Marie Skłodowska-Curie Actions (MSCA)
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SPINe: Numerical and Experimental Repair Strategies
Management Meeting
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A Deep Learning Approach to Biomechanical Simulation of the Lumbar Spine

ESR6: Cameron James

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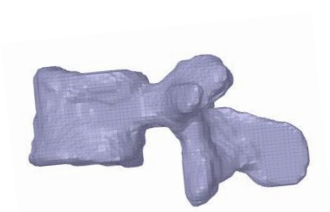
Project Aim

“ To develop real-time biomechanical simulations of spinal surgical setups

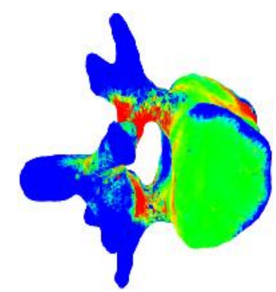
by integrating parsimonious deep learning approaches into the setup and execution of finite element simulations. ”

An ANN-Based Emulator

- Training data is generated by running finite element simulations with slightly different setups (e.g. subject specific spine geometries)
- An artificial neural network (ANN) is trained to predict the simulation results from the setup parameters (e.g. mesh coordinates describes the subject specific geometry)
- The completed ANN can then be exploited to rapidly predict the simulation results for new samples, without the need to setup or run a finite element simulation.



Linear Compression → Low-Dimensional ANN → Linear Decompression



Input: Mesh Shape Description (e.g. Mesh Coordinates)

Output: Simulation Results (e.g. Cauchy Stress Tensors)

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Current Objectives

1) Mesh Morphing for Anatomical Shape Parameterisation

2) Inputs Describing Multiple Classes of Subject-Specific Variations

Future Objectives

1) Apply Methods to a Clinically Relevant Scenario

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Objective 1 : Mesh Morphing for Anatomical Shape Parameterisation

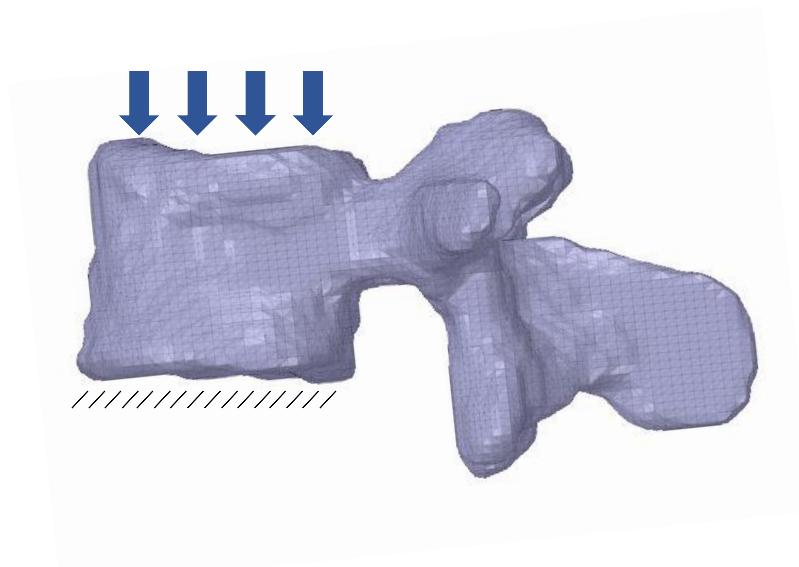
Objective : " By using a mesh morphing approach to parameterise the shape variations in a training set of lumbar vertebra, develop an ANN to substitute the simulation of a lumbar vertebra under a compressive load. "

Dataset (Yao *et al.*, 2012) :

- CT scans with manual segmentations
- 10 spines (50 lumbar vertebrae)
- Fully anonymised and publicly available at:

SpineWeb.DigitalImagingGroup.ca

The Simulation :



Yao, J., Burns, J., Muñoz, H. and Summers, R., (2012). Detection of Vertebral Body Fractures Based on Cortical Shell Unwrapping. *International Conference on Medical Image Computing and Computer Assisted Intervention, 7512, 509-516.*

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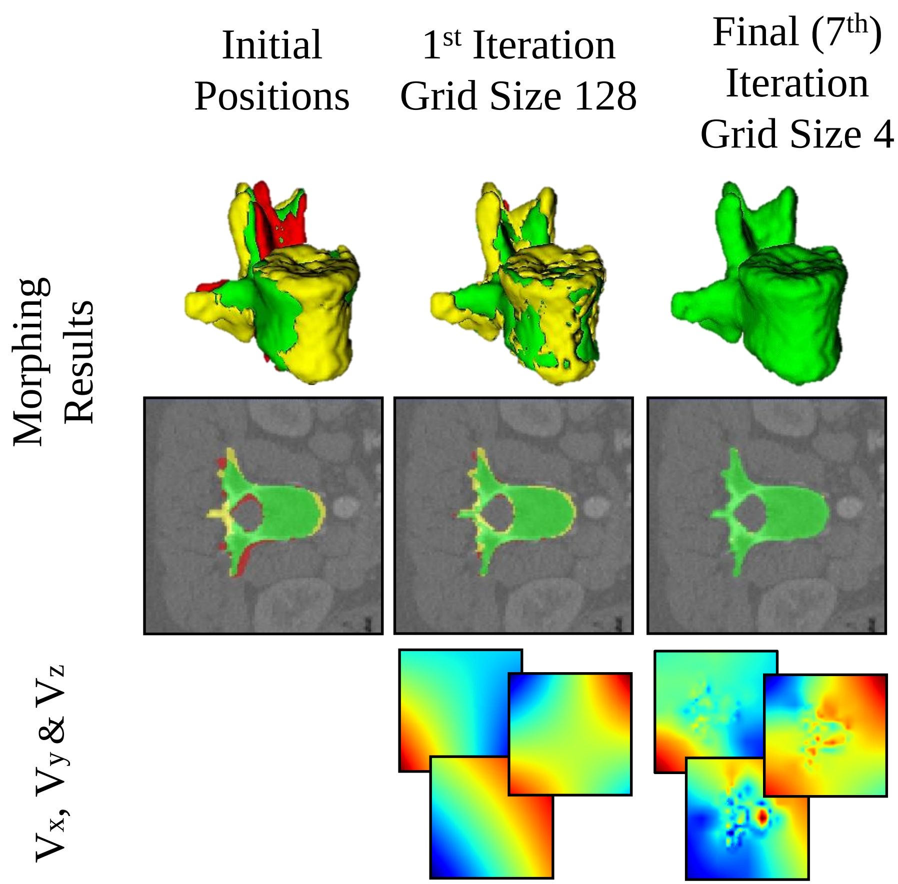
Mesh Morphing



Morphing Results Key :

		Morphed I0	
		True	False
I1	True		
	False		

Metrics

- Dice Similarity Coefficients:
  - 0.999 ± 0.002
- Significance Tests for Variation Modes:
  - Inter-subject vs. Inter-level :
    p = 0.46
  - Inter-subject vs. Inter-Subject & Inter-level simultaneously :
    p = 0.69
  - Inter-level vs. Inter-Subject & Inter-level simultaneously :
    p = 0.59

Fehrenbach, J. and Masmoudi, M., (2008). A fast algorithm for image registration. *Comptes Rendus Mathématique*, **346**(9-10), 593-598.

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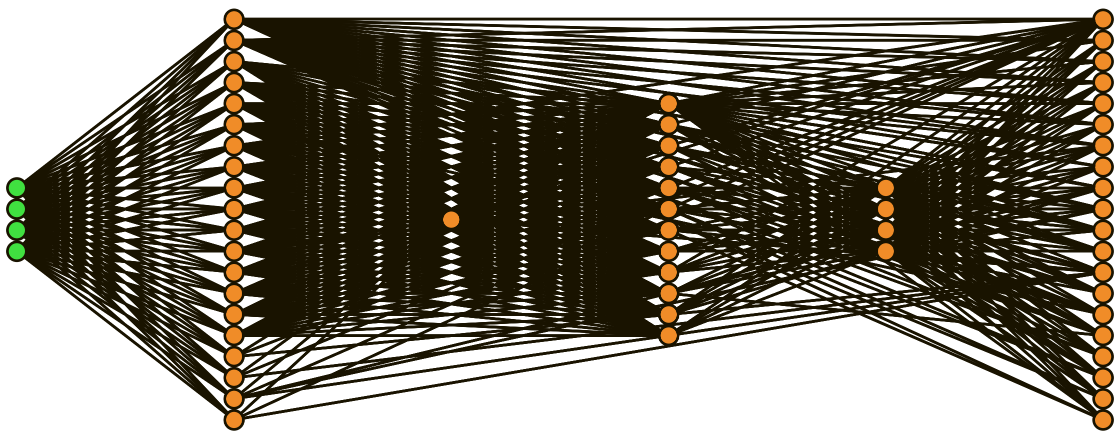
Training the ANN

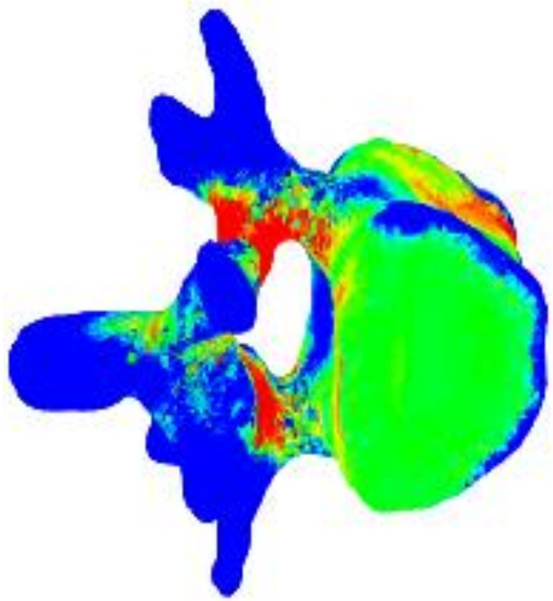
- ANN Trained using NeurEco
- **Inputs :** Mesh coordinates, linearly compressed to reduced dimensionality from 55095 to 4.
- **Outputs :** Corresponding simulation results in the form of Cauchy stress tensors, linearly compressed to reduced the dimensionality from 44058 to 20.



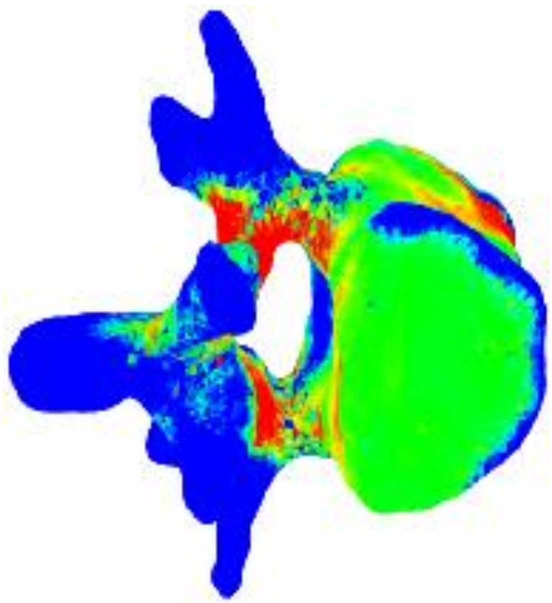
- **Number of Nodes** : 57
- **Number of Links** : 469
- **Number of Layers** : 5 *(Partially Connected)*

Results

Testing Sample Results for σ_{11} of the Cauchy stress tensor



Finite Element Simulation



Neural Network

- **MAPE of 6.00 % in the Euclidean norm of the output vector.**
- **Execution time of the ANN was, on average, around 1% of the execution time of the equivalent FEA simulation.**

Objective 2 : Inputs Describing Multiple Classes of Subject-Specific Variations

Objective : " Developing on the previous work in shape parameterisation, increase the variability within the set of training simulations by incorporating subject-specific material properties and variable loading conditions. "

Material Properties & Forces

Material Properties

- Assigned elementwise using BoneMat
- Density-Elasticity Relationship drawn from (Morgan *et al.*, 2003)
- No Phantom for calibrating Houndsfield-Density Relationship – instead, calibration coefficients were designed based on the expected range of density values
- Each geometric sample was implemented for 36 sets of calibration coefficients - expanding the training set from 40 samples to 1440 samples.

Forces

- Boundary condition were kept exactly the same, with the exception of the magnitude of the compressive force
- Each sample was simulated under 3 different magnitudes

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Training the ANN

Ongoing…

Conclusions & Plans

1. Shape parameterisation using mesh morphing has been successfully used to create a set of simulated training data – leading to a simple ANN-based simulation of a vertebrae under compression.

2. Work on "Objective 2" still needs to be completed

3. Current work has focused mainly on addressing challenges for the methodology – however, the work will have to eventually be demonstrated in the context of a clinical scenario.

Acknowledgements

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