A Parallel Simulator of Musculo-Skeletal Systems.
Application to the Numerical Analysis of Human Accidents

Thesis Proposal MAP-i 2010/2011

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Research Units

CCTC – Computer Science and Technology Center

CT2M – Centre for Mechanical and Materials Technologies

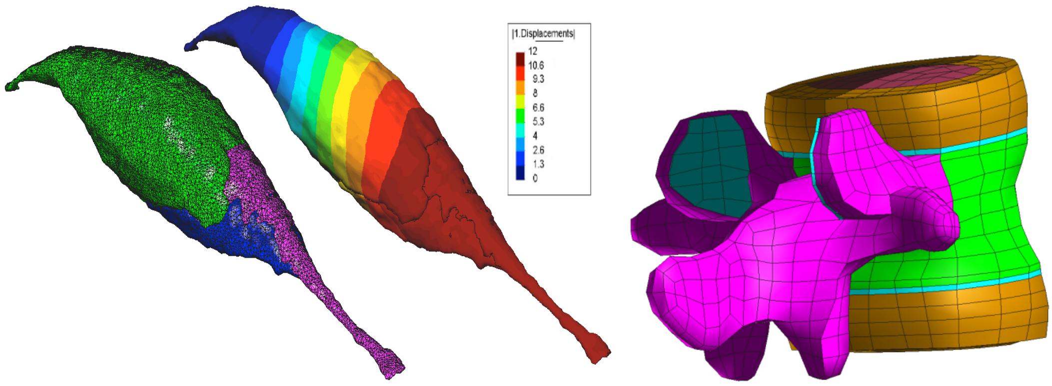
Framework

Bio-engineering and bio-technologies are two areas of science and knowledge that have undergone a strong development in the last decade, being deeply connected with the improvement of our life expectancy and well-being.

The construction of biomechanical models suitable for analysis and prediction of Human motion and Human accidents requires contributions from many fields of engineering. In this setting, several issues are still to be investigated before such models can reach the status of medical applications, which is one of the main targets of the team working at CT2M-UM. Such issues include formulations able to describe the systems with different levels of detail, methodologies for data processing, fast analysis eventually based on optimization algorithms, etc. It is of utmost relevance for the biomechanics analysis that the physiological data used to build models, including anatomical joints, muscles, soft and hard tissues, contact description, merit functions for motion activities, etc., can be validated on a subject-specific level in order to be able to generate realistic results.

V-Biomech is a FE solver that has been developed since 2007 in a collaborative work between CT2M-UM and RIKEN, in Japan. It is mainly devoted to the numerical simulation of musculo-skeletal system. Developed in Fortran 90/95, it comprises around 14k lines and 140 subroutines. Its mechanical formulation comprises the main features of muscle-skeletal structures and biomechanics, namely a hyperviscoelasticity framework, quasi-incompressibility of the continuum media and muscle activation. It can be applied in the numerical simulation of biomechanics, namely as a decision tools for surgery planning, definition of rehabilitation/physiotherapy strategies, project and manufacturing of custom-oriented prostheses and orthoses, as well as, numerical simulation of Human accidents.

However, because bio-structures are generally very complex and bio-tissues are extremely heterogeneous, with a wide range of materials and complex coupling between them, and an accurate geometrical and material modelling requires, either the use of very refined FE meshes, or higher order finite elements (*computationally much more expensive*), it is unavoidable to address the problem of the computational efficiency of V-Biomech.



Objectives

The main goal of this proposal is to develop a high performance parallel scalable version of the V-Biomech FE solver. Its application to the numerical analysis of Human accidents will be pursuit in collaboration with other researchers working on the subject at CT2M.

The main expected tasks and achievements of the present proposal are:

1) A methodological study and evaluation of the current **V-Biomech** sequential code implementation:
    - to be aware of the importance of concurrency, scalability, locality, and modularity;
    - to evaluate scalability, and to identify bottlenecks and other inefficiencies;
    - use profiling and performance models costs to study the efficiency of the different algorithms;
    - to maximize the range of options considered, and try to reduce the cost of backtracking from bad choices.
2) In parallel as in sequential programming, there are many different languages and programming tools, each suitable for different classes of problems and algorithms. As so, we ponder the possibility to evaluate the following alternatives:
    - Fortran vs C versus hybrid programming
    - OpenMP vs MPI vs hybrid parallelization
    - Clustering /SMP/ GPUs vs hybrid architecture

3) The study and development of new parallel versions of the most critical subroutines framed by the algorithm specificities and objectives of V-Biomech; such as hyperelasticity and the adopted total Lagrangian formulation.