured in the energy norm. The different types of a posteriori error estimators are already available for XFEM [7,8,9]. These are gradient-smoothing-based and residual-based explicit / implicit estimators. Thus, the following global error estimates can be constructed for both methods as

$$\|u - u_h\|_\Omega \lesssim C\Big(\sum_{\Omega_e \in \mathcal{P}_h} \eta^2_{\Omega_e}\Big)^{\frac{1}{2}} = C\eta \qquad (4)$$

where stress recovery based estimators are given in the complementary energy. Here, C is a global interpolation constant. Depending on the error estimation method, the local indicator $\eta^2_{\Omega_e}$ is calculated either explicitly from u_h and the given data of the problem yielding a strict upper bound according to Babuska, Rheinboldt and Miller, or implicitly, by solving auxiliary local boundary value problems, usually with equilibrated residua via improved boundary tractions, yielding constant-free and approximated upper bounds.

In engineering practice it is frequently more interesting to estimate the error not in the global energy norm, but in some (local) quantities (linear and nonlinear functionals), such as e.g. the von Mises stress in a critical zone, the J-integral as a fracture criterion or the mean value of the solution on a local support. So-called goal-oriented error estimates for quantities of interest have been developed that estimate the error in a functiona $Q(u)$ using duality technique. Estimates of this type are based on energy-norm estimates of the primal problem

$$\begin{aligned} |Q(u - u_h)| &= |a^*(u - u_h, z - z^h)|, \quad \text{here} \quad a^* = a \\ &\le \sum_{\Omega_e} \left|a_e\left(u - u_h, z - z^h\right)\right| && (5) \\ &\le \|u - u_h\|_\Omega \|z - z_h\|_\Omega && (6) \end{aligned}$$

for u and the dual problem for z

Thus any of the error estimators from (4) can be used to obtain the bounds for the right-hand side in (6) or (5), where only (6) yields a strict upper bound.

An example of implementation of the different error estimation techniques for the J-integral as a quantity of interest and their comparison is illustrated by *figures 8 – 10*. Here uniform mesh refinement is implemented. In particular the mechanical system depicted in *figure 8* is investigated and a sketch of the corresponding XFEM solution is shown. *Figure 9* illustrates the associated dual problem and its XFEM discretization. It has to be noted that the choice of the XFEM branch functions for the dual solution is not self-evident and a regularity study is required. Finally, in *figure 10* the convergence of the error for the J-integral is plotted that is obtained for different types of error estimators. *Figure 10b* shows also the effectivity indices of these estimators.

Due to the product of the lengths of the primal and dual error vectors in the energy norm in (6) (according to the Cauchy-Schwartz inequality) the actual error of $Q(u)$ is usually highly overestimated. The implicit error estimator designated as “residual 2” is calculated with the estimator (6). Therefore, a modification of equation (6) as equation (5), designated as “residual 1”, is also implemented by adding the nominal values of the local bilinear forms yielding

“ These … are of importance for the validation of damage and failure processes of high tech materials due to different loading histories and … new products with a minimum of material and system testing. ”

much less overestimation and thus very good effectivity indices *(figure 10)*, but of course no strict upper bound which, however, holds for all known examples.

Justification and verification of a posteriori error estimation techniques in the XFEM context

The above error estimators are well established and elaborated for the classical finite element analysis. They have been well understood and justified. An extension of these approaches for XFEM, with its different enrichment schemes and various types of enrichment functions, however, is not straightforward and encounters several mathematical difficulties to overcome. In order to obtain the simplest Babushka-Rheinboldt type error estimate for XFEM we construct in [8] a specific quasi-interpolation operator that accounts for singularities and discontinuities and yields optimal local interpolation error estimates not only for typical function spaces but also for more "exotic" ones. Construction of an implicit error estimator for XFEM requires elaborated equilibration procedures on the elements Ω_e that contain crack tip singularities, jumps across the crack or kinks across material interfaces. Furthermore, recovery-based techniques and associated error estimators for XFEM require the proof of the guaranteed upper bound property.

The error estimation analysis for the XFEM also offers the following improvement. As already mentioned, using specific sets of singular enrichment functions fulfilling the equilibrium conditions in the crack tip element, improves the explicit error estimator herein by some orders of magnitude. *(figure 11)*.

Future trends and challenges

The main goals of XFEM remain the prediction of crack nucleation, the development of microcracks, their growth, coalescence and interaction with macrocracks. These effects can only be solved accurately and efficiently by applying multi-scale techniques as well as error controlled adaptive strategies. The methods need to be extended to capture three dimensional fracture processes in heterogeneous and inelastic media. An important task is the development of a model error estimator

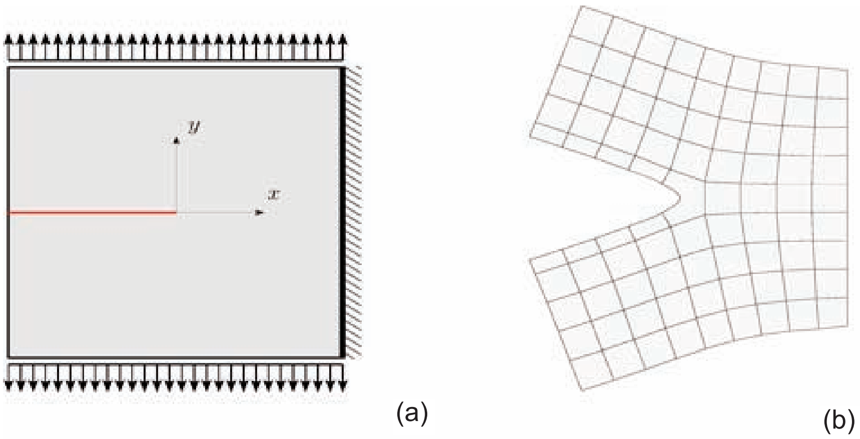


Figure 8:
(a) Structural system: domain with a crack (in red), loading conditions (tractions are prescribed on the upper and lower parts) and zero-displacement boundary condition (on the right edge);
(b) deformed mesh

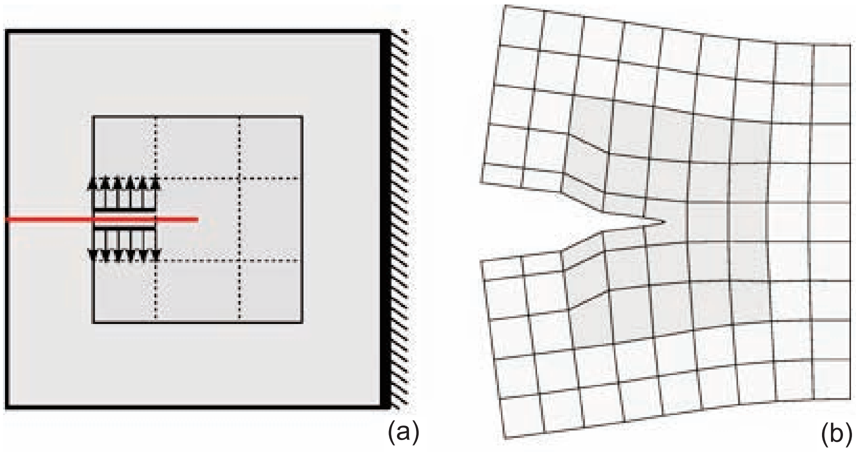


Figure 9:
(a) loading of the dual problem: tractions are applied on the part of each crack face;
(b) displacement of the dual XFEM solution

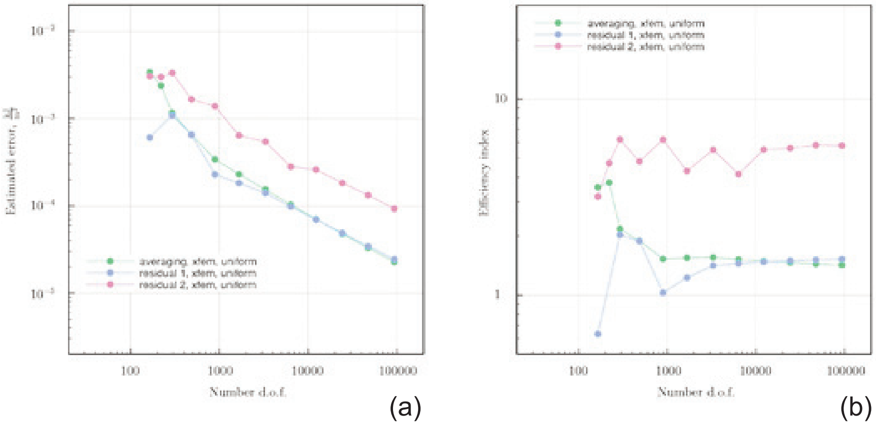


Figure 10:
(a) Three types of error estimators for the J-integral as the quantity of interest: averaging, implicit (residual 1) and explicit (residual 2) ;
(b) effectivity of the corresponding estimators

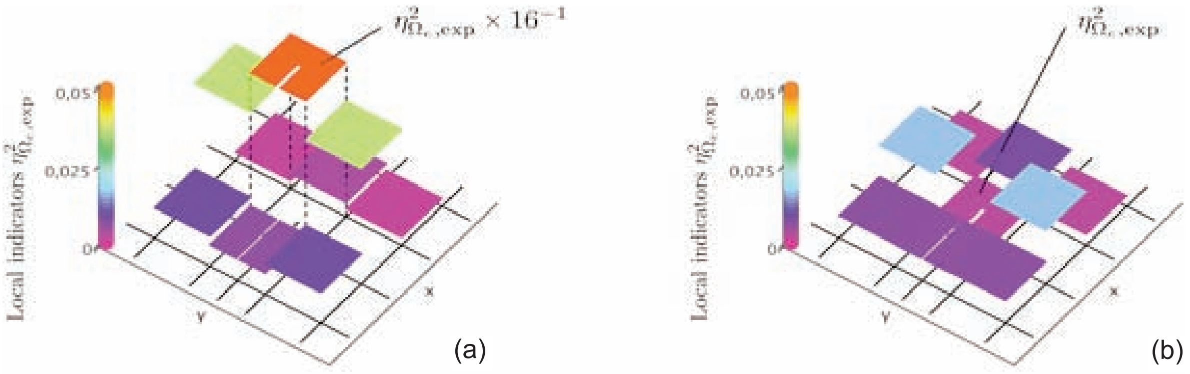


Figure 11:
The map of local error indicators on the patch of nine elements including the crack tip element depending on the set of branch functions used in the XFEM approxinmation:
(a) conventional set of Belytschko and Black,
(b) analytical solutions fulfilling the "equilibrium condition".
A local error (already magnified) on the crack tip element is found to be large in (a)-case and significantly reduced in (b)-case.

that 'a priori' determines the appropriate shape and size of a fine scale domain where the incorporation of detailed microstructural information is essential. In combination with the existing discretization error control reliable predictions will be possible for microstructural as well as macrostructural behavior of complex materials.

These methodologies are of importance for the validation of damage and failure processes of high tech materials due to different loading histories and also for the virtual design of new products with a minimum of material and system testing. ●

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References:

[1] *N. Moës, J. Dolbow , T. Belytschko*. **A finite element method for crack growth without remeshing**. International Journal for Numerical Methods in Engineering 46, 131 – 150 (1999)
[2] *T.-P. Fries*. **A corrected XFEM approximation without problems in blending elements**. International Journal for Numerical Methods in Engineering 75, 503 – 532 (2008)
[3] *S. Loehnert, D.S. Mueller-Hoeppe, P. Wriggers*. **3D corrected XFEM approach and extension to finite deformation theory**. International Journal for Numerical Methods in Engineering 86, 431 – 452 (2011)
[4] *S. Loehnert, T. Belytschko*. **A multiscale projection method for macro / microcrack simulations**. International Journal for Numerical Methods in Engineering 71, 1466 – 1482 (2007)
[5] *S. Loehnert, D.S. Mueller-Hoeppe*. **Multiscale methods for fracturing solids**. Proceedings of the IUTAM Symposium on Theoretical, Computational and Modelling Aspects of Inelastic Media, 79 – 87 (2008)
[6] *S. Loehnert, D.S. Mueller-Hoeppe*. **3D Multiscale projection method for micro- / macrocrack interaction simulations**. In: Recent Developments and Innovative Applications in Computational Mechanics, 223 – 230 (2011)
[7] *C. Hoppe, S. Loehnert, P. Wriggers*. **Error estimation for crack simulations using the XFEM**. submitted to International Journal for Numerical Methods in Engineering (2011)
[8] *T. Gerasimov, M. Rüter., E. Stein*. **An explicit residual-type error estimator for Q1-quadrilateral XFEM in 2D LEFM**. submitted to International Journal for Numerical Methods in Engineering (2011)
[9] *E. Stein, T. Gerasimov, M. Rüter*. **Explicit and implicit residual-type goal-oriented error estimators for XFEM in LEFM**. D. Aubry et. al. (eds.) Adaptive Modeling and Simulations 2011, CIMNE, Barcelona 2011, 44 – 55

> *" An important task is the development of a model error estimator that 'a priori' determines the appropriate shape and size of a fine scale domain where the incorporation of detailed microstructural information is essential. "*

On Future Computational Methods for Exascale Computers

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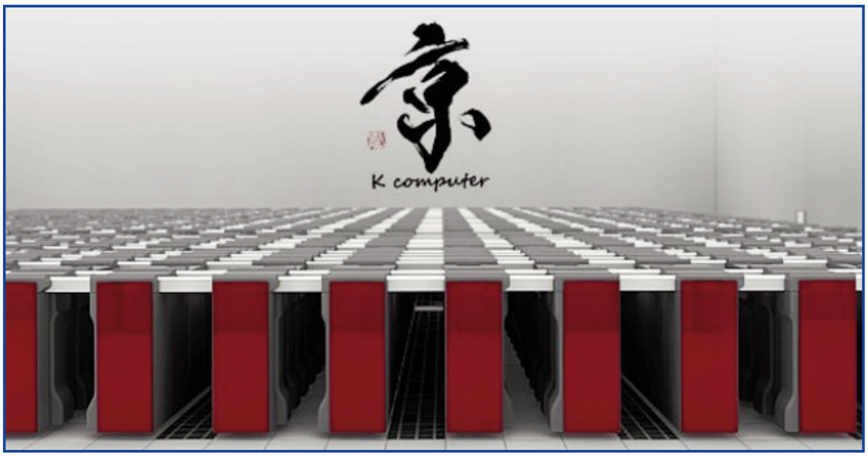
The development of supercomputers has made astonishing progress in USA, Japan, Europe, in recent years in China, and other nations. Many petascale computers are now in operation, contributing effectively to the faster development in science and technology in various areas. The current top performer is the Japanese K Computer with 8 PFLOPS. Such a fast pace of development continues. There are already plans, at least in USA, Japan and China, and possibly in other countries, to build the next generation of exascale computers with 10^{18} floating-point calculations per second (FLOPS), which is 1000 times faster than the current petascale computers! The US plan is to have an exascale computer in operation by 2018, China aims to have one in about 10 years, and Japan may have one even earlier. It is certainly hopeful that we will have many exascale computers in the first half of 21st-century accessible to mass.

Figure 1: *The Chinese Tianhe Computer http://www.nscc-tj.gov.cn/en/*

The need for exascale computers is obvious, judging from the increasing complexity of the problems we are facing and the higher and higher demand for more accurate and faster solutions in various research and application areas. The questions to us in the computational mechanics community would be whether we are ready to run our codes efficiently and making the fullest possible use of future exascale computers. To better prepare ourselves for this exciting and not-so-far foreseeable future, the author has been thinking about the related issues that we may need to bear in mind when working on the development of future computational methods for exascale computers. This article shares with our readers some of the preliminary thoughts that may be quite "speculative".

Figure 2: *The Japanese K Computer (fujitsu.com)*



While it is still being designed, some of the overall major features of the feature exascale computers are predictable at least to a certain degree, from a user point of view. To develop new and reliable computers with 1000 times faster than the current supercomputers, simple accumulative advancement will not work from at least a sustainability point of view, many existing advanced computer technology has been innovatively incorporated, and some drastic transformative changes have to be made as well.

Heterogeneous architecture with massive cores and accelerators

The current supercomputers are essentially built with multiple nodes of CPUs with multiple cores. Such architecture is difficulty to scale up by 1000 times, and has to be changed for the simple reason of energy consumption in running the computers. We know clearly that, in any current supercomputer centers with patascale platforms, the electricity bill is already a huge burden for sustainable operations. If we would have to scale the bill up to 1000s or even 100s times, these centers will have no chance at all to continue their service, despite the support from the governments, assuming that they can afford to purchase such computers. It is estimated that for 1000 times improvement on clock speed, we may only allow less than 10 times increase in power consumption and ideally no increase in power consumption, which is indeed a huge challenge, and the ways to get this done cannot be many. The constraints on power consumption is an "essential boundary condition" and is, unfortunately, not negotiable

One of the possible ways to build exascale computers is to use massive GPU (graphics processing unit) accelerators. This has already been done in the once No.1 for a short period of time and current No.2 Tianhe Supercomputer built in China, where over 7000 Nvidia Tesla M2050 general purpose GPUs are used. This can not only reduce significantly energy consumption in running, but also generate much less heat and hence save substantial electricity for cooling. In addition, reliable GPU pipelines can be produced cheaply and in massive quantities, thanks to the advancement made in graphic displays in the gaming industry driven by mass consumers of game players. Exascale computers can be built by properly adding billions of GPU pipelines into a multi-node and multi-core architecture.

Another possibility may be using a massive number of very low energy-consuming processors (both CPUs and GPUs) the ones that we are using in hand-held devices. In the past, we scientists and engineers, as the major consumers of supercomputers (small in number but extremely high in performance), have paid less attention on issues related to electricity consumption when using computers. Since the supercomputers are either run by government funded organizations or big companies, there were no burning issues in keeping it going. Our attention has been focused more on how to get our scientific problems solved efficiently, using more and more powerful computers. When we need exascale computers, the issue of energy consumption has to be dealt with properly first. On the other hand, the development of hand-held devices were largely driven by mass consumers (huge in number but much less need in computing power), and each of them has been extremely sensitive to the energy consumption (or battery life) of these devices. Hence these types of devices have been forced to be designed with special considerations on minimizing energy consumptions. Handphones are becoming more and more powerful without increase the power consumption. This kind of technology developed in designing and mass-producing processors for the hand-held devices is likely to be applied to the design of exascale computers, in order to overcome the bottleneck issue of energy consumption.

Therefore, it is most likely that future exascale computers will be built using “low performance”, very low-energy-consuming, low-cost, and highly-reliable processors. With huge numbers (hundreds of millions) of such processors, one can achieve quantum leaps in computing power in a practically sustainable manner. Exascale computers with massive processors and/or GPU accelerators to be built into the current supercomputer architecture will possess a highly heterogeneous architecture: multi-nodes, massive-core, and massive-accelerators.

Flops will be free, memory will be more expensive

Using massive number of low-energy-consuming, less powerful but reliable processors and accelerators, the FLOPS may be made practically free in exascale computers. However, the memory will still be very expensive. In an exascale computer with multi-nodes, massive-core, and massive-accelerators, the memory structure is likely to have a multilayer hierarchy and is distributed. The total memory per node may be still the same, but the memory per core and per accelerator will be very limited.

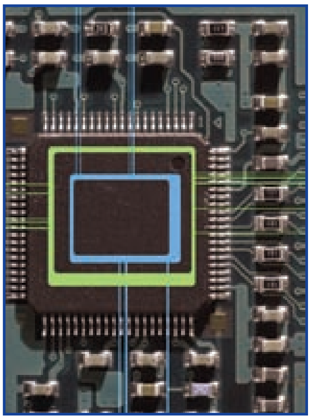
The cost for moving data around

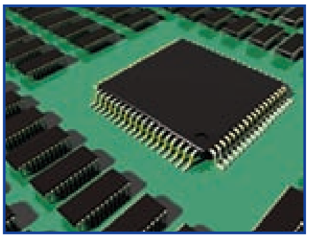
It is found in computer science that moving data around consumes substantial energy and will significantly affect overall operation speed, especially when moving data between chips (across nodes, cores, processors, accelerators, etc.). We need fundamental changes in ways of moving data to overcome this problem (for example optical means), which can be quite a distance future. Until that happens, it is not a good idea to move the data too much between the chips during the computation in an exascale computer.

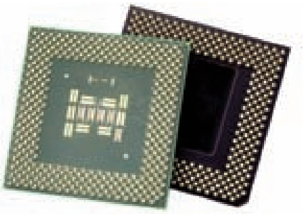
Desired features for future computational methods/algorithms

- *Extremely high parallelism*

Because the future exascale computers will have multi-nodes, massive-core, and massive-accelerators, the total number of processors can be in the order of billions, our future computational methods/algorithms have to be extremely highly parallelized at platform level, node level, as well as accelerator level with good balances and scalability. Otherwise, one will not have the benefit of exascale speed. It is possible that the number of total processors can be even much more than the number of elements in, for example, an FEM model. Therefore, the size of an FEM model will be much less a problem, provided we can fully and effectively tap the resources of all the processors. Numerical models and algorithms that can be easily parallelized with superior salability are of great advantageous, even if one has to sacrifice operation counts and some losses of accuracy (that are assessable, controllable or recoverable). In addition, algorithms that are resilient to errors are of advantageous. This means that we may have to discard many of the operation-counts-minimized algorithms (developed essentially for serial computers) that do not scale well. It is expected that effective parallelism can be much more challenging to develop, due to the







> *" ... it makes good sense to make the simplest model to deliver the best possible accurate solution.."*

heterogeneous architecture of exascale computers, and the scalability with billions of processors will be one of the bottleneck issues. In other words, to take the fullest advantageous of exascale computers, we, as users, will have a significant role to play, in addition to innovative techniques in hardware architectures and at system software level for the exascale computers.

- *Minimal data communication*

The heterogeneous architecture of the future exascale computers shall have even strong impact on memory structures. This requires much more careful and effective strategy on data layout. Since moving data among chips are very expensive compared to operations, consideration in data management will be more important than tricks on reducing operation counts. One may even use "free" FLOPS to re-compute the data instead of get those from the memory in another chip. This kind of simple ideas would be minimizing data movements between chips, and improve overall performance. Note also that the difficulty of data management is compounded by the parallelism. Out-of-box strategies may be needed in order to fully tap the resources of exascale computers, realizing the theoretical clock speed.

- *Simplicity*

Because of the heterogeneous architecture of the future exascale computer, the future computational methods/algorithms need to be implemented in multi-levels or hierarchical. This means that the numerical models should be as simple as possible for easy management of data layout and flow of the executions. Ideally, it is the most effective, if the bulk operations can be broken down (with minimum overhead) and executed at the GPU pipeline level with minimum "talking" to others. This means that when the computer hardware gets more complicated, the numerical models, on the other hand, need to be drastically simplified.

- *Locality*

For the same reason of minimizing the data movement, the operations have to be performed at local levels as much as possible, and communications between the cores, processes and GPUs must be minimized. Thus, algorithms with high local-operation per-memory will be advantageous.

Summary

If the above analysis is valid, our future numerical model should be; 1) as simple as possible; 2) highly parallelizable; 3) highest locality (discrete values at local nodes or particles or elements should have very compact supports). On the other hand, the size (number of nodes or particles) of the model is less of a concern. An exascale computer can have much more processors/pipelines than the total number of the elements of a numerical model! The matter is, how to fully and effectively tap all the available resources, which in turn presents tremendous opportunities for us to developed fast or even real-time computational methods and models. It is becoming more and more essential that our computational methods need to be tailored toward the hardware architecture of exascale computers. The conventional ways of developing computational methods will have to change, if we would like to make the fullest use of exascale computers.

It is the author's expectation that a model using huge number of the simplest 3-node triangular (or 4-node tetrahedral) elements can be one of the best choices for numerical models, at least for solid structural mechanics problems. It has the essential gradients of highest locality, and simplest formulation. It is true that the number of elements will be more than other types of element for the same number of nodes a model. However, the large number will no-longer be a concern for exascale computers. The lower accuracy and overly-stiff behavior of triangular elements can also be largely well-resolved using carefully designed local operations, such as the gradient smoothing operations used in the so-called Smoothed Finite Element Methods (S-FEM). Since local operations can be made practically free, it makes good sense to make the simplest model to deliver the best possible accurate solution. We may also need to advance the theory for creating future numerical methods. Instead of using the standard weak formulations we may want to look at other type of formulations, such as the G space theory and weakened weak (W2) formulations that work well with triangular types of elements and offers a lot more freedom in formulating various types of numerical models. In addition, by using sufficient number of triangular types of elements the complex geometry of the problem domain can also be modeled very accurately to meet the need for engineering design purposes. Algorithms of contacts, breakage, and many other types of nonlinearity can be deal with in triangular types of elements in much simpler manner compared to other types of elements. Most importantly, generated of triangular types of meshes and mesh refinement can be performed automatically without much human intervention, leading to an ideal full automation in computational modeling and simulation: a dream of many since a long time ago. ●

Being Aware of Accuracy. How many Digits you should Trust in your Numerical Results?

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Introduction: accuracy and accuracy control

Any quantity that can be measured or computed is possibly affected by an error. The accuracy is the condition characterizing the error committed in this measurement or computation. This is obvious for daily life quantities like weights: we don't need the same accuracy in measuring 1 kg of potatoes and for the same quantity of gold or enriched uranium to be used as nuclear fuel.
In practice, the accuracy is translated into significant digits: we say, for instance, 1.0 kg of potatoes, 1.000 kg (or 1,000 mg) of gold and 1.00000 kg (or 1,000.00 mg) of plutonium. In this example, two significant digits may be sufficient for potatoes; four are enough for gold; six significant digits are required for plutonium.

The number of correct significant digits (also denoted as significant figures) is directly related with the relative error of the quantity. The relative error (defined as the absolute error divided by the quantity itself), typically expressed as a percentage, is the meaningful value describing accuracy because it does not depend of the units of measure.
If the relative error is below 50%, then the quantity has at least one correct significant digit, if it is below 5%, you can trust two digits, if it is below 0.5%, three digits… In short, you can trust *d* digits if your relative error is below 500 x 10($^{-d}$) %.

Figure 1:
1.0 kg of potatoes, 1.000 kg of gold and 1.00000 kg of plutonium. Same weight?

The number of significant digits is an important issue, both for measurements and computations. Here, we concentrate in discussing some general ideas on the accuracy of the numerical solutions in the context of Computational Mechanics. In other words, we focus in reviewing the tools allowing assessing the number of digits you may trust from your numerical results.

The famous case of the sinking of the Sleipner A offshore platform (Norway, August 1991) is a real motivation for the need of controlling the numerical errors. The design of a tricell device joining the cylindrical floaters was based on a numerical result that underestimated the shear stresses by 47%. This design flaw, causing the disaster, was due to using a too coarse mesh in the Finite Element analysis, without any a posteriori assessment of the numerical quality of the solution. In general, we are extremely sensitive to the accuracy of the numerical results when it comes to "Critical Modeling" (when a wrong decision taken from a deficient model may have dramatic consequences). However, also common practice in Computational Mechanics requires accuracy control.

Verification and validation

We identify three conceptual steps in the overall process of numerical modeling and simulation. First, the real system to be modeled is transformed into a conceptual model (approximation of geometry, simplification of loads and boundary restrictions…). Second, by using the laws of physics, a mathematical model is defined (the equations to be solved with their boundary conditions) such that the solution (typically an unknown function) characterizes the behavior of the system. In the standard case, this mathematical problem has a unique solution, but this solution cannot be found by analytical procedures: some exact solution to the problem exists, but it is not computable. Thus, the third step consists in numerically solving the mathematical model, usually a Boundary Value Problem defined by a Partial Differential Equation (PDE). An approximate solution is obtained that is necessarily affected by an error. This error is hopefully expected to be small.

The verification and validation paradigm consists in assessing the error (or, in other words, evaluating the quality) of these steps. The validation part of the process affects steps one and two, accounting for the approximations introduced in the conceptual model and the physical assumptions. Validation is often summarized as answering the question "Are we solving the right equations?" Verification is understood as the error (or quality) control at step three. This means answering the question "Are we solving the equations right?"

> *" This means answering the question - Are we solving the equations right? "*

Here, we focus in the latter question, corresponding to verification. Of course, the answer to this question cannot be just yes or no. A good answer is the number of digits you can trust in the approximate solution. Then, the user has to decide if this accuracy is sufficient (an then the equation is solved right) or not. The right answer to this question is heavily dependent on the user: you don't need the same accuracy for the weighting the food for your recipe or for dosing the fuel in a nuclear power plant.

Verification: assessing numerical errors

Let us assume that the mathematical problem to be solved is well posed and that all the input data is known "exactly". Then, some numerical method has to be selected among the list of alternatives: Finite Elements, Finite Differences, Finite Volumes, Meshless methods… All these methods require setting a discretization: a mesh, a grid or a cloud of particles. The element size (or distance between nodes or particles) cannot be infinitely small and therefore the numerical solution is just an approximation (likely, a good approximation) of the exact solution, affected by the so-called truncation error.

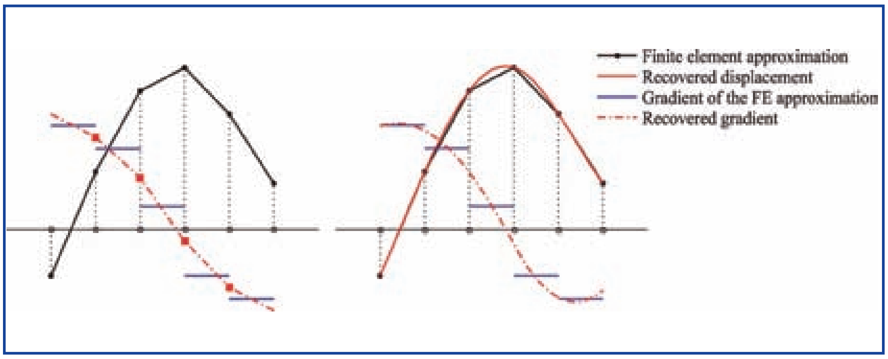


Figure 2: *Illustration of the flux projection (a) and enhancement of displacement (b) recovery estimates*

The goal of Verification is assessing the errors introduced by the numerical method and, in particular, by the discretization.

A priori error estimates are, in general, available for all these methods. That is, there are mathematical results proving their converge. That means that the numerical solution improves as you increase the number of degrees of freedom and that you can even predict how fast the improvement goes. According to these theorems, the numerical error may be as small as desired, provided that the discretization is fine enough. In the limit case, with an infinite number of degrees of freedom, the numerical solution tends to coincide with the exact solution.

A priori error estimates describe the convergence behavior of the method. However, they are not providing any clue on which is the actual error associated with a specific discretization. They tell you how fast the error decreases but they cannot be used to check if the error is already small enough. A posteriori error estimates using the numerical solution are required to assess the value (or some measure) of the actual error. It is worth noting that the error cannot be suppressed but only kept under control. The only paradigm that could be assumed is to reach prescribed some accuracy by selecting a proper mesh, preferably with the lowest computational effort. This pertains to the concept of adaptivity and it is discussed below.

A posteriori error estimates

As previously said, an estimate based in the numerical solution (and therefore denoted as a *posteriori*) is required in order to assess the actual error committed when using some numerical scheme. The ideas behind all the techniques rely on the fact that the numerical solution is not matching the information at hand. Essentially, the only information available is that the unknown solution is a function with some regularity requirements (for instance, the first derivatives are continuous) fulfilling a differential equation (typically a PDE).

Recovery estimates: improve the solution enforcing regularity

The first big family of error estimators is known under different names: flux recovery estimators, post-processing, smoothing estimators or ZZ estimators (after Zienkiewicz and Zhu, the authors of the paper introducing these techniques). They are based on the fact that the approximate (Finite Element) solution is not as regular as the exact solution is expected to be. Typically, the derivatives (fluxes or stresses) are not continuous, as they should be. Thus, a new solution fulfilling the regularity requirements is recovered using any post-processing technique. The error is then measured as the difference between the approximated solution and the recovered solution (which is replacing in the estimate the role that the exact solution plays in the exact error). The usual error measure adopted is the so-called energy norm that is expressed in terms of fluxes (or stresses). Thus, the recovered fluxes are sufficient to compute the estimate.

Residual estimates: check how well the equation is fulfilled

The definition of residual in dictionary resident in my laptop is: “a quantity remaining after other things have been subtracted or allowed for; a difference between a value measured in a scientific experiment and the theoretical or true value”. In mathematics, the definition is generalized and stands for the non-verification of the equation you are wishing to solve. The exact solution fulfills the equation, which can be expressed as making an expression equal to zero, and the approximated solution does not. The quantity (different than zero) resulting when you introduce the approximate solution into this expression is precisely the residual. Obviously, the smaller the residual is, the closer is the approximate solution to the exact one.

The residual-type error estimators are based on the idea of identifying the error associated with some numerical solution from its residual. It is worth mentioning that in the Finite Element context the residual associated with the strong form of the problem is split in two parts. These two parts are seen as two sources of error. First, we identify the error in the differential equation itself that can only be defined (and computed) in the interior of the elements. Second, the so-called singular error is associated with the regularity defaults of the solution (the flux continuity is not enforced a the solution contains flux jumps across the element edges) and the non-verification of the boundary conditions. Both sources of error are integrated in the residual of the weak form of the equation.

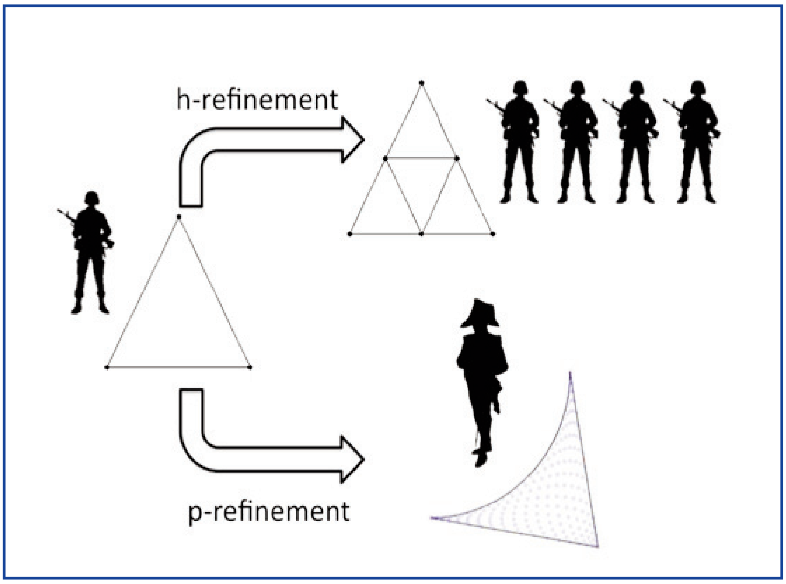


Figure 3:
The mesh is refined by either increasing the number of elements of the same type (h-refinement) or replacing lower order elements by high order elements (p-refinement).
If the linear 3-noded triangle is a simple soldier, the degree 19, 210-noded triangle is a high ranked general

The so-called explicit residual-type estimates are just post-processes of the residual, taking into account the two parts (interior and singular residuals). Typically, these estimates are approximations to the error undetermined up to an unknown constant.

The implicit estimators require solving the error equation (in which the residual plays the role of the source term) and they do provide error bounds. For instance, you may guarantee that the estimate obtained with these strategies is always larger than some measure (typically an energy norm) of the actual error.

Goal-oriented error assessment and pollution

The pioneering error estimates aimed at assessing the energy norm of the error. In the 90`s, attention was paid by many researchers to estimate the pollution error and, more generally, the error in arbitrary quantities of interest.

The quantity of interest is described as a functional output of the solution (some local average of displacements or stresses, some integral quantity or functional restriction…).

Pollution analysis is important to identify which are the zones of the domain or the features of the problem producing errors elsewhere. This is equivalent to say that if the goal of the computation is to produce an accurate approximation of some quantity localized in one part of the domain, the mesh has to be refined not only in the zone of interest but also in the zones producing pollution. If pollution exists, local refinement is not sufficient to guarantee local quality.

The techniques developed to estimate the error in arbitrary quantities of interest are based on the following ideas. First, an auxiliary problem (denoted as dual or adjoint problem) is introduced in which the functional output describing the quantity of interest plays the role of the loading (source term). Second, an error representation is found such that the error in the quantity of interest is expressed in terms of energy products of the errors corresponding to the original (primal) and the dual problems. Third, standard energy norm estimates are applied to both the primal and the dual problem to obtain an error estimate for the quantity of interest. Note that if implicit residual estimators yielding upper and lower error bounds are used, then the estimates for the error in the quantity of interest are also guaranteed upper and lower bounds. Thus, also for goal-oriented error assessment we need using the classical energy norm error estimates.

Adaptivity: send the troops where they are more efficient

Estimating the error makes sense if, in the case that the prescribed accuracy is not reached, there is a remedy. Of course, the straightforward solution is to recompute with a finer mesh. The idea of adaptivity is to optimally refine the mesh in view of the error distribution. In other words, the computational resources (degrees of freedom) have to be located in the most efficient zones. As previously mentioned, the idea is to increase the resolution of the mesh in the zones of interest but also in zones where pollution is generated.

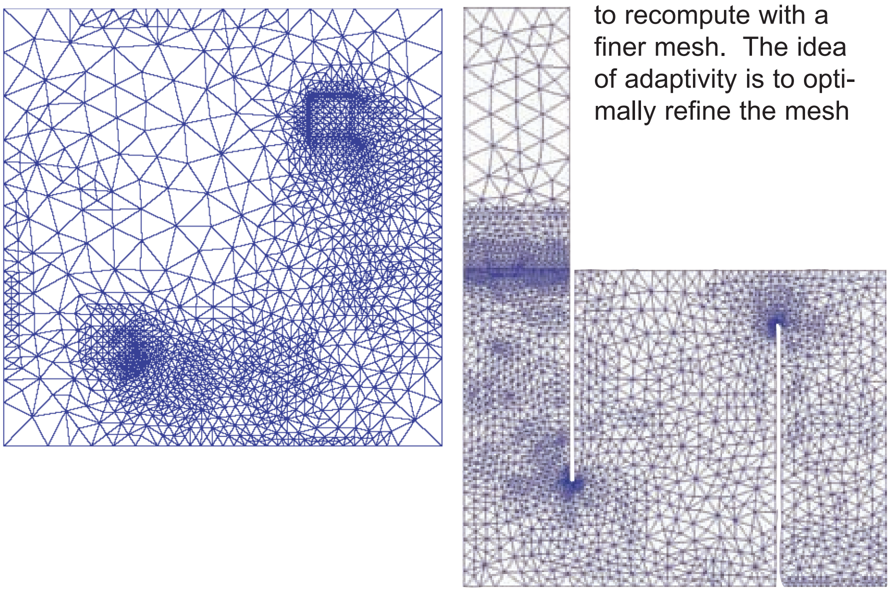


Figure 4.
Examples of goal-oriented h-adapted meshes. Note that refinement is carried out in the zones requiring higher resolution, both in the sources of pollution and where the quantity of interest is localized

In this battle against numerical error, the effectives are the degrees of freedom. The strategy depends on the information provided by the error estimate. The troops must attack the targets producing the best results. Note that the final goal is not suppressing the enemy, but just keeping it under control, as it should be also in real wars.

There are three main strategies in mesh refinement for finite elements. The first one consists in increasing the number of elements and keeping the element type. This is denoted as h-adaptivity (because h denotes the characteristic element size). The h-refinement strategy can be implemented either by subdividing the previous mesh or building a new mesh from scratch. In some sense, this is equivalent to send more soldiers to the battle, preferably to the zones of the battlefield where they have more impact.

The second alternative is denoted as *p*-adaptivity (*p* denotes the degree of the polynomial interpolation in the element) and consists in replacing low order elements by higher order ones (linear by quadratic, cubic…). Following our martial metaphor, this results in replacing soldiers by higher rank officers. In *figure 3*, if the 3-noded linear element is replaced by the 210-noded element of degree 10, the high-ranked general replaces the soldier.

In these two strategies, local refining is performed either decreasing h or increasing *p*. The first is more robust and the second converges much faster to resolve complex singularities. The combined *h-p* refinement is also a common practice in computational mechanics.

A third alternative is r-adaptivity (r standing for relocation) in which the number of degrees of freedom and the mesh topology are kept constant. The nodes are thus relocated to produce a concentration of degrees of freedom where they can be more effective. This means just moving troops without providing any additional supply.

Particular applications in which error control and adaptivity is a must

As discussed above, controlling the accuracy of the solution must be a common practice in Computational Mechanics. The end user has to know how many digits he/she can trust in the numerical answer.

Moreover, there are specific applications and strategies in the Computational Mechanics landscape in which error control and adaptivity are especially important. Three of these particular applications or modeling options are: Optimization, Stochastic Models and Reduced Order Models.

In the context of Optimization, the numerical problem has to be solved a large number of times during the iterative procedure, with slight variations corresponding to the different values of the design variables. Moreover, the goal of the computation is to obtain the objective function to be minimized. This is obviously a perfect framework for goal-oriented error assessment and adaptivity: the accuracy of the evaluation of the objective function must be somehow guaranteed at the minimum computational cost.

The same applies for Stochastic Models, where the problem has to be solved for a number of random samples, again with slight variations.

Both in Optimization and Stochastic Models, the Reduced Order Model paradigm is becoming very popular. There is a recent intensive use of methodologies like “Reduced Basis Method”, “Proper Orthogonal Decomposition” (POD) or “Proper Generalized Decomposition” (PGD). All these methods allow drastically reducing the number of degrees of freedom of the problem to solve by using information provided by the solutions of similar problems. Nevertheless, the dramatic decrease in the complexity of the problem requires a strict control of the accuracy of the solution provided. The error assessment techniques have already been particularized to this context, but there is a clear need of further research to develop more tools and more efficient, and this is certainly the way to go. ●

References: Books

[1] *Ainsworth, M. and Oden, J.T.* (2000) **A posteriori error estimation in finite element analysis**. Pure and Applied Mathematics (New York), Wiley-Interscience [John Wiley & Sons], Chichester.

[2] *Babuska, I. and Strouboulis, T.* (2001) **The finite element method and its reliability. Numerical Mathematics and Scienific Computation**, The Clarendon Press Oxford University Press, New York.

[3] *Bangerth, W. and Rannacher, R.* (2003) **Adaptive finite element methods for differential equations.** Lectures in Mathematics ETH Zurich, Birkhauser Verlag, Basel.

[4] *Ladevèze, P. and Pelle, J.P.* (2005) **Mastering calculations in linear and nonlinear mechanics**. Mechanical Engineering Series. Translated from the 2001 French original by Theofanis Strouboulis. Springer-Verlag, New York.

[5] *Ramm, E., Rank, E., Rannacher, R.* et al. (2002) **Error-Controlled Adaptive Finite Elements in Solid Mechanics** (ed. E. Stein), Wiley, Chichester.

[6] *Verfurth, R.* (1996) **A Review of a Posteriori Error Estimation and Adaptive Mesh-Refinement Techniques**, Teubner Verlag and John Wiley, Stuttgart.

References: Papers

[1] *Zienkiewicz, O.C. and Zhu, J.Z.* (1987) **A simple error estimator and adaptive procedure for practical engineering analysis**. Int. J. Numer. Methods Eng., 24, 337–357.

[2] *Zienkiewicz, O.C. and Zhu, J.Z.* (1992) **The superconvergent patch recovery(SPR) and adaptive finite element refinement**. Comput. Methods Appl. Mech. Eng., 101, 207–224.

[3] *Wiberg, N.E., Li, X.D. and Abdulwahab, F.* (1996) **Adaptive finite element procedures in elasticity and plasticity**. Eng. Comput., 12(2), 120–141.

[4] *Huerta, A., Rodríguez-Ferran, A., Díez, P. and Sarrate, J.*, **Adaptive finite element strategies based on error assessment**, International Journal for Numerical Methods in Engineering, Vol. 46:10, 1803 - 1818, 1999

[5] *Díez, P. and Huerta, A.*, **A unified approach to remeshing strategies for finite element h-adaptivity**, Computer Methods in Applied Mechanics & Engineering, Vol. 176:1-4, 215 - 229, 1999

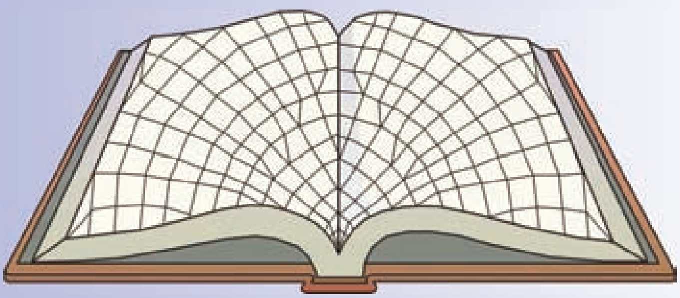
[6] *Díez, P.and Calderón, G.*, **Remeshing criteria and proper error representations for goal oriented h-adaptivity**, Computer Methods in Applied Mechanics and Engineering, 196 719-733 (2007)

[7] *Cottereau, R., Díez, P. and Huerta, A.*, **Strict Error Bounds for Linear Solid Mechanics Problems using a Subdomain-Based Flux-Free Method**, Computational Mechanics, 44 (4) 533-547 (2009)

[8] *Ammar, A., Chinesta, F., Diez, P. and Huerta, A.*, **An error estimator for separated representations of highly multidimensional models**, Computer Methods in Applied Mechanics and Engineering, 199 (25-28) 1872-1880 (2010)

[9] *M. Paraschivoiu, J. Peraire, and A. T. Patera*, **A posteriori finite element bounds for linear-functional outputs of elliptic partial differential equations**, Comput. Methods Appl. Mech. Engrg., 150 289–312 (1997)

NUMERICAL METHODS FOR FLUID DYNAMICS
WITH APPLICATIONS TO GEOPHYSICS
2ND EDITION



Dale R. Durran
Springer, New York, 2010

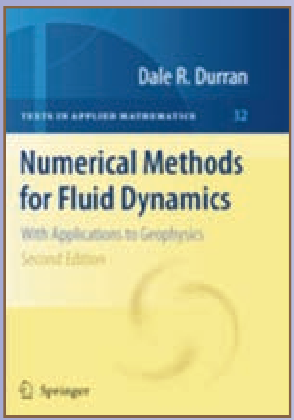
BOOK REVIEW

ISBN: 1441964118,
516 pages, hard cover
$84.95 (List Price).
Contents:
Preface, 1. Introduction, 2. Ordinary Differential Equations,
3. Finite-Difference Approximations for One-Dimensional Transport,
4. Beyond One-Dimensional Transport, 5. Conservation Laws and Finite-Volume Methods, 6. Series-Expansion Methods, 7. Semi-Lagrangian Methods,
8. Physically Insignificant Fast Waves, 9. Nonreflecting Boundary Conditions,
A. Numerical Miscellany, References, Index.

This is the second edition and a major revision of *Numerical Methods for Wave Equations in Geophysical Fluid Dynamic*s (from 1999) by the same author. I liked the first edition, and I like this second edition even more. The change of title conveys the fact that the scope of the book has been broadened significantly. As the author states in the Preface, this book is designed to serve graduate students and researchers studying Geophysical Fluid Dynamics (GFD) while also providing a general introduction to numerical methods for the solution of time-dependent problems governed by differential equations. Elliptic (steady-state) problems are not covered here. The majority of the schemes presented here frequently appear in the context of GFD; however the book's focus is not on the details of particular atmospheric models but rather on fundamental numerical methods that have applications in a wide range of scientific and engineering areas.

GFD is concerned with waves and fluid flow in the atmosphere and in the ocean. Oceanography and weather prediction are branches of GFD. Many of the numerical techniques presented here are commonly used in the area of Numerical Weather Prediction (NWP). Despite the absence of the word Wave in the acronym GFD, the field is characterized more by wave phenomena than by fluid flow phenomena. The book concentrates on initial value problems, namely problems that have no physical boundaries and are driven by initial data, as typical in many NWP models. The only boundary conditions considered in depth in this book are artificial non-reflecting boundary conditions.

Chapter 1 starts with a short introduction to NWP and to GFD in general, and then introduces the differential equations encountered in GFD. It then briefly explains basic notions related to computational methods, namely discretization in space and time.



Dale R. Durran
TEXTS IN APPLIED MATHEMATICS 32
Numerical Methods for Fluid Dynamics
With Applications to Geophysics
Second Edition
Springer

Dale R. Durran

by
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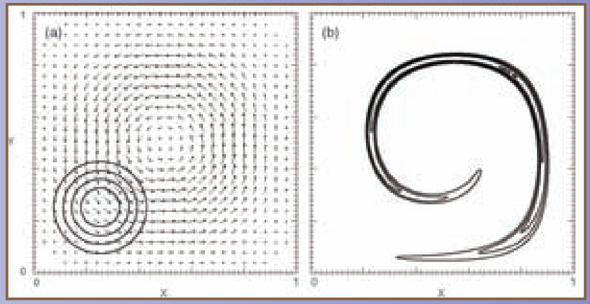
Chapter 2 discusses numerical methods for (scalar) ODEs. It includes a long and nice discussion on stability, consistency and convergence. Various stability notions are discussed, including A-stability and L-stability. Runge-Kutta methods receive special attention due to their importance in GFD and other fields of application. Linear Multi-Step methods are also treated, including a discussion of the Dahlquist barriers. Leapfrog and Adams-Bashforth schemes are especially popular in GFD, and the reason for this fact is explained. A special section (2.5) is dedicated to stiff problems.

Chapter 2 ends with two excellent tables that summarize the properties of all 14 numerical methods presented in this chapter (three of which are implicit ,i.e., Backward Euler, Trapezoidal and Adams-Moulton, and all the rest are explicit). For each method the tables indicate its order of accuracy, the formulae defining it, and additional properties associated with it, i.e., storage factor, efficiency factor, amplification factor, phase error and stability limit. These tables are extremely helpful, and I am sure I will return to consult with them from time to time.

The book does not discuss in a detailed way numerical methods for the solution of *systems* of ODEs. Such systems commonly arise, for example, when one uses the finite element method for space discretization, as indeed discussed on p. 321. Which of the 14 methods presented in *Chapter 2* can be extended to deal with systems? How are their properties (e.g., stability limit) modified when applied to systems? It would have been nice to relate to these questions; perhaps in the next edition.

Chapter 3 discusses finite difference approximations for 1D transport problems; these involve advection or diffusion or both. Since the governing equation is now a PDE, the notions of consistency, stability and convergence are discussed anew in this more complicated context. The general definition of stability is presented here, and energy and von Neumann stability analyses are discussed and demonstrated. The important concepts of numerical dispersion and dissipation are also discussed in detail. *Chapter 4* presents various generalizations to the basic 1D transport problem, and discusses among other subjects staggered grids and staggering in time, 2D and 3D transport problems, fractional-step schemes, equations with variable coefficients and nonlinear instability.

Figure 1:
Result of a numerical example obtained using finite volumes. This is Figure 5.23 taken from the book, p. 265



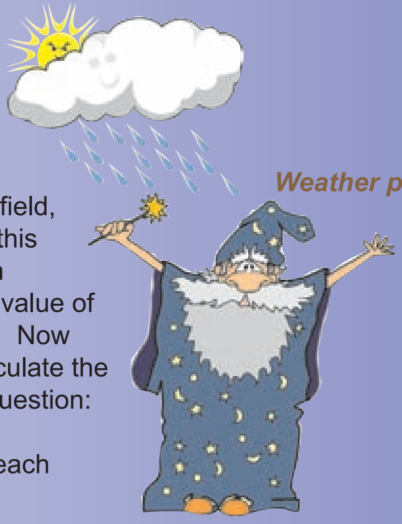
Chapter 5 covers very important classical subjects in CFD based on conservation equations and finite volume methods. Among other subjects, the Riemann Problem, Entropy consistent solutions, flux-limiter methods, Godunov's method, ENO and WENO methods, operator splitting and upstream differencing are discussed. *Figure 1* is a result of a numerical example taken from the book. *Chapter 6* covers spectral and pseudo-spectral methods and finite element methods.

Chapter 7 deals with semi-Lagrangian methods which are time-stepping methods extremely popular in GFD. These methods are *explicit and unconditionally stable* – undoubtedly a very tempting combination. To present the basics of semi-Lagrangian methods, let us consider the scalar one-dimensional advection equation

$$\frac{\partial u}{\partial t} + V\frac{\partial u}{\partial x} = f$$

in the unbounded domain $-\infty < x < \infty$. Here $u(x,t)$ is the unknown wave field, $V(x,t)$ is a given velocity function and $f(x,t)$ is a given source function. To this equation we append the initial condition $u(x,0)=u_0(x)$. Let us discretize both space and time, and let u_j^n and f_j^n denote the approximation of u and the value of f at spatial location x_j (i.e. at node j) and time t_n (i.e. after n time-steps). Now suppose we have completed calculations up to time t_n, and we wish to calculate the solution u_j^{n+1}. In the semi-Lagrangian approach we first ask the following question:

What is the location $\tilde{x}_j^n$ at the current time (t_n) of a "particle" that would reach location x_j at time t_{n+1}?



Weather prediction

Assuming that we know how to answer this question, a basic semi-Lagrangian scheme is given by

$$u_j^{n+1} = \tilde{u}_j^n + \frac{\Delta t}{2}(f_j^{n+1} + \tilde{f}_j^n)$$

Here $\tilde{u}_j^n$ and $\tilde{f}_j^n$ are the estimated values of u and f at $\tilde{x}_j^n$. The last formula is obviously explicit.

It is easy to see that the procedure to find the solution at a desired location at the next time level amounts to finding the solution on the same characteristic at the current time level. This is illustrated in *Figure 2*.

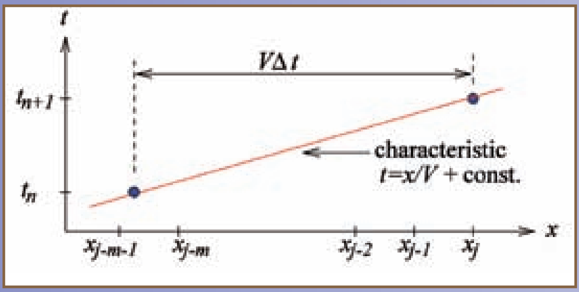


Figure 2:
Setup for the semi-Lagrangian time-stepping method. A similar figure is included in the book (Figure 7.1, p. 359)

Additional considerations establish the *unconditional stability* of the scheme. Thus, although the scheme is explicit, it is possible to take arbitrarily large time steps without violating a CFL condition. *Figure 3* illustrates the procedure required for data passage between grids within the semi-Lagrangian framework.

The very important *Chapter 8* is entitled “physically insignificant fast waves.” It deals with those nasty waves that are not of any importance from a physical viewpoint, yet have a major unpleasant effect on the stability of time-explicit methods. In GFD these are, e.g., acoustic waves, which may not be of interest when one is interested in gravity and/or Rossby waves. This chapter presents various methods for efficiently dealing with this difficulty. One important type of methods is the class of *semi-implicit methods*, in which those terms in the governing equations that are strongly related to the propagation of the fast waves are evaluated implicitly, whereas all the remaining terms are evaluated explicitly.

The last chapter deals with non-reflecting boundary conditions, a subject that is close to my heart and which receives here a very good treatment.

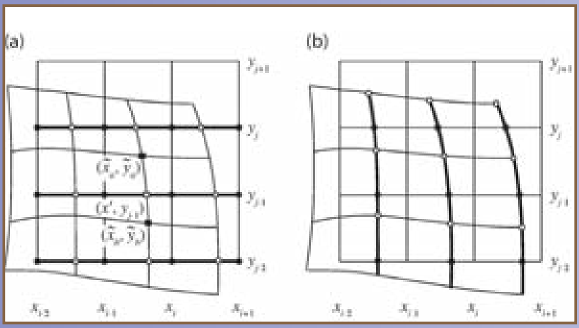
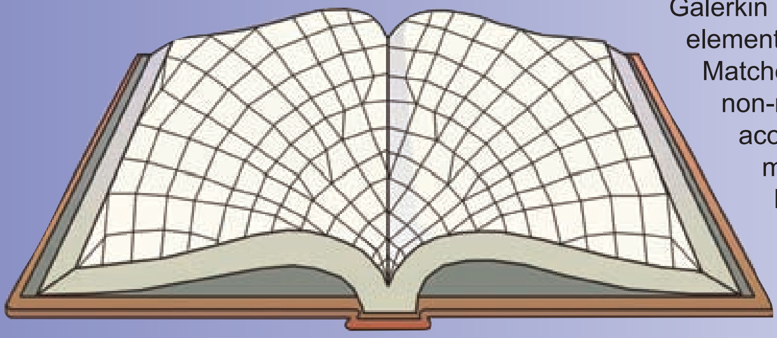


Figure 3:
Semi-Lagrangian cascade interpolation. This is Figure 7.2 taken from the book, p. 364

The book explodes with useful information. The derivations and explanations are nice and clear. Figures are used quite a lot to illustrate the text. For some of the subjects that the book covers, e.g., the Riemann problem, I found here a better explanation than given in most other books I have seen. In addition, I found the explanations on subjects that I had not been very familiar with, like semi-Lagrangian and semi-implicit methods, easy to understand and digest. Every chapter ends with a number of well thought of Problems that clarify and sometimes extend the techniques discussed in the text.

The GFD jargon used in this book would have a slightly foreign ringing to members of the CM community. For example, the semi-discrete system of equations is called here the “set of differential-difference equations,” and the finite element method is included in the category of “series expansion methods,” along with spectral methods. More seriously, Petrov-Galerkin methods (pp. 324-5) are presented in a way that would seem strange and outdated to CM practitioners, and there seems to be some confusion here between Discontinuous Galerkin methods on one hand and p-version and spectral element methods on the other (pp. 339-350). Perfectly Matched Layers (PML), which are quite popular as non-reflecting boundary schemes in computational acoustics and in some disciplines of CM, are not mentioned here at all. This “cultural difference” between the GFD and CM communities is, of course, natural and unavoidable. I think that for CM readers this is a very small price to pay for benefiting from the treasures that this book has to offer. ●



Chilean Society for Computational Mechanics

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The Chilean Society for Computational Mechanics (CSCM) is glad to report the activities developed during 2010-2011.

Universidad de La Serena has hosted the IX Workshop on Computational Mechanics (JCM 2010, acronym in Spanish) at La Serena from September 2-3 2010. That meeting was chaired by Profs. Carlos Garrido and Mauricio Godoy from the Mechanical Engineering Department. The Workshop was officially opened by Prof. Dr. Ricardo Castillo B, Head of the Mechanical Engineering Department.

The X Workshop on Computational Mechanics (JCM 2011) was organized by Profs. Sergio Gutiérrez, Daniel Hurtado and Sebastián Saez from the Structural and Geotechnical Engineering Department of Pontificia Universidad Católica de Chile. This meeting was held at Santiago de Chile during October 13-14 2011.

National and international professionals, faculty members and students attending JMC 2010 and 2011 were warmly welcoming by Prof. Diego Celentano as President of the CSCM. These two-day Workshops encompassed different activities: Plenary Lectures, Technical Parallel Sessions, the Annual CSCM Members Meeting and particularlly, symposiums devoted to present industrial problems by enterprise members and stands from software companies.

Dr. Enrique Poulain from Universidad Autónoma Metropolitana de México at La Serena 2010 and Dr. Aubry Denis from Ecole Centrale de Paris at Santiago de Chile 2011, were the international speakers invited to deliver Plenary Lectures. Profs. Carlos Conca (Universidad de Chile), Alvaro Valencia (Universidad de Chile), Héctor Jensen (Universidad Técnica Federico Santa María) and Diego Celentano (Pontificia Universidad Católica de Chile), have presented relevant talks as Plenary Lectures representing the local scene.

Participants from different countries and Chilean universities presented around 40 works from several areas of computational mechanics during each meeting. Moreover, a collection of full written papers were reported in the journal of the CSCM "Cuadernos de Mecánica Computacional", Vols. 8 (2010) and 9 (2011).

Figure 1: *IX Workshop on Computational Mechanics JMC 2010 at Universidad de La Serena*

The CSCM warmly thanks the participation of authors and speakers and, specially acknowledged the active participation of under and post graduate students.

Finally, the CSCM cordially invites to participate in the next version of the Workshop (JMC 2012) to be held in Valparaiso at the Universidad Técnica Federico Santa María. Contact Profs. Mario Toledo (mario.toledo@usm.cl) or Franco Perazzo (franco.perazzo@usm.cl) for further information on this next meeting or visit the the web page of the CSCM: www.scmc.cl. ●

Figure 2: *X Workshop on Computational Mechanics JMC 2011 at Pontificia Universidad Católica de Chile*

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19th UK ACME Conference

UK ACME School and Conference held at Heriot-Watt University in Edinburgh, Scotland

Over 100 participants from universities across the UK came to Heriot-Watt University in Edinburgh, Scotland, for the UK Association for Computational Mechanics in Engineering (ACME) meeting on 4th, 5th and 6th April 2011. The event consisted of the first ever ACME School and the 19th UK ACME conference, and both were organised under the auspices of the UK Association for Computational Mechanics in Engineering (ACME).

The Association was founded with the aims of promoting research in computational mechanics in engineering within the UK, and establishing formal links with similar organisations in Europe and the International Association for Computational Mechanics (IACM). The principal activity of ACME involves the organisation of the annual conference. The first such conference took place at the University college of Wales Swansea in 1993. The conferences have provided a forum for reviewing research activities in many areas of mechanics, with an emphasis on interdisciplinary aspects. The conferences have proved to be particularly useful events for drawing together researchers from different disciplines, and especially for providing young researchers with opportunities for presenting their work.

Professor Roger Owen from Swansea University, a member of the IACM Executive Council, gave the opening lecture entitled ‘Challenges in the Modeling of Particulates and Multi-Fracturing Materials with Coupled Field Effects.’ The participants enjoyed listening to Professor Owen showing the significant progress made over the last decade in the effective modelling of the failure and transition from continuum to discontinuum of quasi-brittle materials.

The Conference also saw the strong participation of young researchers. Three prizes were awarded for the presenters of the best papers. The Mike Crisfield Prize was awarded to Mr. Thomas Ruberg, from Cambridge University, for his paper entitled ‘Immersed Finite Element Method for

Figure 1:
Participants at the 19th UK Association for Computational Mechanics in Engineering (ACME) conference

Fluid-Structure Interaction'. The Best Post-Doctorate Paper prize went to Dr. Robert Simpson from Cardiff University for his paper on 'An isogeometric boundary element method for elastostatic problems'. Finally, Mr. Chun Lee, from Swansea University, was awarded the Best PhD Paper prize for his paper on 'Development of a Finite Volume Algorithm for a New Conservation Law Formulation in Structural Dynamics'.

The conference was preceded by the 1st UK ACME School, which consisted of a series of lectures given by established ACME members on new research trends in computational mechanics. This year's School was dedicated to mesh reduction techniques. The first lecture was given by Professor Harm Askes, from Sheffield University, who introduced the Meshless Methods. Professor Jon Trevelyan and Dr. Charles Augarde, from Durham University, presented respectively the Boundary Element Method and the Scaled Boundary Methods. The 1st UK ACME School saw strong participation of young researchers. The ACME community intends to make the School part of future ACME Conferences. ●

Figure 2: *From left to right*
Barry Topping, Andrew Chan, Ian May, Roger Owen, Anne Ormston, Omar Laghrouche, Carlo Sansour

Figure 3:
Conference Dinner at the Edinburgh Caledonian Hilton

Figure 4:
Professor Roger Owen gives the Opening Lecture of the 19th UK-ACME Conference

Figure 5:
Chun Lee (left), a student from Swansea University, receives the Best PhD paper award from the ACME President (right, Carlo Sansour) and ACME Chairman (middle, Omar Laghrouche)

Figure 6:
Robert Simpson (left), a student from Cardiff University, receives the Best Post-Doctorate paper award from the ACME President (right, Carlo Sansour) and ACME Chairman (middle, Omar Laghrouche

Tsinghua-Swansea Workshop on Computational Mechanics

The first Tsinghua-Swansea Workshop on Computational Mechanics was recently held in Tsinghua University, Beijing.

Led by Professor Javier Bonet, Head of Swansea University's College of Engineering, a team of nine academic researchers from Swansea attended the workshop, which was hosted by Professor Zhuo Zhuang, Dean of School of Aerospace at Tsingua, and his colleagues.

Chaired by Prof Song Cen (Tsinghua University) and Dr Chenfeng Li (Swansea University), a wide range of research works in computational mechanics and computational engineering were presented during the workshop, including biomedical modelling, computational fluid dynamics, computational electro-magnetics, fluid-structure interaction, hp-FEM, inverse problems, mesh generation, multi-scale simulations, optimization, particle methods and stochastic analysis technology.

Figure 1: *Delegates attending the workshop*

The workshop takes the existing research collaborations between researchers in Swansea and Tsinghua one step further, initiating a strategic long-term collaboration between Swansea's College of Engineering and Tsinghua's School of Aerospace in the field of Computational Mechanics and Computational Engineering. Plans have been made for bilateral academic visits, exchange of research students, joint research projects, and the next Swansea-Tsinghua workshop, which will be held in Swansea in July 2012. ●

Figure 2: *Prof Roger Owen receiving Tsinghua One-hundred Years' Anniversary Memorial Medal from Prof Zhuo Zhuang, Dean of School of Aerospace at Tsinghua University.*

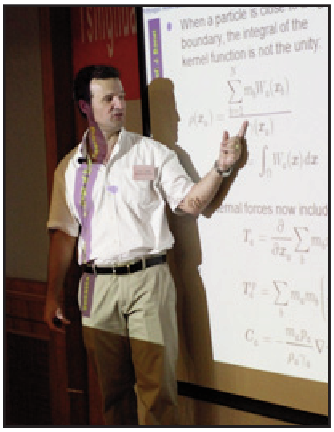

Figure 3: *Prof Javier Bonet giving plenary presentation at the workshop*

During the Tsinghua-Swansea Workshop on Computational Mechanics recently held at Tsinghua University, Beijng, Professor Roger Owen FRS, FREng awarded the Emerald Literati Highly Commended Paper Award 2011 to Professor S Cen of Tsinghua University, Dr CF Li of Swansea University, Dr XR Fu of China Agriculture University and Dr XM Chen of China Academy of Building Research, for their joint paper "Analytical trial function method for development of new 8-node plane element based on the variational principle containing Airy stress function", recently published in Engineering Computations.

Figure 4: *(from left to right)*
Dr CF Li, Prof S Cen, Prof DRJ Owen, Dr XM Chen and Dr XR Fu)

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CMM 2011

The 19th International Conference on Computer Methods in Mechanics

The 19th International Conference on **Computer Methods in Mechanics (CMM 2011)** was held on May 9-12, 2011, at the Warsaw University of Technology in the historical rooms of its Main Building, see the photo in *Figure 1* (all photos by Grzegorz Adamczewski).

***Figure 1**. The façade of the Main Building of the Warsaw University of Technology*

The International CMM Conferences are organized in Poland biennially. They have a long, 38-year tradition tracing back to the year 1973, when the first conference of this series was organized in Poznań by the well-known experts on mechanics: Antoni Sawczuk and Jan Szmelter. The CMM 2011 conference was organized under the auspices of European Community on Computational Methods in Applied Sciences (ECCOMAS) and Central European Association for Computational Mechanics (CEACM), under the patronage of Michał Kleiber, President of the Polish Academy of Sciences and Włodzimierz Kurnik, Rector of the Warsaw University of Technology. The main organization tasks were performed by the Department of Structural Mechanics and Computer Aided Engineering (Faculty of Civil Engineering, Warsaw University of Technology), as well as the following organizations: Section of Mechanics of Structures and Materials (Committee on Civil Engineering and Hydroengineering), Section of Computer Methods in Mechanics (Committee on Mechanics, Polish Academy of Sciences) and Polish Association for Computational Mechanics (its Polish acronym is PTMKM). The heads of these organizations have nominated Prof. Adam Borkowski and Prof. Tomasz Lewiński as chairmen of the Scientific Committee of CMM 2011. Dr. Grzegorz Dzierżanowski and Dr. Zbigniew Kacprzyk played the roles of the Chairman and Secretary of the Organizing Committee, respectively. It is stressed hereby that due to their commitment the organization of this meeting was perfect.

It has become the tradition of the CMM conferences to award selected distinguished researchers the Olgierd Cecil Zienkiewicz medal. The Zienkiewicz Medal (*Figure 2*), issued by the Polish Association for Computational Mechanics, is awarded by the Chapter of the Medal for outstanding outcome in the field of computational mechanics. The award ceremony took place during the opening of the Conference. During this meeting the Zienkiewicz medal was awarded in two categories. The medals *for foreign scientists of particular merit for the development of computational mechanics in Poland* were granted to Bernhard A. Schrefler (Department of Structural and Transportation Engineering, University of Padua) and Robert L. Taylor (Department of Civil and Environmental Engineering, University of California at Berkeley), see *Figures 3 and 4*.

***Figure 2:** The Zienkiewicz Medal*

The medals *for the whole activity* were given to Tadeusz Burczyński (Department for Strength of Materials and Computational Mechanics, Faculty of Mechanical Engineering, Silesian University of Technology) and Andrzej Garstecki (Poznań University of Technology, Institute of Structural Engineering), see *Figures 5 and 6*. This was the third edition of this medal.

Figure 3:
Prof. Bernhard A. Schrefler, presenting the Diploma of the O.C. Zienkiewicz Medal

About 250 participants from 27 countries attended the conference, see *Figure 7*.
51 researches were under the age of 30. Over 260 papers were submitted, out of which, after an evaluation process, 244 contributions were finally printed in the conference proceedings as Short Papers.

The CMM 2011 had a rich scientific programme encompassing 6 Plenary Lectures, 31 Keynote Lectures given within 15 Minisymposia, 8 Thematic Sessions, and was accompanied by book exhibitions in which carefully selected books on computational mechanics were presented.
The papers were presented in 5 parallel sessions during 4 days.
The plenary lectures were delivered by J.S.Chen (Civil and Environmental Engineering Department, University of California, Los Angeles - UCLA), F.Jouve (Universite Paris Diderot, Laboratoire J.L. Lions, Paris), T.Kowalewski (Institute of Fundamental Technological Research, Polish Academy of Sciences, Warsaw), G.Meschke (Institute for Structural Mechanics, Department for Civil and Environmental Engineering, Ruhr University Bochum), B.Schrefler (Department of Structural and Transportation Engineering, University of Padua) and T.Uhl (Department of Robotics and Mechatronics, AGH University of Science and Technology, Cracow).

Figure 4:
Prof. Robert Taylor's speech on behalf of all the awardees

Prominent researches organized 15 Minisymposia that covered a wide spectrum of topics:

Computational Aspects of Smart Materials and Structures (M.Kuczma, R.Müller, J.Schröder, G. Szefer), Computational Mechanics of Materials (T.Łodygowski, J.Pamin, A.Rusinek), Structures under extreme actions (M.Giżejowski, L.Kwaśniewski), Identification and Optimization (K.Dems, W.Gutkowski), Growth Phenomena and Evolution of Microstructures. Applications in Solids (J.F. Ganghoffer, J. Sokołowski), Asymptotic Analysis and Singular Perturbations in Solids and Fluids. Applications in Topology Optimization and Inverse Problems (A. Novotny, J. Sokołowski, A. Żochowski), Computational Mechanics of Multiphase Porous Materials Including Durability (D. Gawin, B. A. Schrefler, F. Pesavento), Heat transfer (E. Majchrzak, B.Mochnacki), Dynamics of multibody systems (J.Frączek, W.Blajer), Modelling of blood flow (J.Szumbarski, J. Mizerski), Multiscale Modelling and Nanomechanics (T.Burczyński, M.Pietrzyk, P.Dłużewski), Artificial Intelligence Computational Methods in Mechanics of Structures and Materials (T.Burczyński, Z. Waszczyszyn, L.Ziemiański), Meshless and Related Methods (J.Orkisz, J.S.Chen, S.Milewski), Computational Mechanics of Plates and Shells (J. Chróścielewski, W.Gilewski, I. Kreja), Adaptive Methods and Error Estimation (W.Cecot, W.Rachowicz, G. Zboiński).

The written versions of most of the plenary and keynote lectures will appear in the following scientific journals: *Computer Assisted Mechanics and Engineering Sciences, Bulletin of the Polish Academy of Sciences.Technical Sciences, Archives of Civil Engineering, The Archive of Mechanical Engineering* and *Acta of Bioengineering and Biomechanics.*

This intensive technical programme was complemented by a Warsaw sightseeing tour and a marvelous conference banquet in the Great Hall of the main

Building of the Warsaw University of Technology, see *Figure 8*.

During this Conference the competition for the best paper presented by a young researcher was organized. The Polish Association for Computational Mechanics and the Scientific Committee of the Conference decided to grant the *Jan Szmelter Award* to Thomas Wick (Institute of Applied Mathematics, University of Heidelberg, Germany) for the best paper entitled *Monolithic fluid-structure interaction modeling for a long axis heart valve simulation.* This award was sponsored by the Simulia Company.

The CMM 2011 was successful thanks to all those who contributed to this event substantially, which is well seen in the valuable volume of Short Papers (two-pages each). The book includes a CD ROM with the same material and with the extended versions of some papers. The great majority of the presentations were very well prepared. We do hope the standard of this meeting will be kept in the future, and the next CMM conference is planned to be held in Poznan in September 2013.

Please visit the conference website (http://www.cmm.il.pw.edu.pl/) for further details. ●

by
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and
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Figure 5:
Prof. Tadeusz Burczyński receives his medal from Prof. M.Kleiber

Figure 6:
Prof. Michał Kleiber awards the medal to Prof. Andrzej Garstecki

Figure 8.
The banquet organized in the Great Hall of the Main Building of the Warsaw University of Technology

Figure 7:
The group photo of participants of CMM 2011 (Wednesday, May 11, 2011)

Israel Association for Computational

The Israel Association for Computational Methods in Mechanics (IACMM) has held two IACMM Symposia since our last report (see IACM Expressions No. 28). In this issue we shall report on them.

The 29th IACMM Symposium was held in October 2010 at the Technion in Haifa. The local organizers were Pinhas Bar-Yoseph and Dan Givoli. The very impressive Opening Lecture was given by Prof. Manolis Papadrakakis from the National Technical University of Athens, Greece, and was entitled "Mastering computational demanding problems in mechanics with neural network predictions." See *Figure 1*, where Prof. Papadrakakis is seen with the three founders of IACMM, and *Figure 3*, where he is seen with the IACMM Council.

Figure 1:
Prof. Manolis Papadrakakis and the three founders of IACMM at the 29th IACMM Symposium. From left: Pinhas Bar-Yoseph, M.P., Isaac Harari and Dan Givoli

An afternoon Keynote Lecture was presented by Alexander Gelfgat from Tel Aviv University. The symposium also included 8 other lectures, presented by practitioners and researchers from industry and academia. *Figure 2* is taken from the lecture of Alexander Yakhot from the Ben-Gurion University of the Negev, on using Proper Orthogonal Decomposition (POD) for analyzing evolving data.

Fig. 4 is taken from the talk of Polina Pine, Yuval Yaish and Joan Adler from the Russell Berrie Nanotechnology Institute of the Technion, on the simulation of vibration of carbon nanotubes. Fig. 5, showing radial metal cutting simulation, is taken from the lecture of Ofir Shor from RAFAEL.

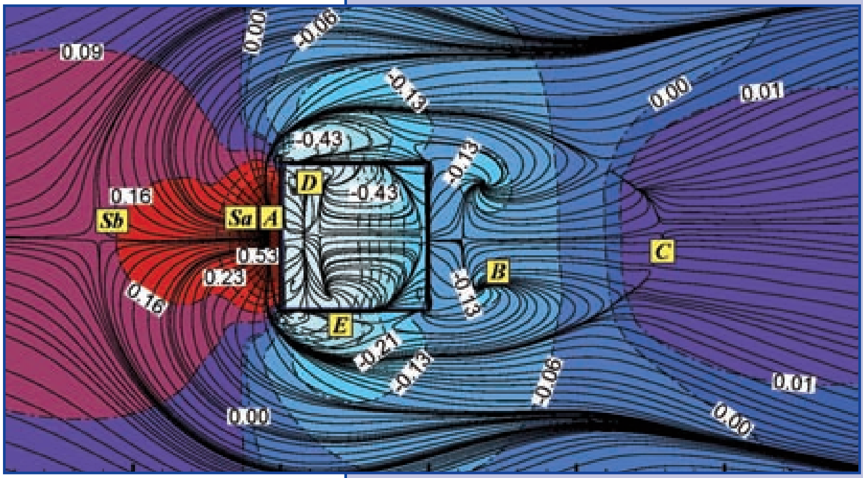

***Figure 2**:*
Figure taken from the lecture of Alexander Yakhot from the Ben-Gurion University of the Negev, on using Proper Orthogonal Decomposition (POD) for analyzing evolving data.
The figure shows a flow simulation around a cube

Figure 3:
Prof. Manolis Papadrakakis and the IACMM Council.
From left: Dan Givoli (President), M.P., Robert Levy, Emanuel Ore, Isaac Harari, Amiel Herszage (Secretary/Treasurer) and Pinhas Bar-Yoseph

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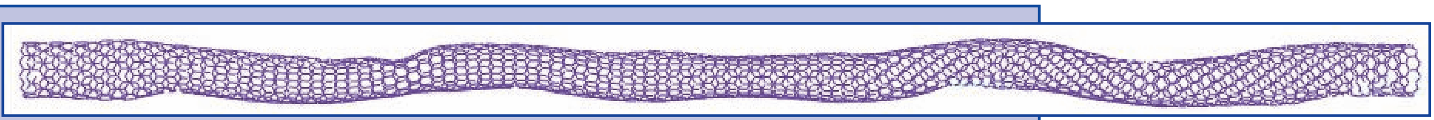


The 30th IACMM Symposium was held in March 2011 in Tel Aviv University. The local organizers were Rami Haj-Ali and Slava Krylov. The opening Keynote Lecture was given by Prof. Eugenio Oñate, Head of the International Center for Numerical Methods in Engineering (CIMNE), Technical University of Catalonia in Barcelona. The title of his fascinating talk was "Advances in the particle finite element method for multidisciplinary problems in computational mechanics."

Figure 6 is taken from Prof. Oñate's presentation and shows a highly nonlinear sloshing simulation using particle FEM. *Figure 7* shows Prof. Oñate at a festive dinner held in his honor, and *Figure 8* shows him with the IACMM Council and the local organizers of the Symposium.

The 30th IACMM Symposium also included a Keynote Lecture by Prof. Michel Bercovier from the Hebrew University in Jerusalem, on the exciting subject of Isogeometric Analysis. Nine more lectures were presented in this Symposium. One of them was a talk by Alon Katz, Nir Trabelsi and Zohar Yosibash from the Ben-Gurion University of the Negev, on the investigation of implants and fixtures in human femurs. *Figure 9* is taken from this talk.

The 30th and 31st IACMM Symposia (the latter is to be held in late October 2011) have been announced to include a Lecture Competition. One of the presenters in these symposia, typically a student or a young IACMM member from the industry, will win the IACMM Award for the Best Lecture. The winner will receive IACMM's support for traveling to a CM conference abroad to present the winning work to an international audience. ●

Figure 4:
Figure taken from the talk of Polina Pine, Yuval Yaish and Joan Adler from the Russell Berrie Nanotechnology Institute of the Technion, on the simulation of vibration of carbon nanotubes. The figure shows the lateral vibration of a doubly clamped armchair nanotube.

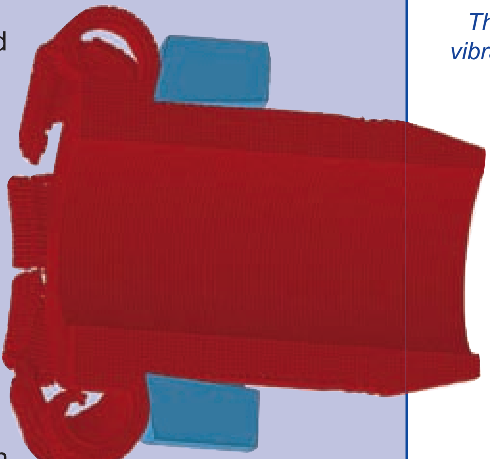


Figure 5:
Figure taken from the lecture of Ofir Shor from RAFAEL, on radial metal cutting simulation. A cutting tool is moved across the axis of the pin causing plastic deformations and chip formation

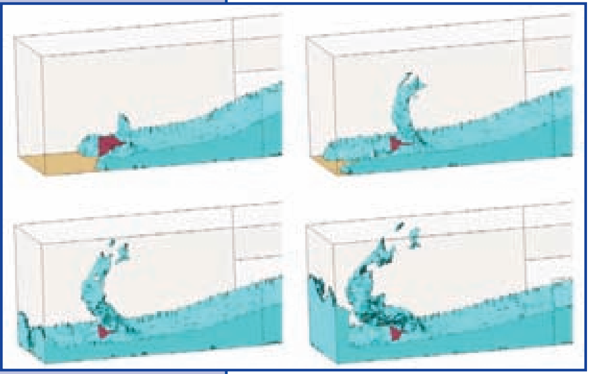


Figure 6:
Figure taken from Prof. Eugenio Oñate's Opening Lecture in the 30th IACMM Symposium. It shows a highly nonlinear sloshing simulation using particle FEM

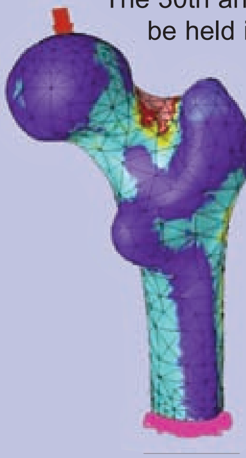


Figure 9:
Figure taken from the lecture of Alon Katz, Nir Trabelsi and Zohar Yosibash from the Ben-Gurion University of the Negev, on the investigation of implants and fixtures in human femurs

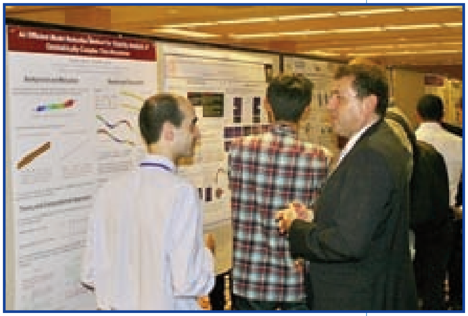
Figure 7:
Prof. Eugenio Oñate at a festive dinner after the 30th IACMM Symposium. From right: E.O., Rami Haj-Ali (local organizer) and Zohar Yosibash (member of IACMM Council)

Figure 8:
Prof. Eugenio Oñate, IACMM Council members and hosts. From left: Isaac Harari, Amiel Herszage, Pinhas Bar-Yoseph, E.O., Rami Haj-Ali (local organizer), Slava Krylov (local organizer) and Dan Givoli

11th U.S. National Congress on Computational Mechanics

Minneapolis, MN
July 25-28, 2011

Figure 1:
Poster session held at USNCCM11



The U.S. National Congress on Computational Mechanics was held in Minneapolis, Minnesota, July 25-28, 2011 in the beautiful Hilton Minneapolis. Over 1100 participated in 63 minisymposia and over 1200 presentations were made. In addition to Plenary and Semi-Plenary speakers and oral presentations, the congress featured a student poster competition with over 100 participants on Wednesday afternoon, July 27.

The Congress was organized by a local organizing committee consisting of Professors Kumar Tamma (chair), Henryk Stolarski, Wojciech Lipinski, and Chris Hogan, all from University of Minnesota.

Figure 2:
Banquet Speaker Dr. Steven E. Koonin

Speakers

Plenary speakers were Prof. J. Tinsley Oden, University of Texas at Austin, Dr. Leslie Greengard of Courant Institute, Prof. Thomas J. Hughes, University of Texas at Austin, and Dr. Horst Simon, Lawrence Livermore Laboratories, Semi-Plenary Speakers included Professors Ekkehard Ramm, D.J.R. Owen, Michael Sacks, George Biros, Garth Wells, and Denis Zorin.

The guest banquet speaker was Dr. Steven E. Koonin, Undersecretary for Science in the Department of Energy.

Student Poster Competition

An entire afternoon of the congress was dedicated to a student poster session. The posters were presented by graduate students and postdoctoral fellows from various fields associated with computational mechanics such as engineering, physics, chemistry, biology, nanosciences, and allied disciplines. The competition was judged by a panel of 3-5 expert scientists from academia, government, and industry; a $500 award as well as commemorative plaques were awarded to the following students for outstanding posters: Jason Marshall (Carnegie Mellon), Yu Zhao (University of Nebraska-Lincoln), Sofie Leon (University of Illinois), Mostafa Jamshidian (National University of Singapore), and Praveen Nakshatrala (University of Illinois).

Minisymposia

Of the 63 minisymposia, three were organized to honor the contributions of individuals in various fields of

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USACM Awards

USACM presented the following awards at the congress

John von Neumann Medal – Mark Shephard, RPI
For pioneering research on technologies for reliable simulation automation and parallel adaptive methods

Computational Structural Mechanics – Noboru Kikuchi, University of Michigan
For seminal contributions to the field of topology optimization in computational structural design

Computational Fluid Dynamics Award – Roland Glowinski, University of Houston
For outstanding contributions to establish computational mathematics for variational inequalities, extended domain methods, and others that enhanced computational fluid dynamics worldwide

Computational and Applied Sciences Award – K.C. Park, University of Colorado at Boulder
For inventing staggered time-integration procedures, and subsequently generalizing to it partitioned methods for a wide class of multiphysics application in computational mechanics

Gallagher Young Investigator Award – Yuri Bazilevs, University of California, San Diego
For contributions to isogeometric analysis and strong coupling algorithms in fluid-structure interaction, with applications to wind turbines and cardio-vascular flow.

computational mechanics. These were Dr. George Raithby (computational radiative and convective heat transfer), Dr. Gordon Johnson (computational mechanics for defense applications) and Dr. Noboru Kikuchi (homogenization and topology optimization for CAE). Topics of the other minisymposia included development of numerical methods (general developments and solids and fluids), adaptive techniques and modeling errors, multiscale applications, coupled problems (multiphysics), materials, damage, fracture, and failure, solid mechanics, structural mechanics and geomechanics, fluids, contact, fluid-structure interaction, interfaces, optimization, inverse problems, probabilistic approaches, and biomedical applications.

Shortcourses

Five pre-congress shortcourses were held in the areas of Quadrilateral and Hexahedral Mesh Generation: Theory and Application, Atomistic Simulations Using Standardized Interatomic Potentials, Uncertainty Quantification in Mechanics: Theoretical and Computational Aspects, Goal-Oriented Methods: Error Estimation, Adaptive Algorithms, Multiscale Modeling, and Discontinuous Petrov-Galerkin (DPG) Method with Optimal Test Functions.

Photos of the congress may be found by going to the USNCCM11 website: **usnccm.org**. ●

Figure 3:
Dr. George Raithby presented with plaque

Figure 4:
USNCCM11 Poster Award Winners:
Y. Zhao, J. Marshall, S. Leon, and M. Jamshidian

USACM Conferences

The first USACM Thematic Conference on **Multiscale Methods and Validation in Medicine and Biology 1: Biomechanics and Mechanobiology** will be held in *San Francisco, California, February 13-14, 2012*. Over 90 abstracts have been submitted for presentation during the two-day workshop in the following seven areas:

1 Mechanobiology at the molecular, cellular, tissue and organ levels,
2 Multiscale mechanics of biological macromolecules in health and disease
3 Multiscale biofluid mechanics and mass transport,
4 Multiscale mechanics of biological membranes, films and filaments
5 Multiscale mechanics of adhesion
6 Biomolecular motors and force generation
7 Mechanics of bionanoporous materials

Information about the workshop may be found at **http://mmvmb.usacm.org**.

First **SIAM/ASA/USACM Conference on Uncertainty Quantification**, *Raleigh-Durham April 2-4, 2012*. Uncertainty quantification is key for achieving validated predictive computations in a wide range of scientific and engineering applications. The field relies on a broad range of mathematics and statistics groundwork, with associated algorithmic and computational development. This conference strives to bring together an interdisciplinary mix of mathematicians, statisticians, scientists, and engineers with an interest in development and implementation of uncertainty quantification methods. The goal of the meeting is to provide a forum for the sharing of ideas, and to enhance communication among this diverse group of technical experts, thereby contributing to future advances in the field.
More details at **http://www.siam.org/meetings/uq12/index.php**.

12th U.S. National Congress on Computational Mechanics, *July 23-25, 2013, Raleigh, North Carolina*
Further information may be found on the website: **12.usnccm.org**

SEMNI Awards
- 2011 -

The Spanish Society of Numerical Methods in Engineering (SEMNI) established in its 1999 conference its prizes. The Juan C. Simó prize for young researchers is awarded annually to outstanding researchers under the age of 35. This year, Dr. Estefanía Peña, from the University of Zaragoza, has been awarded for her short, but outstanding, career in the field of numerical methods and constitutive modelling in biomechanics.

Figure 1: *Prof. Xavier Oliver (center), SEMNI president, with the J. C. Simó prize recipients, Dr. Santiago Badía (2010 prize, left) and Dr. Estefanía Peña (2011 prize, right)*

Dr. Peña did her Ph.D. thesis under the advice of Profs. Manuel Doblaré and Begoña Calvo on numerical methods for the Biomechanical Study of the Healthy, Injured and Reconstructed Human Knee Joint. Since then, she has been a visiting researcher in the University of Grenoble under the advice of Prof. Ohayon and the University of Southampton under the advice of Prof. M. Taylor. Previously, Dr. Peña had been awarded as the 2002 Young Researcher Award of the Spanish Society of Biomedical Engineering and the 2003 Orbimed Research Award of the Spanish Society of the Knee. She was also elected as the 2004 SEMNI Award for The Best Ph.D Thesis on Computational Methods In Applied Sciences and Engineering.

Her prize, together with the 2010 Juan C. Simó prize, awarded to Dr. Santiago Badía (see previous report from SEMNI in expressions #27), were given to their recipients by the SEMNI president in the ceremony held during the gala dinner of the CMNE 2011 Spanish-Portuguese joint conference on Numerical Methods in Engineering in Coimbra (Portugal) last June.

On the other hand, the annual prize for the best Ph.D dissertation in the field of numerical methods in engineering has been awarded ex aequo to Dr. Mónica de Mier (Universitat Politècnica de Catalunya), for her thesis on Numerical Simulation Of Multi-Fluid Flows with the Particle Finite Element Method, advised by Profs. S. Idelsohn and E. Oñate, and to Dr. Lindaura M. Steffens (Universitat Politècnica de Catalunya) for her thesis on Assesment of the Dispersion Error and Goal-Oriented Adaptivity for Wave Problems, whose advisors were Profs. P. Díez and A. Huerta.

Figure 2: *From left to right: Dr. Mónica de Mier, Dr. Xesús Nogueira (2010 thesis awardee), Prof. Xavier Oliver (president of SEMNI) and Dr. Lindaura M. Steffens*

In addition, SEMNI awards every two years the SEMNI prize to an outstanding researcher with a close relationship with the Spanish community of numerical methods. The 2011 prize has been awarded to Prof. Miguel (Michael) Ortiz, from Caltech, in recognition for his scientific and professional achievements.

Very well known in our community, Prof. Ortiz received a BS degree in Civil Engineering from the Technical University of Madrid, Spain, and MS and Ph.D. degrees in Civil Engineering from the University of California at Berkeley.

From 1984-1995 he held a faculty position in the Division of Engineering of Brown University, where he carried out research activities in the fields of

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mechanics of materials and computational solid mechanics. He is currently the Dotty and Dick Hayman Professor of Aeronautics and Mechanical Engineering at the California Institute of Technology, where he has been in the faculty since 1995, and currently serves as the director of Caltech's DoE/PSAAP Center on High-Energy Density Dynamics of Materials. He is a Fellow and an elected member-at large of the US Association for Computational Mechanics, and an elected Fellow of the American Academy of Arts & Sciences.

Among other international distinctions and awards, Prof. Ortiz is the recipient of the Alexander von Humboldt Research Award for Senior U.S. Scientists, the IACM International Computational Mechanics Awards for Research, the USACM Computational Structural Mechanics Award, the ISI Highly Cited Researcher Award, the inaugural IUTAM Rodney Hill Prize and the Hans Fischer Senior Fellowship of the Institute of Advanced Studies of the Technical University of Munich. Prof. Ortiz has distinguished himself by his sustained involvement in the Spanish community of numerical methods, from which he once emerged. ●

Figure 3:
Prof. M. Ortiz receiving the 2011 SEMNI award from its president, Prof. Xavier Oliver

EXECUTIVE COUNCIL

SEMNI has renewed its executive council

The Spanish Society for Numerical Methods in Engineering has renewed its executive council in the last year. The council is formed by the following members, after the elections:

Xavier Oliver (*Universitat Politècnica de Catalunya*, president), **José M. Goicolea** (*Universidad Politécnica de Madrid*, vice-president), **Irene Arias** (*Universitat Politècnica de Catalunya*, Secretary-General), **Eugenio Oñate** (*Universitat Politècnica de Catalunya*) and **Manuel Casteleiro** (*Universidad de La Coruña*) as former presidents and **Pilar Ariza** (*Universidad de Sevilla*), **Jesús María Blanco** (*Universidad del Pais Vasco*), **Miguel Cervera** (*Universitat Politècnica de Catalunya*), **Ignasi Colominas** (*Universidad de la Coruña*), **Elías Cueto** (*Universidad de Zaragoza*), **Antonio Huerta** (*Universitat Politècnica de Catalunya*), **Fermín Navarrina** (*Universidad de la Coruña*), **José Luis Pérez Aparicio** (*Universidad Politécnica de Valencia*), **Antonio Rodríguez Ferran** (*Universitat Politècnica de Catalunya*) and **Riccardo Rossi** (*Universitat Politècnica de Catalunya*).

ENIEF 2011

XIX Congress on Numerical Methods and their Applications

1 - 4 November 2011
Rosario, Argentina

for all inclusions under
AMCA
please contact:

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http://amcaonline.org.ar

The nineteenth edition of the *Congress on Numerical Methods and their Applications* of the *Argentine Association of Computational Mechanics (AMCA)* was held from November 1st to November 4th, 2011 in Rosario, Argentina. The congress was organized by the Faculty of Exact Sciences, Engineering and Surveying, of the National University of Rosario.

The organizing committee was integrated by: Oscar Möller (chairman), Javier Signorelli (chairman of Scientific Committee), Rita Abalone, Juan Pablo Ascheri, María Delia Crespo, Analía Gastón, Mabel Medina and Cristina Sanziel.

Figure 1:
Organizing Committee of ENIEF 2011

Plenary lectures invited for this congress were:
Gustavo Buscaglia (Univ. Sao Paulo, Brazil),
Ricardo Foschi (Civil Engineering, UBC, Canada),
Carlos Tomé (Los Alamos National Lab., USA),
Rainald Löhner (George Mason University, USA),
Ives Du Terrail (SIMAP; France) and Roland Loge (Centre de Mise en Forme des Matériaux, France),.

270 papers had been presented in 25 sessions of different areas of computational mechanics.

A special session was devoted to posters by undergaduate students, with awards for the best posters.

Figure 2:
Lecture of G. Buscaglia

Full length papers were submitted to a review process prior to publication. From them, 233 papers had been accepted and included in the XXX Volume of the AMCA Series “Mecánica Computacional”, edited by Oscar Möller, Javier Signorelli and Mario Storti. The papers at “Mecánica Computacional” are publicly available at the website: http://www.cimec.org.ar/ojs/inex.php/mc/issue/archive .

In a climate of friendship the members of the Computational Mechanics community presented the developments, results and conclusions found in the last year, exchanging opinions and suggestions with colleagues, thereby enhancing the work done, and creating new linkages between groups working on similar subjects.

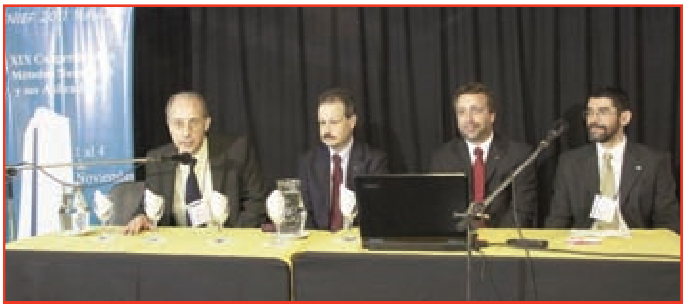

Figure 3:
Opening ceremony ENIEF 2011

The congress received support from the Secretary of Science, Technology and Innovation of the Government of the Santa Fe province; from the Municipality of Rosario; from the Faculty of Exact Sciences, Engineering and Surveying, of the National University of Rosario, from National Agency of Scientific and

Technological Promotion (ANPCyT); from National Council for Scientific and Technological Research (CONICET); from the Professional Association of Civil Engineering of Santa Fe, District II; and from KB Engineering.

The scientific activity was accompanied by some social events, like the cocktail reception and the Congress Banquet, which serve to share a nice time with friends. ●

Figure 4:
Participants ENIEF 2011

Call for Papers

MECOM 2012

X Argentine Congress on Computational Mechanics

Homage to Prof. Sergio Idelsohn in his 65th anniversary.

13 – 16 November 2012, Salta, Argentina

The Argentine Association for Computational Mechanics (AMCA) announces the X Argentine Congress on Computational Mechanics (MECOM 2012).

The congress is of interest for engineers, mathematicians, physicists, researchers, and other professionals who develop numerical methods or use them as part of their professional practice. Among the main topics to be covered in this congress:Fluid Mechanics, Solid Mechanics,Constitutive Modelling of Materials, Structural Dynamics, Stability and Non Linear Structures, Heat and Mass Transfer, High Performance Computation, Control and Optimization, Inverse Problems and Applications, Bioengineering, Aero spatial Technology, Computational Geometry.

Organized by the Faculty of Engineering of the National University of Salta, this congress will give a frame to honour Prof. Sergio Idelsohn, in the year of his 65th birthday.

Together with this congress, the Second Meeting of the *Red de Aulas CIMNE*, in bioengineering, will take place.

Deadline for abstract submissions: 15 May 2011

The congress will take place in the beautiful city of Salta, in the north-western Argentine, is characterized by its neo-colonial architecture, their natural beautiful landscapes, as well as for his history and folklore. ●

E-mail: mecom2012@unsa.edu.ar
Web: www.unsa.edu.ar/mecom2012

Figure 1:
MECOM 2012 will be a Conference celebrating the 65th birthday of Prof. Sergio Idelsohn

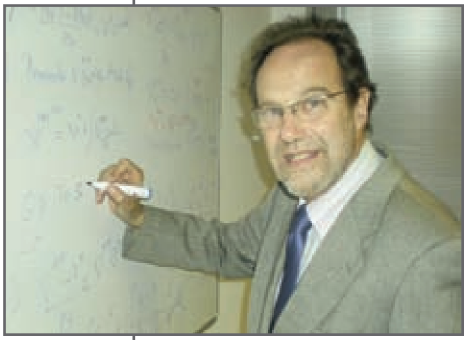

Figure 2:
Salta, venue of MECOM 2012

news

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3rd ECCOMAS Thematic Conference on the Mechanical Response of Composites

Composite materials are used in various structural applications in a broad range of engineering disciplines, such as aerospace, automotive, wind energy, marine, mechanical, and civil engineering. The capability to accurately and efficiently predict the complex mechanical behavior of composite materials and structures is required in order to fully exploit the potential of using composites in order to achieve efficient structural designs.

At the **3rd ECCOMAS Thematic Conference on the Mechanical Response of Composites**, held from **21 to 23 September 2011** in **Hannover**, recent developments in describing the mechanical behavior of composite materials and structures have been presented. The Public Forum of the EU large-scale integrating project MAAXIMUS (More Affordable Aircraft through eXtended, Integrated and Mature nUmerical Sizing) was part of the conference.

The conference was attended by 119 participants from academia and industry, from various countries. Keynote speakers were Prof. Olivier Allix (École Normale Supérieure de Cachan, France), Dr. Mark Hilburger (NASA Langley Research Center, United States), and Prof. Anthony Waas (University of Michigan, United States). The conference was organized by the Institute of Structural Analysis, Leibniz Universität Hannover, in collaboration with the Graduate School on Multiscale Methods for Interface Coupling (MUSIC) at Leibniz Universität Hannover, the German Aerospace Center DLR, and REpower Systems SE. ●

Figure 1:
Prof. Rolfes, chairman of the conference

Figure 2:
Delegates at the 3rd ECCOMAS Conference

ICCCM 11 Conference on Computational Contact Mechanics

The 2nd International Conference on Computational Contact Mechanics (ICCCM 11) was held in **Germany** at **Leibniz Universität Hannover**, Germany **June 15-17, 2011**.

Figure 1:
Delegates at ICCCM

The conference under the auspices of the European Community on Computational Methods in Applied Sciences (ECCOMAS) was attended by over 90 participants coming from 27 countries and provided a wide forum for researchers, PhD-students and practitioners interested in the field of interface and contact mechanics.

The conference had no parallel session since all presentations fit in series in one lecture room (including 5 keynote lectures). Chairmen of the ICCCM11 were Prof. Dr.-Ing. P. Wriggers (Leibniz Universität Hannover) and Prof. Dr.-Ing. G. Zavarise (University of Salento).

Aachen Conference on Computational Engineering (AC.CES) 2011

at RWTH Aachen University

The Graduate School Aachen Institute for Advanced Study in Computational Engineering Science (AICES) organized the **AC.CES 2011** conference held in **Aachen**, **Germany**, on **July 13-15, 2011**. Focusing on "Inverse Problems: Methods and Applications," the conference featured seventeen internationally renowned invited speakers from half a dozen countries including USA, France and Germany. They presented lectures on methodological developments in a wide range of topics covering model order reduction and optimization, materials design, and applications as diverse as seismology or polymer manufacturing. The objective of the conference was both to present cutting-edge research as well as to facilitate and initiate interdisciplinary collaborations.

Two accompanying events helped to enhance the interdisciplinary nature of the conference. A panel discussion led by Prof. W. Dahmen of RWTH and Prof. O. Ghattas of UT Austin focused on future trends in computational engineering sciences and related issues like third-party funding, as well as necessary structural changes at scientific institutions. A poster session featured nearly fifty posters from attendees; the winners of the best poster competition came from Asia, Europe, and North America.

More than 180 international participants attended.
The invited talks were given by L. Biegler (CMU), P. Binev (South Carolina), K.-U. Bletzinger (TU Munich), A. Cohen (Paris 6), R. DeVore (TAMU), C. Floudas (Princeton), O. Ghattas (UT Austin), M. Gunzburger (Florida State), M. Heinkenschloss (Rice), B. Kaltenbacher (Alpen-Adria), R. King (TU Berlin), S. Macchietto (Imperial), A. Patera (MIT), R. Rannacher (Heidelberg), S. Ulbrich (TU Darmstadt), K. Willcox (MIT) and E. Zuazua (BCAM).

Detailed information can be found at:
www.acces11.rwth-aachen.de ●

Figure 1:
The Poster Exhibition

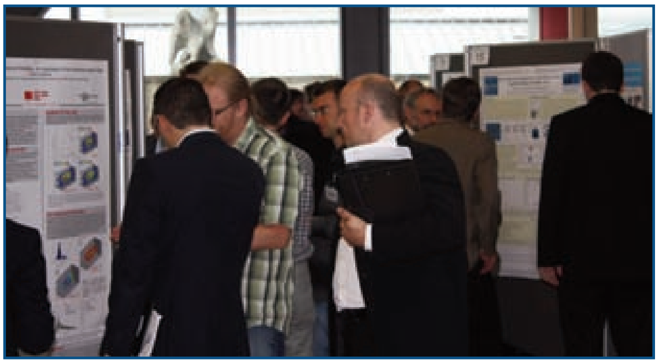


Figure 2:
AC.CES Delegates

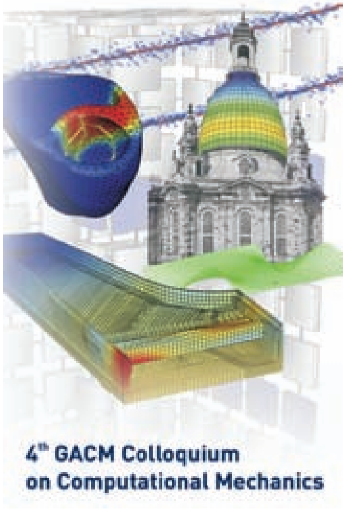
An event with international response

The keynote lectures on different topics reflected on the latest developments in computational contact mechanics applied to various fields of engineering, science and applied mathematics and were presented by T. A. Laursen, Khalifa University, Abu Dhabi, I. Temizer, Bilkent University, Ankara, P. Alart, CNRS, Montpellier, B. Wohlmuth, TU Munich and J. Korelc, University of Ljubljana.

More than half of the participants came from abroad and even from different continents. The participants discussed recent advances and future research directions with their colleagues from all around the world. They also had the chance to participate in an entertaining social and cultural program that included a guided tour through the famous Herrenhäuser Gardens of Hannover. A dinner banquet at the Hanover city hall gave the participants the opportunity to deepen their conversations and to network. Everybody was impressed by the strict format and scientific quality of the conference and enjoyed the social program. ●

Figure 2:
Prof. Laursen giving a keynote lecture

Figure 3:
Prof. Zavarise, chairman of the ICCCM



The **4th GACM Colloquium on Computational Mechanics** took place from **August 31 to September 02, 2011** at the **TU Dresden**. As in the former GACM events the conference was organized by young scientists, these were Uwe Reuter, Jan-Uwe Sickert and Frank Steinigen with support of the chair Prof. M. Kaliske.

The colloquium provides a forum for young scientists both from academia and industry engaged in research on Computational Mechanics and Computer Methods in Applied Sciences, where they may present and discuss results from recent research efforts and non-standard industrial applications. Particular emphasis was given to the exchange of ideas among various fields in Computational Mechanics to support further progress of ongoing research and the initiation of new promising research directions.

The colloquium has attracted 180 participants from eleven European countries. In total, they gave 136 presentations structured in the thirteen minisymposia which were mainly organized by young researchers. For details see **http://gacm2011.bau.tu-dresden.de/Minisymposia.htm**.

Following the tradition of former colloquia, an international and a national notable scientist as well as a reputable researcher from industry were invited to provide a keynote lecture. The international guest, Professor Roger Owen, Swansea University (UK) gave a survey on the development of Finite Elements from the past to future perspectives. Professor Marek Behr, RWTH Aachen (Germany) provided in his keynote lecture “Physiological Modeling in Computational Hemodynamics” inside into the field of fluid mechanics. Thereby, he focused on biomechanical applications. Dr. Michael Gruenewald, EADS Innovation Works Munich (Germany) summarized in his keynote lecture “High speed computing in aerospace industry: opportunities and challenges” the state-of-the-art in relation to the transfer of computational solutions and capabilities from academia to industrial applications.

The GACM decided to donate again 1000 EUR for the Best Poster Award. Due to the high quality of the presented posters, the jury, consisting of the present keynote speakers, the GACM president Professor Peter Wriggers and the colloquium chairman, decided to split the award into a First Price and two Second Prizes. The First Prize was awarded to Kei Müller (Munich) for the poster “Modeling the Cytoskeleton with three-dimensional, nonlinear Beam Elements”. Both, Karl Steeger (Duisburg-Essen) and Christian Windisch (Aachen) received the Second Prize for the Posters on least-squares mixed finite element formulations and numerical studies of laminar supersonic film cooling”.

Again the colloquium was very successful thus the next conference.

It was announced in the closing session that the successive GACM Colloquium will be held from September 30 to October 02, 2013 in Hamburg. ●

Figure 1:
Kei Müller is receiving the first prize of best poster award from GACM president Prof. Wriggers (m) and colloquium chairman Prof. Kaliske (r)

Figure 2:
Prof. Owen presenting the keynote lecture

Figure 3:
Participants of the Colloquium

Figure 4:
Local organizing committee: Frank Steinigen, Jan-Uwe Sickert, Uwe Reuter (from left to right)

APMTAC

Associação Portuguesa de Mecânica Teórica, Aplicada e Computacional

for all inclusions under
APMTAC
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CMNE | 2011

CMNE | 2011was jointly promoted and organised by the Associação Portuguesa de Mecânica Teórica, Aplicada e Computacional/Portuguese Association of Theoretical, Applied and Computational Mechanics (APMTAC) and the Sociedade Española de Métodos Numéricos en Ingeniería/Spanish Society of Numerical Methods in Engineering (SEMNI).

This conference is the outcome of a longstanding collaboration between these bodies which decided in 2000 to organise a two-yearly conference on "numerical methods in engineering", to be held alternately in Spain and Portugal. The first conference was held in Madrid in 2002, followed by Lisbon in 2004, Granada in 2005, Porto in 2007 and Barcelona in 2009. The goal of this scientific event is to foster cooperation between researchers in the field of numerical methods in engineering.

CMNE | 2011 had six plenary sessions and sixty-five parallel sessions (divided into themed sessions), thus making a total of three hundred and eighteen papers, coming from thirteen different countries: Portugal, Spain, Brazil, Colombia, Mexico, United Kingdom, Denmark, Germany, Iran, Poland, Sweden, USA and Uruguay. Among authors and co-authors, around 1050 investigators were involved and more than three hundred people participated in the Congress.

The work to organise CMNE | 2011 started at the end of 2009 and involved the efforts of a huge team. We would like to express our sincere thanks to all our colleagues/collaborators who have contributed to the success of this scientific event. We are also grateful to the Faculty of Sciences and Technology of the University of Coimbra (FCTUC), the Instituto de Investigação e Desenvolvimento Tecnológico em Ciências da Construção/Institute for Research and Technological Development in Construction Sciences (ITeCons), the UT Austin | Portugal programme, Coimbra Municipal Council, the Hewlett-Packard Company and Timberlake for their support.

CMNE | 2011 Steering Committee

APMTAC	SEMNI
António Tadeu (DEC-FCTUC)	Antonio Rodríguez-Ferran (UPC)
Isabel Narra Figueiredo (DM- FCTUC)	Irene Arias (UPC)
Luís Filipe Menezes (DEM-FCTUC)	Jesús M. Blanco (UPV-EHU)

The Japan Society for Computational Enginering and Science

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JSCES
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Kenjiro Terada
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Over eight months have past since the March-11 earthquake of magnitude 9.0, which caused the Higashi Nihon Daishinsai (Great East Japan Disaster). Although many cities stricken by the disaster seem to have been regaining vitality by generous assist from home and abroad, it needs ample time for many coastal areas in East Japan to be restored and reestablished. Engineers and researchers in computational mechanics community in Japan have to support the efforts towards nation-building in a more active manner. Since the JSCES will also assume a more active role in the community for that common purpose, the understanding and cooperation of the members of IACM are really appreciated.

The JSCES will hold several events within several months. Above all, International Seminar for Nonlinear Computational Solid Mechanics "Advances in Multiscale Modeling and Analyses" will be held on December 6, 2011, in Tokyo, in which Professor Peter Wriggers, who is the winner of the JSCES Grand Prize this year, will provide a special lecture. The report on this forum will be delivered in the next issue. Instead, the recent accomplishment on JSCES's standardization for numerical simulations is reported in this occasion. ●

by
K. Terada

Publication of JSCES Standards

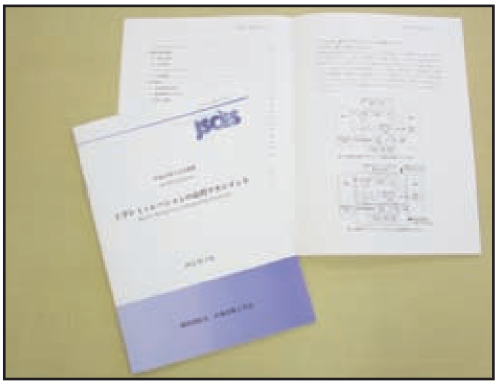


Figure 1:
JSCES S-HQC001:2011 Quality management of Engineering simulation

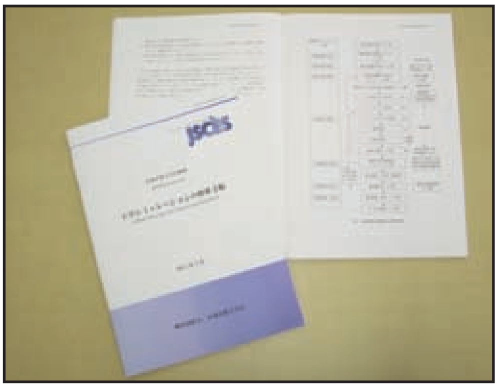


Figure 2:
JSCES S-HQC002:2011 A model procedure for engineering simulation

Figure 3:
Prof. Masaki Shiratori, Chairman of HQC Committee

High Quality Computing (HQC) Committee in JSCES began its intensive activities since 2009, and has just published the following two booklets of JSCES Standards.

1) JSCES S-HQC001: 2011 Quality management of engineering simulation
   (ISBN978-4-9905870-0-0)
2) JSCES S-HQC002: 2011 A model procedure for engineering simulation
   (ISBN978-4-9905870-1-7)

Professor Masaki Shiratori (Yokohama National University) chairs this Committee. The steering members are Professor Seiichi Koshizuka (The University of Tokyo), Professor Naoki Takano (Keio University), Dr. Hitoshi Nakamura (ITOCHU Techno-Solutions), Dr. Yuichiro Yoshida (Toshiba Information Systems) and Dr. Akitoshi Hotta (TEPCO Systems). More than 30 members of this HQC Committee are from important Japanese engineering companies including heavy industry (Mitsubishi Heavy Industry, Kawasaki Heavy Industry), automobile companies (Toyota, Nissan, Honda), electronic and electric power companies and related national institute (Toshiba, Hitachi, TEPCO etc.), material manufacturers (Nippon Steel, Yokohama Rubber), many software companies (MSC Software, ANSYS Japan, JSOL, Prometec Software, Fuji Technical Research, Mizuho Information & Research Institute) and so on. Discussion about the documents and/or manuals published by NAFEMS (National Agency for Finite Element Methods and Standards, UK) and ASME V&V (10-2006, 20-2009) and the analysis of current situation in Japanese companies have finally led to the publication of two JSCES Standards.

The Quality Management Standards (JSCES S-HQC001:2011) is based on ISO 9001:2008, with reference to NAFEMS QSS001. *Figure 4* shows the constitution of the total engineering simulation. The table of contents is shown in *Figure 5* for S-HQC001, but note here that it is actually written in Japanese language.

The standard for a model procedure, S-HQC002, is summarized in our original flowchart, which is briefly seen in *Figure 2*. This procedure is designed to be widely utilized in variety of FEA tasks in companies. For instance, the communication between analyst and customer in the case of outside order of FEA is also described. Since typical cases in making a plan and writing a report are shown in annexes, this is not only a standard but also a useful textbook in education both for companies and universities. ●

by
N. Takano
and all the figures were taken by
Y. Yoshida

Figure 4:
Constitution of manuals for engineering simulation by JSCES based on ISO9001

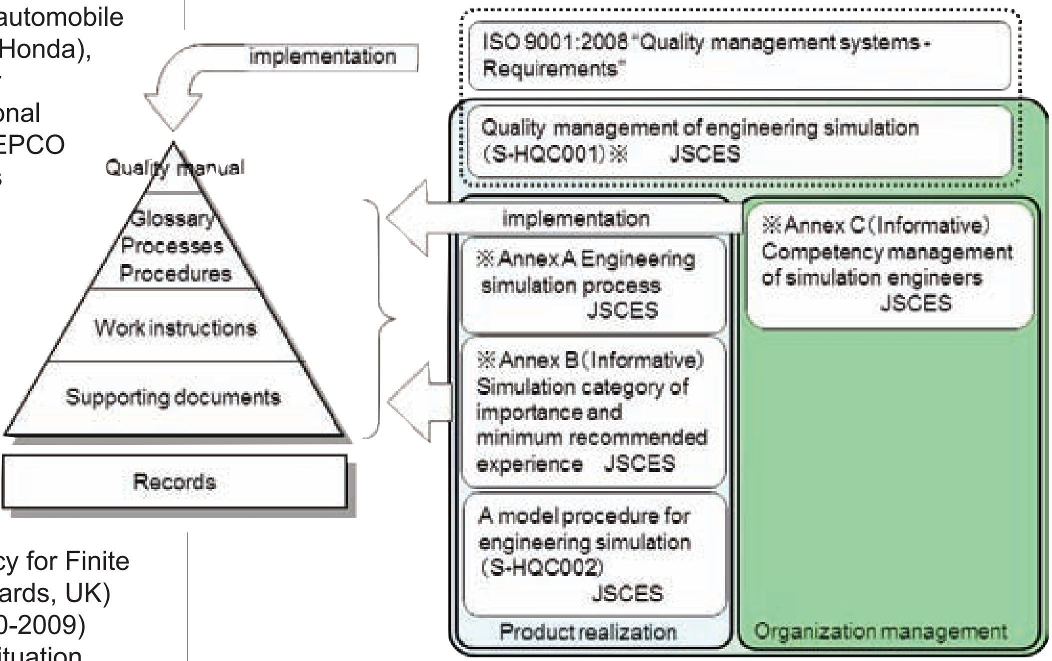
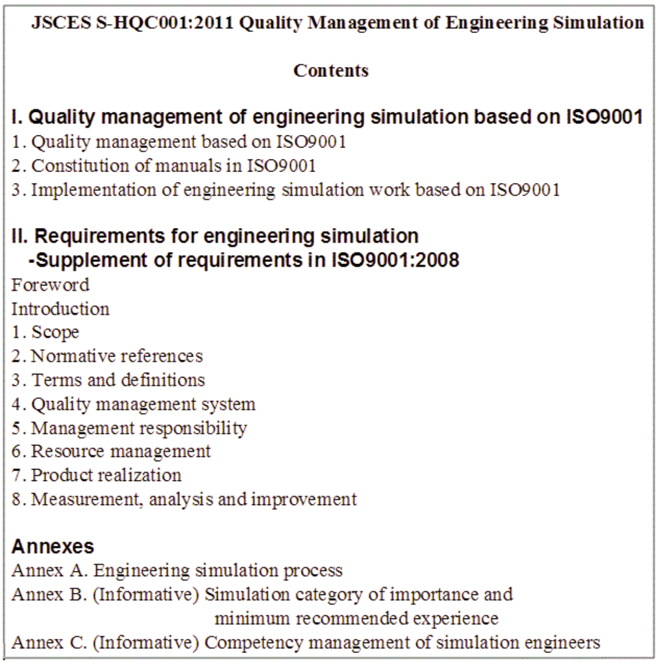


Figure 5:
Contents of JSCES Standards S-HQC001:2011


JSCES S-HQC001:2011 Quality Management of Engineering Simulation

Contents

I. Quality management of engineering simulation based on ISO9001
1. Quality management based on ISO9001
2. Constitution of manuals in ISO9001
3. Implementation of engineering simulation work based on ISO9001

II. Requirements for engineering simulation
-Supplement of requirements in ISO9001:2008
Foreword
Introduction
1. Scope
2. Normative references
3. Terms and definitions
4. Quality management system
5. Management responsibility
6. Resource management
7. Product realization
8. Measurement, analysis and improvement

Annexes
Annex A. Engineering simulation process
Annex B. (Informative) Simulation category of importance and minimum recommended experience
Annex C. (Informative) Competency management of simulation engineers

Figure 6:
Steering members (Prof. S. Koshizuka, Prof. N. Takano, Dr. H. Nakamura, Dr. Y. Yoshida, Dr. A. Hotta)

JAPAN ASSOCIATION FOR COMPUTATIONAL MECHANICS

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On 11th March 2011, Great East Japan Earthquake / Tsunami of 9.0 Mw occurred. 15,824 persons have been dead, 3,846 persons have been missing, and the total of evacuee is still 71,578 persons as of 17th October, 2011. We sincerely express our deep sorrow to those victims. At the same time, we deeply appreciate warm and strong supports to Japan from many countries in the world. We wish to make more efforts to perform R&D on computational mechanics to prevent and mitigate those problems caused due to strong natural hazards.

The JACM is a union of researchers and engineers working in the field of computational mechanics in Japan, and is also an umbrella organization covering almost all computational mechanics related societies in Japan. Currently 23 societies send 31 members to the General Council of JACM. The Computational Mechanics Division of JSME (The Japan Society of Mechanical Engineers), the number of whose division members is 5,400, is the largest CM community in Japan, and a number of JACM members also belong to the JSME-CMD. In October 2011, Professor Gui-Rong Liu of University of Cincinnati, Secretary General of APACM, who received 2010 Computational Mechanics Award of the division, was invited to the 2011 Annual Conference of JSME-CMD held in Okayama city, and gave a special invited lecture on “Computational Methods for Certified Solutions, Adaptive Analysis, Real-time Computation, and Inverse Analysis of Mechanics Problems”. Many JSME-CMD members and JACM members enjoyed his stimulus lecture. (*Figure 1*)

On the occasion of 11th USNCCM held in Minneapolis, USA in July 2011, the JACM meeting was held to discuss the prospects of the association and to present the 2011 JACM Awards. As a part of JACM’s activity, Professor Noriyuki Miyazaki, JACM President, reports that JACM members have organized 2 mini-symposia for 11th USNCCM, and will organize 13 mini-symposia for WCCM 2012 in Sao Paulo, and appreciates their great contribution to the IACM congresses. The 2011 JACM Awards ceremony was then followed. (*Figures 2*) The JACM Awards for Computational Mechanics were presented to Dr. Ryutaro Himeno, Professors Shinobu Yoshimura and Takayuki Aoki. (*Figure 4*)

Figure 1:
Gui-Rong Liu and Noriyuki Miyazaki at 2011 Annual Conference of JSME-CMD in Okayama

Figure 2:
JACM meeting in Minneapolis, USA

Figure 3:
K-Computer

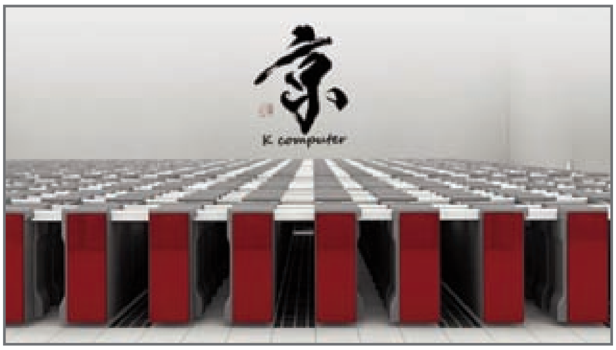

Figure 4:
The JACM Awards for Computational Mechanics :
Ryutaro Himeno (left), Shinobu Yoshimura (central), Takayuki Aoki (right)

The JACM Fellows Awards were presented to Professors Shinji Nishiwaki and Yoji Shibutani. (*Figure 5*) The JACM Awards for Young Investigators in Computational Mechanics were presented to Dr. Tomonori Yamada and Professor Kisaragi Yashiro. (*Figure 6*)

In 2012, JACM will support two international events held in Japan. The first event is "Lectures on Computational Fluid-Structure Interaction" to be held on 5-6 March, 2012 at University of Tokyo, Japan, whose co-chairs are Professors Yoichiro Matsumoto of University of Tokyo, Tayfun Tezduyar of Rice University, Shinobu Yoshimura and Kenji Takizawa of Waseda University, Japan. This workshop has two objectives. The first day of the workshop will be an "FSI Exchange" where the lecturers will focus on computational FSI techniques and will exchange information on what challenges are faced and how the challenges addressed. The second day of the workshop will be short-course style, where the lectures will focus on "FSI Fundamentals". In more detail, please visit the website, **http://save.sys.t.u-tokyo.ac.jp/LecFSI12/**.

The second event is International Computational Mechanics Symposium 2012 to be held in 9-11 October, 2012 in Kobe, which is 25th anniversary event of JSME-CMD. Besides a number of Mini-symposia, it will have invited plenary talks by Professors Jack Dongarra of University of Tennessee, J. S. Chen of UCLA, Roger Ohayon of CNAM and Genki Yagawa of Toyo University. The symposium also includes a technical tour to the world's fastest supercomputer, K-computer. In more detail, please visit the website, **http://www.jsme.or.jp/cmd/Doc/ICMS2012FirstAnnouncement_v2_2.pdf** ●

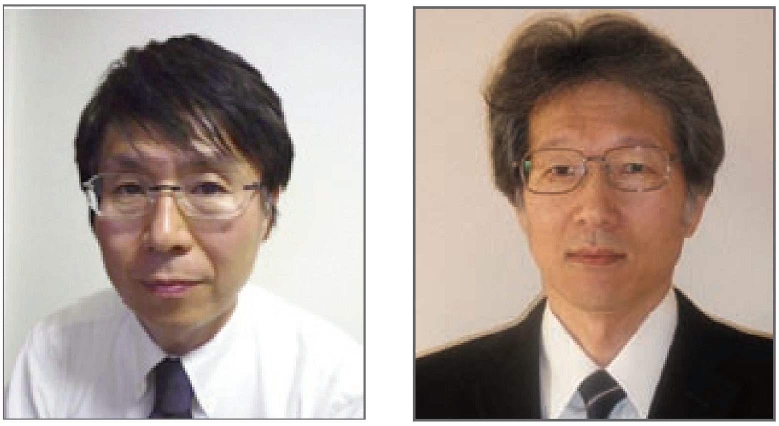

Figure 5:
The JACM Fellows Awards :
Shinji Nishiwaki (left),
Yoji Shibutani (right)

Figure 6:
The JACM Awards for Young Investigators :
Tomonori Yamada (left),
Kisaragi Yashiro (right)

conference diary planner

2 - 6 Jan 2012 **CM Thematic Conference: Biomechanics and Mechanobiology**
Venue: Port of Spain, Trinidd *Contact:* www.pacamxii.org

13 - 14 Feb 2012 **USACM Thematic Conference: Biomechanics and Mechanobiology**
Venue: San Francisco, USA *Contact:* http://mmvmb.usacm.org/

26 Feb - 2 March 2012 **CIMENICS 2012 : XI Congreso Int. de Métodos Numéricos en Ingeniería y Ciencias Aplicadas**
Venue: Isla Margarita, Venezuela *Contact*: www.cimenics.org

2 - 4 May 2012 **7th Int. Conf. on Computational Mechanics for Spatial Structures**
Venue: Sarajevo/Bosnia .*Contact*: http://www.gf.unsa.ba/iass-iacm-2012/

13 - 16 May 2012 **CCGrid-2012 : Int. Symp. on Cluster, Grid and Cloud Computing**
Venue: Ottawa, Canada .*Contact*: http://www.cloudbus.org/ccgrid2012

21 - 25 May 2012 **ParCFD 2012 : Int. Conf. Parallel CFD**
Venue: Atlanta, USA .*Contact*: http://parcfd2012.jsums.edu

29 May - 1 June 2012 **IMSD2012 : 2nd Joint International Conference on Multibody System Dynamics**
Venue: Stuttgart, Germany .*Contact*: http://www.itm.uni-stuttgart.de/imsd2012

10 - 14 June 2012 **CIMTEC 2012 : Smart Materials, Structures and Systems**
Venue: Montecatini terme, Italy .*Contact*: http://www.cimtec-congress.org/2012/

18 - 20 June 2012 **Mechanics of Nano, Micro, Macro Composite Structures**
Venue: Torino, Italy . *Contact*: http://paginas.fe.up.pt/~icnmmcs/welcome.html

20 - 22 June 2012 **OPTI 2012 : Optimum Design of Structures and Materials**
Venue: New Forest, U.K. *Contact*: http://www.wessex.ac.uk/opti2012rem1a.html

24 - 28 June 2012 **ECCM15 - 15th European Conference on Composite Materials**
Venue: Venice, Italy *Contact*: http://www.eccm15.org

25 - 28 June 2012 **BEM/MRM 2012 - Int. Conf. on Boundary Elements & other Mesh Reduction Methods**
Venue: Split, Croatia *Contact*: http://www.wessex.ac.uk/bem2012cfpa.html

1 - 5 July 2012 **EngOpt 2012 : 3rd Int. Conf. on Engineering Optimization**
Venue: Rio de Janiero, Brazil *Contact*: http://www.engopt.org

8 - 13 July 2012 **WCCM 2012 - 10th World Congress on Computational Mechanics**
Venue: Sao Paulo, Brazil *Contact*: http://www.wccm2012.com

9 - 13 July 2012 **ESMC 2012 8th European Solid Mechanics Conference**
Venue: Gratz, Austria *Contact*: www.esmc2012.tugraz.at

17 - 20 July 2012 **VECPAR 2012 : High-Performance Computing for Computational Science**
Venue: Kobe, Japan *Contact*: http://nkl.cc.u-tokyo.ac.jp/VECPAR2012/

4 - 9 Sept 2012 **ECT2012: 8th Int. Conf. on Engineering Computational Technology**
Venue: Dubrovnik, Croatia *Contact*: http://www.civil-comp.com/conf/ect2012.htm

10 - 14 Sept 2012 **ECCOMAS 2012 - 6th European Cong. on Computational Methods in Applied Science & Eng**
Venue: Vienna, Austrai *Contact*: http://eccomas2012.conf.tuwien.ac.at

2 - 5 Oct 2012 **CAIM 2012 : III Congreso Argentino de Ingeniería Mecánica**
Venue: Buenos Aires, Argentina *Contact*: http://www.caim2012.frba.utn.edu.ar/

9 - 11 Oct 2012 **International Computational Mechanics Symposium 2012**
Venue: Kobe, Japan *Contact*: http://www.jsme.or.jp/cmd/

May 2013 **MARINE VI: Marine engineering.**
Venue: *to be confirmjed* *Contact:* *http://congress.cimne.com/marine2013*

17 - 19 June 2013 **COUPLED V: Coupled Problems in Science and Engineering.**
Venue: *Ibiza, Spain.* *Contact:* *http://congress.cimne.com/coupled2013*

3 - 5 September 2013 **COMPLAS XII: Computational Plasticity. Fundamentals and Applications.**
Venue: *Barcelona, Spain.* *Contact:* *http://congress.cimne.com/complas2013*

September 2013 **PARTICLES III: Particle-based Methods. Fundamentals and Applications.**
Venue: *Stuttgart, Germany.* *Contact:* *http://congress.cimne.com/particles2013*

October 2013 **MEMBRANES V: Textile Composites and Inflatable Structures.**
Venue: *Münich, Germany.* *Contact:* *http://congress.cimne.com/membranes2013*