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POSITION PAPER

Meshless finite element analysis: A fallacy or reality?

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In the late 1980s someone in the CAD software arena coined the phrase in the main title. A decade passed by and the appealing idea is still not realized. Is it ever going to be or is there an inherent fallacy in the idea? The following is the author's position on the subject, admittedly biased by a structural engineering background.

The term is usually interpreted as the following: with the advancement in automatic mesh generators the designer does not necessarily need to know about the mesh when using a finite element analysis software for analysis. Specifically, the engineer would:

- not need to understand the finite element method,
- not require the knowledge of the analysis software, and
- be able to work directly on geometry basis.

From an educational point of view, it would simplify the engineering curriculum. It would also minimize the software investment at the engineering teaching laboratories of the schools. The realization of the idea would also increase the range of tasks an entry-level designer would be able to execute.

It is also appealing to the industrial complex for the reason of coinciding with the practical reality of the so-called engineer pyramid. The pyramid consists of a relatively few analysts at the top, significantly more engineers in the middle, and a large number of designers on the bottom. The respective characteristics of these categories of engineers are:

- Analysts: methods oriented, fully understand and able to manually control the solution process;
- Engineers: results oriented, focus on validation of design and correlation of test results; and
- Designers: product design oriented, concentrate on design performance, shape, fit, and function.

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So what is the current position of the automatic meshers? Are they able to fulfill the requirements of the idea? A possible (and likely not complete) taxonomy of automatic meshing may be viewed as:

Automatic meshing	
Mapped	Free
Lofts	Recursive subdivision
Patches	QUADtree/OCtree
Sweeps	Delaunay
Extrusions	Paving/plastering
Hyperpatches	Medial axis method

All industrially available meshers today produce unacceptable and poor quadrilateral and hexahedronal meshes, and create barely acceptable triangular and tetrahedronal meshes.

Even in the latter category, distorted elements, such as slivers and splinters as well as zero volume elements, occur frequently.

Also, from a finite element solution point of view, these triangular elements are inferior to rectangular and hexahedronal elements. With respect to latter elements, they are:

- easier to visualize;
- easier to load;
- more accurate (shear stresses, etc.); and
- more efficient (1 HEXA for 5 TETRAs).

The usually suggested solution to overcome these disadvantages by using higher order (p-version) elements is just not practical. While the p-version method has its place in adaptive analysis environments, the global use to alleviate above difficulties is impractical because of the unreasonably large computer resource requirements. It should be noted that the status of hp mesh optimization is a long way from supporting automated p-element analysis.

So, what is the solution to make the title idea reality? First, the robustness and performance of the truly automatic, noninteractive hexahedronal meshers have to be improved. There

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are two promising methods in the works, the HEXAR method from CRAY Research and the medial axis method. The first one is coming from the fluid dynamics area and being evaluated in structural engineering now. It is generating too large mesh sizes now, in some cases 10 times as many as the tetrahedronal meshers. It seems, however, that it is possible to take advantage of the near uniformity of the interior of these meshes in the iterative solvers currently used in finite element software. The success of this ongoing research may make this method a viable solution.

The second promising method has been demonstrated for surface meshes (for which the medial axis method is designed). The extension of the method to volumes, that is, the calculation of medial surfaces is being heavily researched mainly in Europe.

Second, it is important that the problem of multiple surfaces and volumes be resolved. This issue transcends the actual meshing types, it is common in all methods today. There are some promises in methods of trying to simplify the geometry, such as the so-called rapid surface meshing. This problem seems to be an even bigger obstacle in realizing the meshless analysis than the shortcomings of the specific meshers.

However, all of these problems seem to be solvable and I assume success in the years coming. I do not see a fallacy and in my opinion the title idea may become a reality around the turn of the century.

Louis Komzsik received Bachelor's, Master's and Doctor of Sciences Degrees in engineering and applied mathematics from the Technical University of Budapest, in Hungary. From 1972 to 1980 he has worked for the Hungarian Shipyards and Crane Factory, starting in the position of engineer and numerical analyst, later as director in charge of corporate engineering computing. In 1981–1982 he worked for McDonnel-Douglas as a senior CAD (Computer Aided Design) analyst where he was involved in the development of the UNIGRAPHICS CAD product, still in use in the industry. In January of 1983 he joined The MacNeal-Schwendler Corporation, where he held the positions of Senior Numerical Analyst, Manager of Computational Mathematics Section, Director of Numerical Methods Development and currently is the Chief Numerical Analyst. During the past 25 years working in above capacities in scientific computing, he revolutionized some areas of finite element computations, supervised and conducted research as well as worked on the implementation of various engineering computational methods. He has developed the first shared memory parallel primitives and modules for MSC/NASTRAN in the 1980s, first for CRAY XMP computers. Since then, these methods have been implemented on other shared memory parallel computers. Since the early 1990s he has been involved in the distributed memory parallel work for MSC/NASTRAN. He has researched distributed memory implementation of major computational elements occurring in the finite element area and has led and participated in the programming effort of those methods to the IBM SP. Currently, he is engaged in a project expanding the distributed memory parallel technology into network parallel processing. He is also investigating the applicability of parallel processing to other areas of finite element computations, such as frequency response analysis and data recovery. He is the author of over 35 articles and has contributed to several books. He is a member of SIAM and MAA. He was the keynote speaker at the Australian Supercomputing Conference in Melbourne 1993, and the Supercomputing Europe '94 in the Netherlands. More recently he was the keynote speaker at the Supercomputing in the Automobile Industry in Europe, held in Florence, Italy in June of 1996.