Effective Adaptation Technique for Hexahedral Mesh

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Abstract

This paper describes simple and effective adaptive technique for Finite Element Method. Proposed refinement method is based on modified octree dividing. The modified octree-based method can be applied to an arbitrary hexahedral unstructured mesh. Hex-R which is an implemented application refines a mesh in corporation with finite element viewer: GPPView. Refined mesh keeps original coarse mesh topologically. Therefore the proposed method can be used for multigrid generation easily. Finally capability of adaptive method using Hex-R is mentioned.

Introduction

Adaptive technique is one of the most important issues in order to realize effective FEM analysis task. Many works for adaptive mesh generation and error estimation are conducted. But there is a problem that is very complex implementation of such kind of systems. Especially mesh generation is difficult issue, because there is no guarantee to succeed in a complete mesh generation systems with an arbitrary shape and node distribution.

Adaptive mesh generation is highly required on CFD area. Much work has been progressed for adaptive mesh generation for CFD area, especially aerospace area. Structured mesh or tetrahedral unstructured mesh are well utilized in that area. Structured grid is easily obtained without fail. This is why structured grid is utilized in the area. On the other hand, unstructured hexahedral mesh refinement is very difficult and challenging problem. Hexahedral mesh is still required for mechanical analysis , especially contact and large deformation problems. Essentially hard geometrical restriction to fill in arbitrary domain exists in hexahedral mesh generation. Therefore hexahedral mesh generation is a time consuming process rather than structured and tetrahedral grids. Since mesh regeneration process requires information on object geometry from CAD system or geometrical curved surfaces, the process demands much time and cost in programming and execution of application.

The present study is conducted as a part of the research on parallel finite element platform for solid earth simulation, named GeoFEM [1]. One of the targets of GeoFEM is development of FE code for earthquake generation cycles. In the analysis store and release of stresses at plate boundaries are occurred. In order to obtain more accuracy such kind of analysis requires adaptive or multigrid finite element analysis. Furthermore it is very difficult to regenerate a mesh of plate model because of requirement of hexahedral mesh and complex geometries.

We propose a simple and effective hexahedral mesh refinement method. The method is based on modified octree-based hexahedral mesh generation [2]. The refinement method which is based on local mesh refinement utilizes original mesh connectivity. In other words new fine elements are generated in each element. An original method is proposed for fully automatic hexahedral mesh generation with isomorphism technique [3]. In the paper [3] the octree-based generation is used for filling the interior of the object with arbitrary density. We find out that the octree-based can control density of elements and it is very useful for adaptive and multigrid mesh generation. We present the effectiveness of refinement and how to apply the octree-based method to the arbitrary hexahedral mesh.

General Strategy

Figure 1 shows hexahedral refinement processes using modified octree-based method. Figure 1 (a) shows an initial cubic mesh and Figure 1 (b) and (c) represent instruction of which element to be refined and result of first refinement. Figure 1 (d) and (e) shows second instruction and result. Figure 1 (f) and (g) shows third instruction and result. Figure 1 (h) and (i) shows final instruction and result of mesh refinement. As shown Figure 1 hexahedral mesh refinement can be applied to any elements. To realize reliable refinement, assignment of patterns is very important.

The octree algorithm is a well known to represent geometric shape or features or to optimize and reduce quantities of computational search. The octree structure used here is modified one. One octree structure has 27 sub-octree which is called octant. This 27-tree octant is suitable for hexahedral mesh refinement, because an octant can be easily connected to sub-octants using patterns as shown in Figure 2. P4 is a pattern located in the center of refinement. P3 is a pattern which faces each surface of P4. Six patterns of P3 should be ordinarily generated around one P4. P2 is a pattern which is generated beside P3. Finally P1 is a pattern to be generated beside elements of P2. How to assign each pattern is explained in detail in the next section.

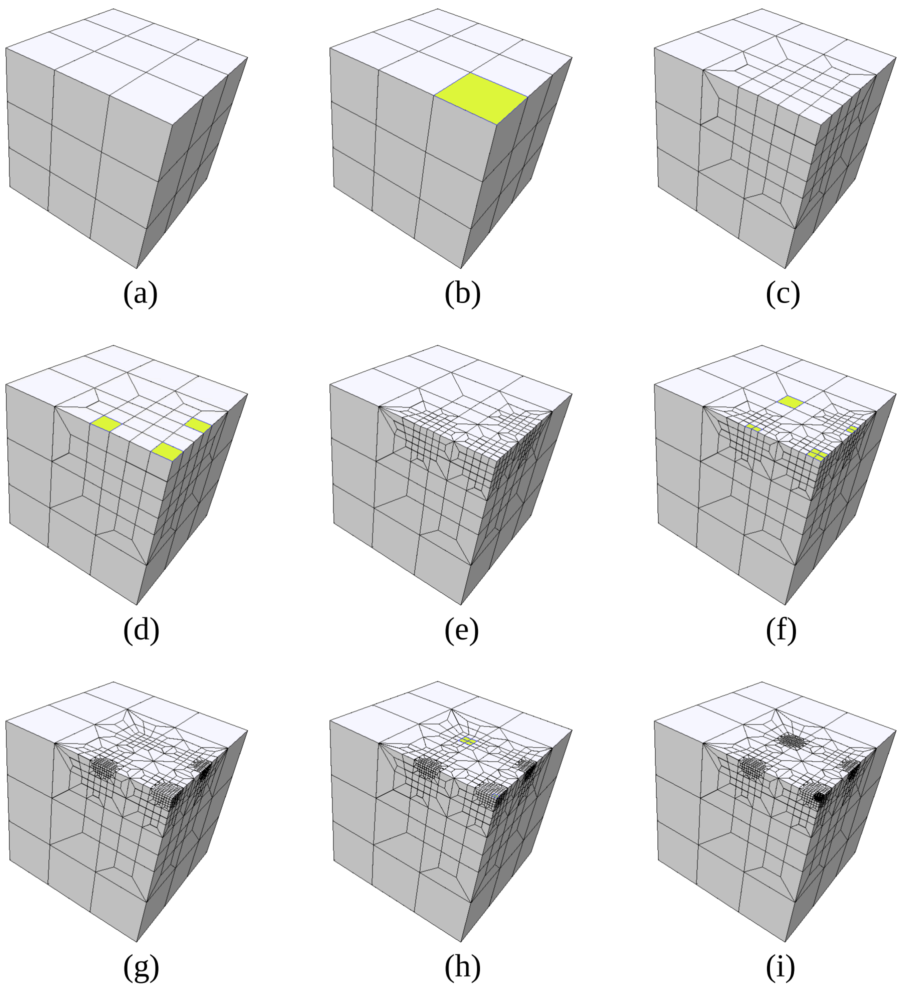


Figure 1. Recursive Mesh Refinement

The modified octree-based refinement has three steps as follows.

- Octree level is assigned to where elements should be refined. Higher octree level means finer mesh to be generated.
- Then the octree structure is examined to apply mesh refinement patterns without fail.
- Finally, refinement patterns are applied to a mesh.

Firstly we will explain the basic algorithm of 2-D in the next section. Then 3-D case of refinement will be described. Essentially the 3-D process is the same as 2-D. Only difference is number of patterns for each case. In case of 2-D number of refinement patterns is 3. In case of 3-D number of refinement patters is 4. The above steps are described in detail in the next section.

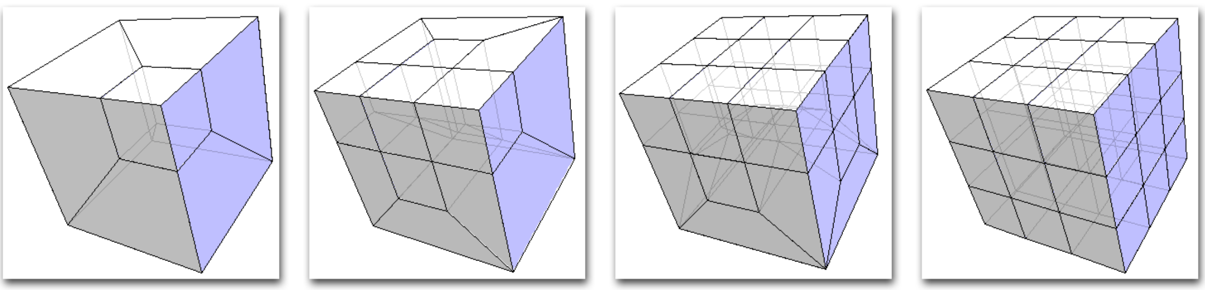
Modified Octree-Based Mesh Refinement

As mentioned previous section, modified octant has 27 sub-octant. This 27-tree octant can be directly applied to arbitrary hexahedral meshes.

Basic 2-D Processing

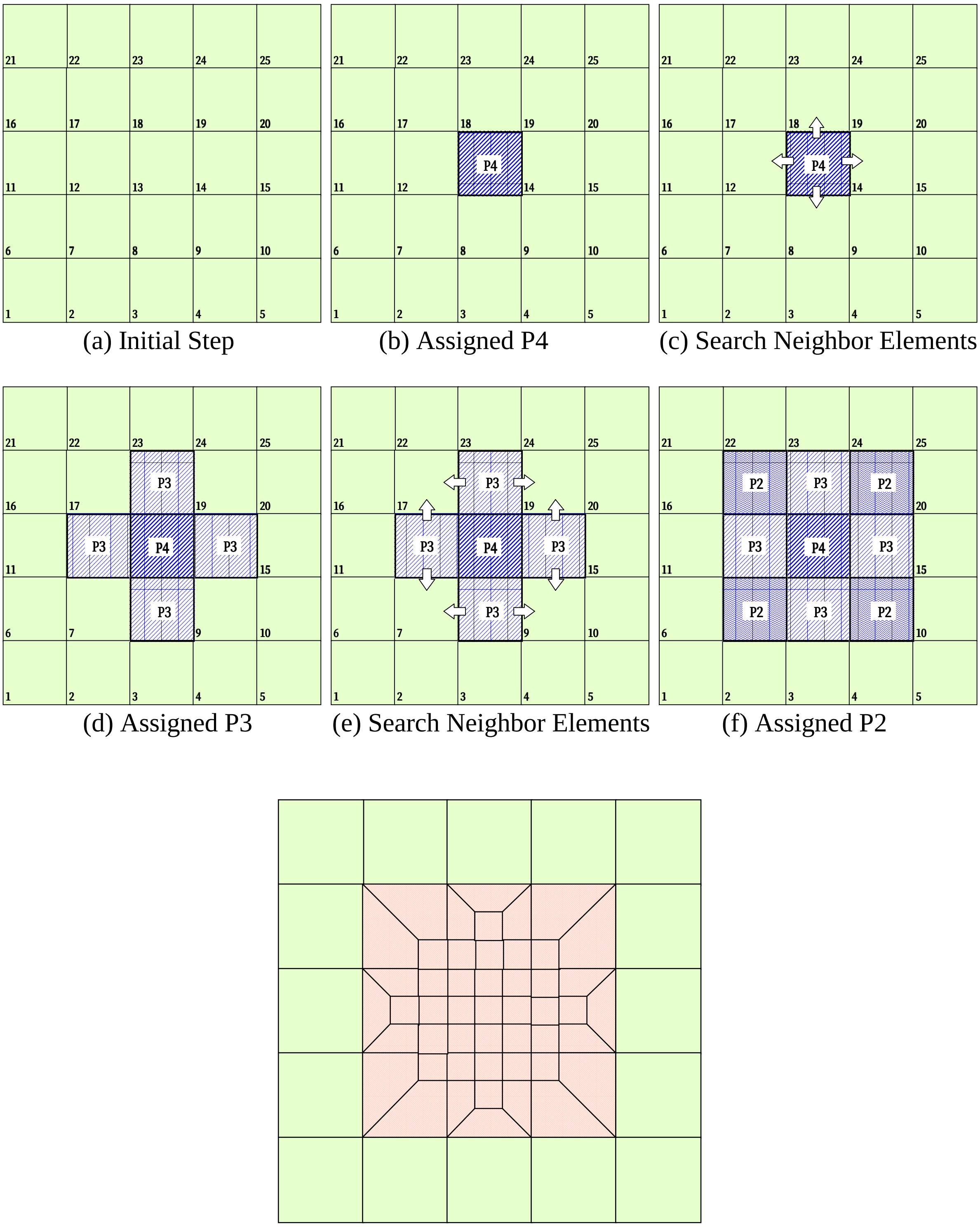
Assuming that an initial mesh is as shown Figure 3 (a). Firstly P4 is assigned at the element numbered as 13 in Figure 3 (b). Then four element numbers are searched around the element. In this case four elements numbered as 12, 14 8 and 18 are selected. Pattern P3 is assigned to these elements. Elements are searched as shown Figure 3 (e). Finally consistent configuration of patterns is obtained. Figure 3 (g) shows result of 1st level refined mesh.

Figure 4 shows an example for refinement of actual mesh is unstructured. Firstly P4 is assigned to 13th element and P3 is assigned to adjacent four elements. Figure 4 (d) illustrates inconsistent configuration. 12th element should be assigned as P2. We pay attention to number of assignments of P2. Figure 4 (e) shows the number of assignments. Usually assignment of P2 is occurred twice in 2-D and 3-D. But 10th and 19th elements are assigned only once. We can detect inconsistent configuration watching counts of assignments. Ordinal number of assignments is also twice in case of 3-D. After detecting inconsistent of P2 assignment, 1 count adds to number of assignments at 9th and 18th element. Then the number becomes 2. Finally P2 is assigned to 12th element from both 10th and 18th element. All of number of assignment of P2 is 2 and we can obtain consistent configuration of pattern. Figure 4 (h) shows result of 1st level refined mesh.



(a) Pattern 1 (b) Pattern 2 (c) Pattern 3 (d) Pattern 4

Figure 2: Refinement Patterns

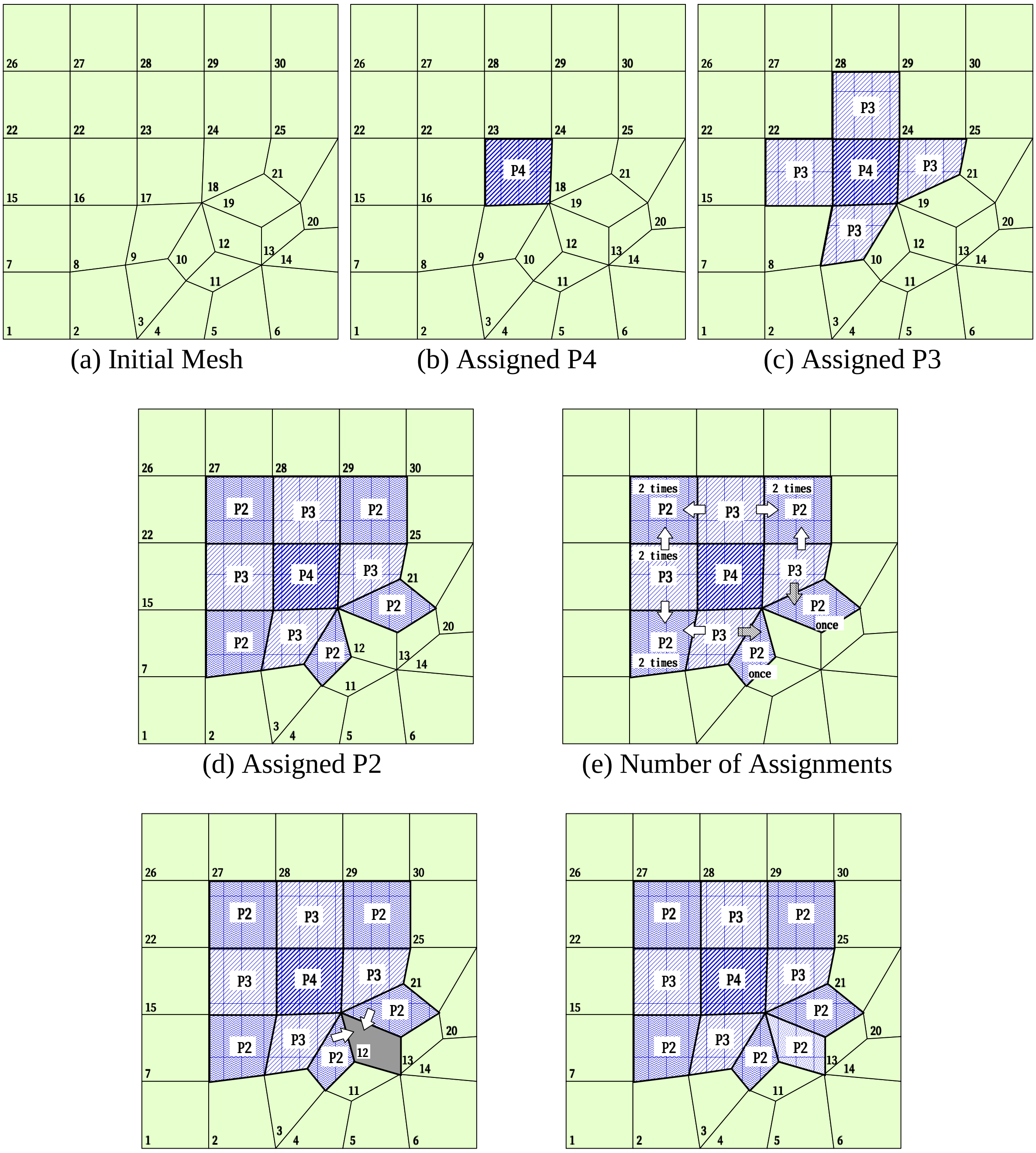


(a) Initial Step (b) Assigned P4 (c) Search Neighbor Elements

(d) Assigned P3 (e) Search Neighbor Elements (f) Assigned P2

(g) Refined Mesh

Figure 3. Basic Pattern Assignment

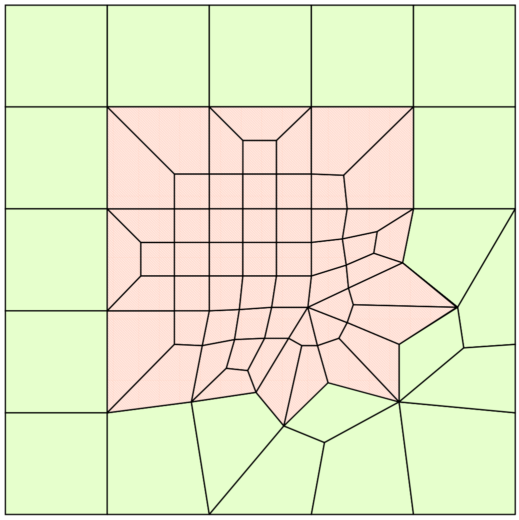


(a) Initial Mesh (b) Assigned P4 (c) Assigned P3

(d) Assigned P2 (e) Number of Assignments

(f) Assigned P2 (g) Final Configuration of Pattern

Figure 4. Actual Pattern Assignment



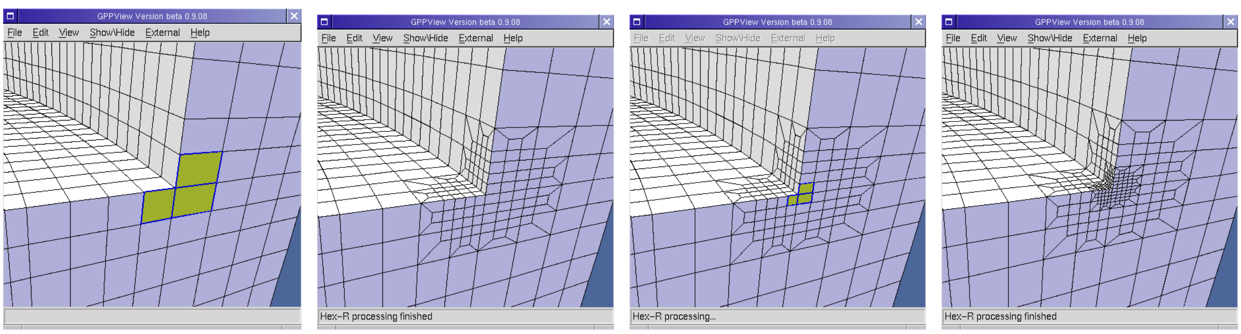
(h) Refined Mesh

Figure 4. Actual Pattern Assignment

Implementation of Modified Octree-Based Refinement

Figure 5 shows an example of recursive refinement using Hex-R [4]. Hex-R is an application of modified octree-based refinement of hexahedral mesh. Hex-R reads numbers of elements to be refined and write a refined mesh out. Figure 5 shows a process of recursive mesh refinement on GPPView [5] which is a finite element viewer being developed in GeoFEM. Firstly elements to be refined are selected in Figure 5(a). The Hex-R generates a refined mesh as shown Figure 1(b). Secondly the elements are selected again in Figure 5(c). The same process is conducted and more refined mesh is obtained as shown in Figure 5(d).

GPPView is a viewer for finite element and can communicate with external applications to process mesh, for instance Hex-R. Because of the function of communication, we can easily extend capability of mesh processing and function of reading any FE formats. GPPView is now released and obtained freely from the web site [5].



(a) Initial Selection (b) First Refinement (c) Second Selection (d) Second Refinement

Figure 5: Recursive Mesh Refinement using Hex-R

Examples

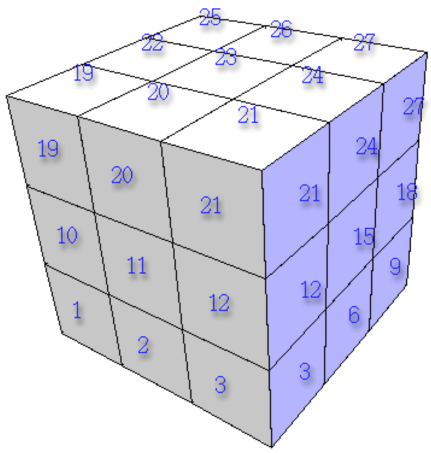
Simple Cube Model

As mentioned in the section of 'Modified Octree-Based Mesh Refinement', 2-D algorithm to make consistent configuration of pattern can be straight extended to 3-D case. One difference is that pattern P1 is necessary for 3-D case. Figure 6 (a) shows initial mesh and element numbers. The mesh consists of 27 cubes.

In first step, P4 is assigned to 14th element which is located at center of the mesh. In second step, P3 is assigned to 6 elements around 14th element. In third step, P2 is assigned to elements beside elements of P3. In final step, P1 is assigned to elements beside elements having P2. This consistent configuration makes refined mesh as shown Figure 7. The refinement process produces 304 new nodes and 323 elements.

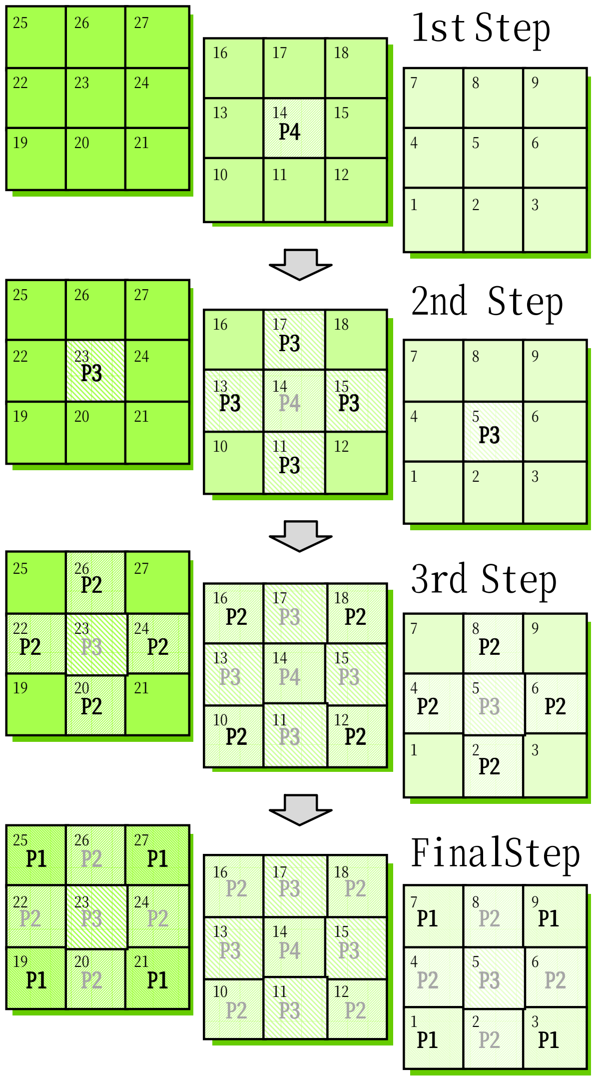
Tube Sheet Model

Figure 8 (a) and (b) illustrate finite element model of structure for nuclear plant. It is called tube sheet and has 55877 nodes and 45624 elements initially. Since heat is repeatedly generated around all of holes, stress is concentrated between holes. In this case inner holes are assigned to be refined as shown Figure 8 (b). Figure 8 (c) and (d) shows refinement mesh of tube sheet model. First level refinement is applied to the mesh, and 170,205 new nodes and 197,904 elements are generated.



(a) Initial Mesh

Figure 6. Pattern Assignment in 3-D



(b) Consistent Configuration of Patterns in 3-D

Figure 6. Pattern Assignment in 3-D

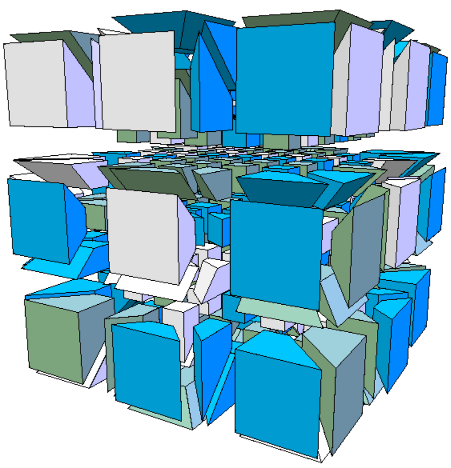
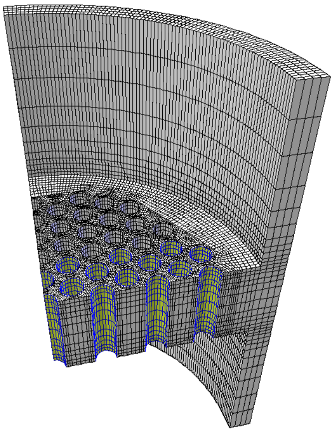
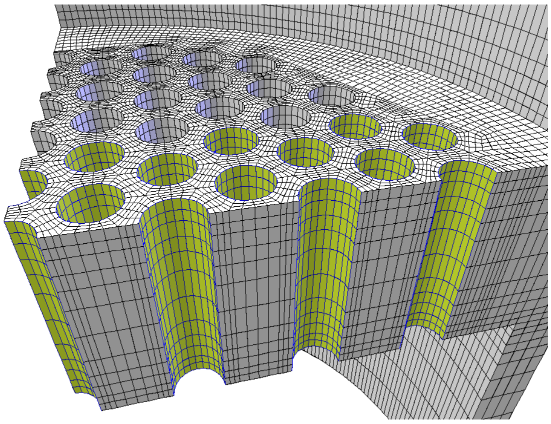


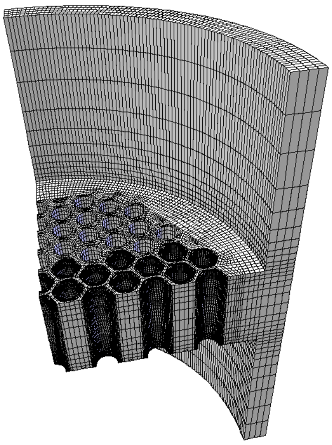
Figure 7. Structure of Refined Mesh



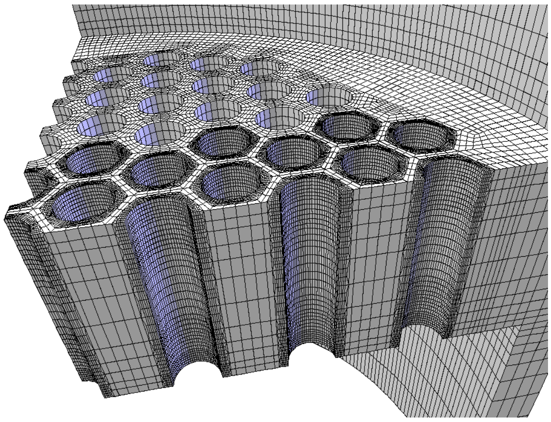
(a) Initial Whole Model



(b) Indication of Refinement



(c) Refined Whole Model



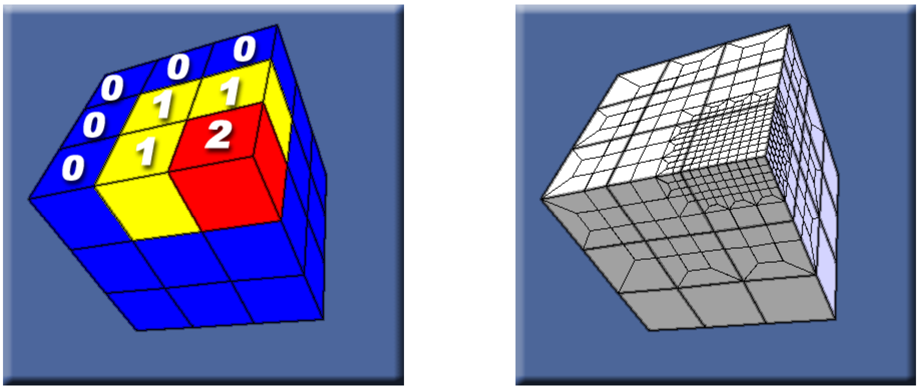
(d) Refined Holes

Figure 8. Refinement of Tube sheet.

Adaptation using Hex-R

Hex-R can easily create an adaptive mesh. Of course there are some limitations. Firstly, the method is not a regeneration method. It is a refining method which means elements will be subdivided into fine elements. In other words resolution of element should be divided into three using the modified octree-based method. Secondly a shape of refining area must be concave. In other words elements not to be desired for refinement would be refined. This causes to increase number of nodes.

On the other hand those limitations reduce complexity and failure of the mesh generation. Figure 9 illustrates simple case of adaptive data and a mesh. Figure 9 (a) shows adaptive information which is how refining a mesh. Figure 9 (b) shows a mesh refined by the adaptive information. In order to generate an adaptive mesh, a result of error estimation or physical values should be converted to information for subdivision of each element as shown in Figure 9 (a). There are three kinds of subdivision information in Figure 9 (a). Blue area denoted by 0 represents not to be subdivided. Yellow area denoted by 1 represents that each element are divided into 27 elements respectively. Red area denoted by 2 represents to be divided into 729 elements. In this way adaptive level information convert to consistent configuration of patterns, and adaptive mesh can be obtained.



(a) Adaptive information on initial mesh (b) Refined Mesh for adaptation

Figure 9: Adaptive Instruction and actual mesh

Conclusion

We propose an effective mesh refinement and adaptive mesh generation method. The method can refine meshes without fail. In further research we will apply the method to the several analyses and investigate relations between increase of nodes and accuracy of FE analysis.

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