Project Title: Population-Scale Biomechanics: Modelling of a Spinal Unit using HPC
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Project Description: **The relevant context of the project, including overarching goals:** The size and shape of the bones in our spine (called vertebrae) play a massive role in how our bodies handle everyday physical stress and how well spinal surgeries work. This is especially true in the lower back, specifically at the joint between the fourth and fifth bones, commonly referred to as the L4 and L5 vertebrae. However, current computational studies largely rely on generic, single-geometry models of an "average" person, neglecting population-level variability. To address this, our research group has developed an automated Python-based workflow that creates a Statistical Shape Model (SSM), based on a dataset of CT scans, to characterise population variation. We have used this to successfully generated finite element (FE) models for these shape variants using simplified linear elastic material properties.

The overarching goal of this internship is to make our spinal simulations much more realistic by focusing on the intervertebral discs, the soft, shock-absorbing cushions that sit between the spinal bones. Working closely with the supervisory team, the intern will iterate on our preliminary material formulations and apply them across an initial set of 52 L4-L5 vertebral body segments that represent a wide variety of human shapes. Each segment will be tested (in FE), under four load conditions: flexion, extension, lateral bending and axial rotation. They will then conduct finite element sensitivity analyses to assess Range of Motion (ROM) and kinematic responses under physiological loads. By the end of the project, the intern will have contributed to a scalable workflow designed for application to large-scale medical imaging databases.

The computational aspects and why HPC compute resources are key to its success: This project is inherently computationally intensive and aligns closely with the Digital Health theme. Shifting from linear elastic to hyperelastic finite element modelling introduces significant mathematical non-linearities (e.g., complex material behaviours and contact mechanics between the vertebral bodies, discs, and facets). Solving these non-linear equations for a single FSU model requires considerable computational power and memory.

When this complexity is scaled across a population dataset of 52 distinct statistical shape models, standard desktop computing becomes entirely unfeasible. High-Performance Computing (HPC) resources are therefore strictly required to solve these large-scale batch simulations in a timely manner.

During the internship, the student will gain hands-on experience in the digital Research Technical Professional (dRTP) domain by:

- Adapting and optimising finite element meshes for HPC environments.
- Writing bash scripts to deploy and manage batch FE simulation jobs on a supercomputing cluster (e.g., Aire, Bede).
- Processing and visualising large, complex output datasets (e.g., multi-axis ROM).
- Collaborating with a named dRTP to ensure best practices in Research Software Engineering and Research Data Management are embedded into the workflow.