ETH Eidgenössische Technische Hochschule Zürich
Ecole polytechnique fédérale de Zurich
Politecnico federale di Zurigo
Swiss Federal Institute of Technology Zurich

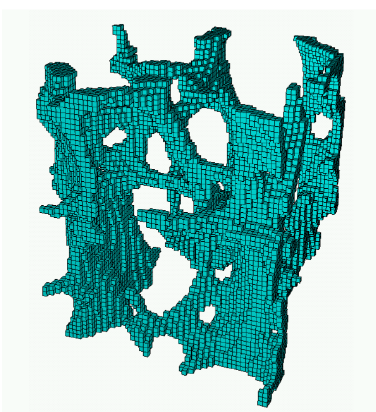
Chair of Computational Science
Prof. Dr. Peter Arbenz

Bone structure analysis with GPGPUs

Proposal for a master thesis

Introduction

The aging of the human population made the number of bone fractures due to osteoporosis increase considerably. In Switzerland, the risk for an osteoporotic fracture in women above 50 years is about 50%, for men the risk is about 20%[1]. Not surprisingly, research concerning osteoporosis plays a prominent role in health science. Often, large scale computer simulations are conducted to improve the understanding of the bone structure and bone strength [1]. These simulations are based on voxel models of the bone that are obtained by high-resolution CT scans. The voxel model constitutes a structure that is investigated for its elastic properties. The structures are composed by millions of tiny cubes (voxels), see the image on the left. Our simulations are based on finite element discretizations for linear or non-linear elasticity and lead to very large linear or non-linear systems of equations with hundreds of millions or even billions of unknowns [1–3, 7, 8].



The typically symmetric positive definite linear systems are solved by the preconditioned conjugate gradient algorithm on large parallel computers [4].

In recent years we have developed a computer program called ParFE that solves these problems very efficiently, in terms of computing time and in terms of memory space [2, 3, 6]. The program combines the conjugate gradient algorithm with a smoothed aggregation-based multilevel preconditioner. More recently, we have developed codes that are similarly fast as ParFE but much memory-efficient [7,8]. One of the approaches, that we called the *full-space approach*, is very well suited for general purpose graphics processing units (GPGPUs) [8]. In the full-space approach the void space between the bone is filled by a very soft material that does not affect (much) the elastic properties of the bone. Linear elasticity is then applied to the filled bone. The computational domain in this appraoch extends to a cuboid that encases the original bone.

Description of the task

In the full-space approach the computational domain is a cuboid. The degrees of freedom are the displacements of the (extendend) bone at the grid points of a regular rectangular grid. This is true for all levels of the hierarchy of the multigrid preconditioner. Since all data are distributed in a regular fashion it is quite straightforward how to implement, e.g., a matrix-vector product on a GPU or on a multi-/many-core machine.

The complete algorithm for bone structure analysis has to be translated into CUDA or OpenCL. The present parallel algorithm is a plain C++ code complemented by MPI for communication. The matrix-vector product is implemented by element-by-element techniques. The prolongation and restriction operators of the multigrid preconditioner are also implemented in a very memory-efficient way.

[1] See http://www.osteoswiss.ch

In a first step, the algorithm shall be adapted to run on a single GPU. In a second step, the algorithm is to be extended to multiple GPUs. The communication among the multiple GPUs has to be implemented by the Message Passing Interface (MPI). The target machine is the Brutus cluster at ETH[2].

Requirements

- Good knowledge in C++.
- Some knowledge of finite elements.
- The attendance of a parallel computing course is very useful.
- Willingness to work in an interdisciplinary environment.

Deliverables

The work is to be documented in a short and concise thesis (LaTeX, PDF). It must be written such that it is intelligible to a fellow-student.

The code should be written as clean as possible. It must be complemented by a short user's guide.

Presentation

At the end of the thesis, the work is to be presented in a talk at a seminar of the Chair of Computational Science. The date of the talk will be determined later.

Contact

- Prof. Dr. Peter Arbenz, arbenz@inf.ethz.ch, Tel: 044 632 7432
- Cyril Flaig, cflaig@inf.ethz.ch, Tel: 044 632 7522

Literatur

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[2] http://en.wikipedia.org/wiki/Brutus_cluster