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THE STRUCTURE OPTIMIZATION SYSTEM WITH ADAPTING LARGE SCALE FINITE ELEMENT COMPUTATIONS

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Abstract. In the paper the assumptions of the structure optimization system based on the bone surface remodeling are presented. In the presented solution the algorithm of bone remodeling stimulated by mechanical loading is used. Mechanical stimulation is simulated by the large scale Finite Element Method computations. The base for the computation was a Personal Computer cluster. For the decomposition of the computation domain, a domain decomposition tool METIS has been used. Structure adaptation is based on the rebuilding of the tetrahedral finite element mesh. In the paper the 3D mesh generation tool, mesh evolution tool, and parallel FEM environment are described.

Key words: trabecular bone adaptation, large scale finite element computations

1. Introduction

Trabecular bone is able to adapt to the mechanical stimulation. This adaptation tends to optimize the trabecular structure where the mechanical stimulation is one of the most important factors of the normal bone functionality. The models of bone remodeling [1, 2, 3] usually assume the sophisticated material of the bone and overlook the real structure of the trabecular network. The progress in computer hardware technology and parallel computations enable now modeling the bone adaptation process using the real topology of the trabecular structure. Such approach is the most promising because it provides the real geometry of the structure together with the linear elastic material model of the bone tissue.

2. The System Structure

The simulation with Finite Element Method (FEM) of the remodeling process needs both FEM mesh generation (including the mesh evolution) and structural analysis. Figure 1 presents the elements of the computational system needed to mimics trabecular bone adaptation. The system is composed of three main elements: FEM preprocessing, FEM solution, optimization and modification procedures. The presented method enables to mimic the real geometry evolution. The system is thus able to copy the real processes occurring in the trabecular structure.

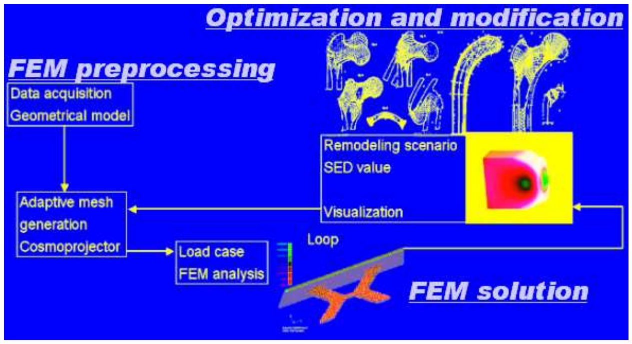

Figure 1. The structure of the system mimics trabecular bone adaptation.

3. Mesh Preparation and Adaptation

The input to the system is based on the collection of the two dimensional images. The two dimensional image is first translated into the bitmap, where '0' represents void and '1' the tissue. The discretized two dimensional image is projected to the following one. If there are the areas containing tissue on both images, the tetrahedral volume elements are created. The user is able to describe the minimal volume of the tetrahedral element. In the presented simulations the strain energy density (SED) distribution, obtained from the FEM computation is used as a remodeling criterion. The adaptation procedure is based on the model described in [1]. The tissue is added on the structure when the SED value reaches the assumed value, and the tissue is removed when the SED value is lower than the another assumed level. The mesh adaptation is based on the modification of the input information. According to the SED distribution the input images are respectively modified, reflecting tissue building or removing. Due to remeshing the simulation can accurately follow the modeled phenomenon protecting also correctness of the FEM model.

4. Large Scale FEM Computation

There are two advantages of the proposed here approach: the detailed modeling of the structure and the linear elastic material model. Both of them allow preparing the exact model of the analyzed structure avoiding the sophisticated formulation of the material properties. But the cost of the approach is the large size of the FEM matrices. The biological objects are very complicated and need many elements to the proper shape modeling. Thus to perform the efficient numerical simulation a parallel Finite Element computations are needed. The solution can be a cluster. Figure 2 shows the Personal Computer cluster - Beowulf developed on Division of Machine Design Methods on Poznań University of Technology. The parallel computations were performed

Figure 2. PC based cluster at Poznań University of Technology.

with use of Message Passing Interface (MPI) – the program MPICH, the Linux implementation of MPI standard. The cluster contains of diskless nodes running under Linux Redhat. For the decomposition of the computation domain a domain decomposition tool METIS was used.

5. Results of Remodeling Simulation

As a example of the large scale computation, on Fig. 3 the remodeling simulation of the trabecular bone sample under compression is depicted. The model contains about 1 million tetrahedral elements and covers about 60mm^3. The adaptation procedure formulation is based on the assumptions described in [4].

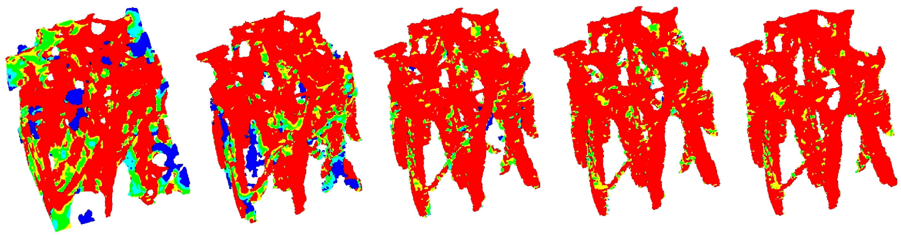

Figure 3. Remodeling simulation - bone sample under compression.

Due to flexibility of the presented configuration it is possible to extend both computational abilities and adaptation assumptions.

6. Conclusions

Presented here approach enable to simulate the evolution of the trabecular bone. The described environment including mesh generation and adaptation tool together with the parallel FEM software can be a base for the complex large scale analysis of the biological objects.

In future work the system will be extended with additional computers. There are many directions of possible code development. One of the most important is the enhancement of the mesh generator including the parallel version of the tool.

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