A poro-aniso-hyperelastic model coupled with solute transfer model for the in-silico study of Intervertebral Disc degeneration, within an HPC framework

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1. INTRODUCTION

The main objectives of the current work are the design of a poromechanical Finite Element (FE) solver and its coupling with a solute transfer FE solver, within an HPC framework. This new and complex methodology is implemented in a high performance computational mechanics FE code, Alya, which is a multi-physics, parallel and highly scalable code. This endeavour targets the study of the intervertebral disc (IVD) and its degeneration [2]. IVD degeneration is likely dictated by intricate spatio-temporal events that require the aggregation of multi-physics models. The simulation of such models is computationally expensive, hence large-scale computing infrastructures would be mandatory for in-silico cohort simulations.

2. Methods

This complex problem is treated as a coupling of its two individual components, the poromechanical and the solute transport. For the poromechanical simulations, a Modified Neo-Hookean material model is employed [3]. Collagen fibres reinforcement is added in the material model, for which a modified HGO model is used [4].

The porosity of IVD tissues is modelled using Darcy's law [5]. The fluid pressure also includes the contribution of Donnan osmosis [3]. The poromechanical scheme is solved in a two-way coupling setup, as described in Figure 1.

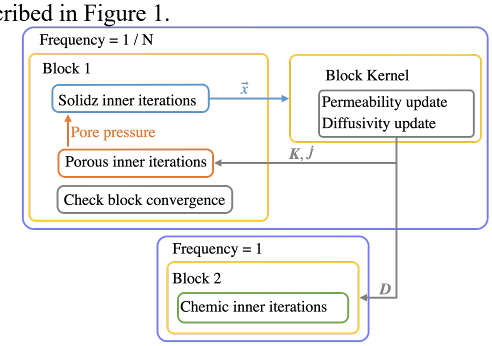

Figure 1: Schematic description of the solution scheme.

Coupled with the poromechanical model, the diffusion of certain solutes is simulated [2]. A one-way coupling between the poro-mechanical and the solute transport solvers is considered.

3. Results

The described scheme can produce results that match previously reported simulations [2,4]. In Figure 2 some performance metrics are given, comparing the runtime of the proposed scheme and existing implementations with user subroutines [2] in commercial software [6]. The performance upgrade is evident, while most of the runtime is devoted to the solution of the numerical problem.

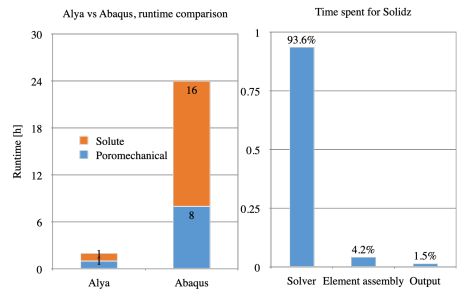

Figure 2: Performance of Alya compared to commercial solutions

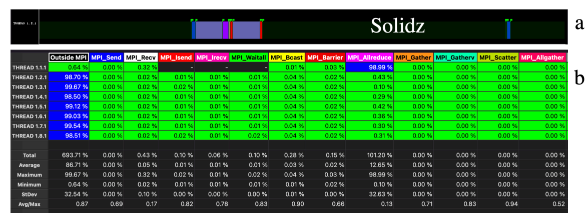

Figure 3: Trace of one simulation step of Alya. Events, timings and MPI calls are presented.

In Figure 3a, a single timestep of the simulated scheme is presented. Solid mechanics simulation takes most of the computational time. In Figure 3b the histogram of MPI calls is presented. The load balance reaches 98%.

4. Discussion and conclusions

The employed model is believed to offer a full description of the IVD and capture a wide spectrum of the mechanics observed in it. The results are pending verification against real life results.

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