

Finite element modelling of bones loaded by muscle-induced forces with heterogeneous material properties from CT scans of fossils



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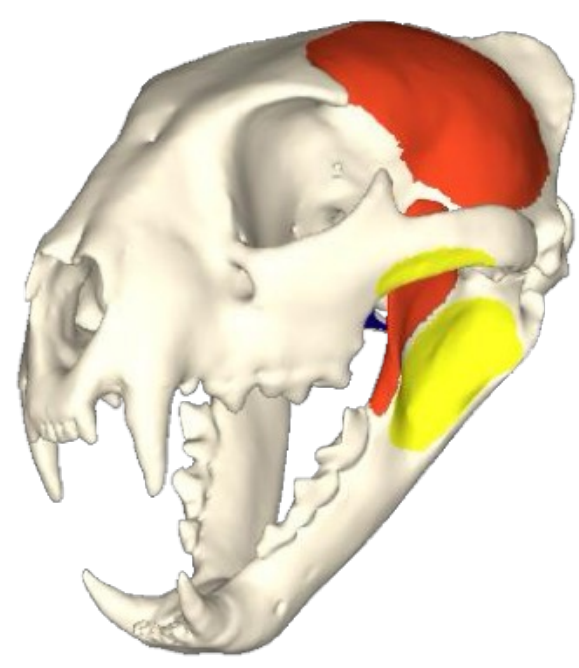


UC Berkeley

Context

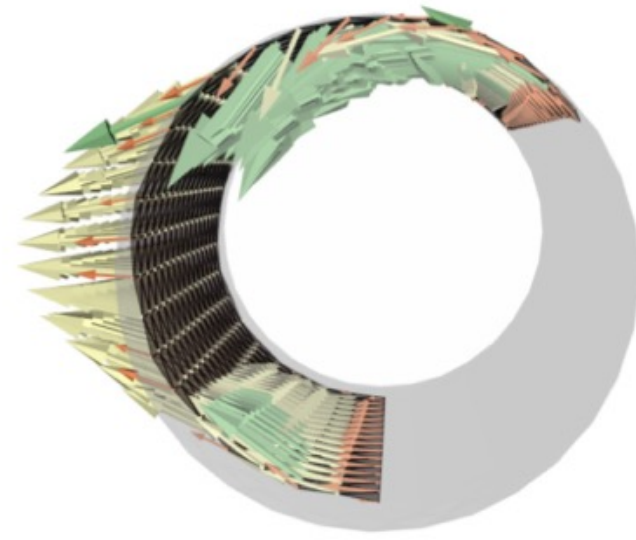
The open-source software **Fossils** enables fast finite element modelling of fossil bones loaded by **muscle-induced forces**. Built around **Gmsh**, it generates tetrahedral meshes, distributes muscle forces, and solves **linear static elasticity** problems in an accessible workflow designed for **palaeontological biomechanics**.

Muscle delimitation

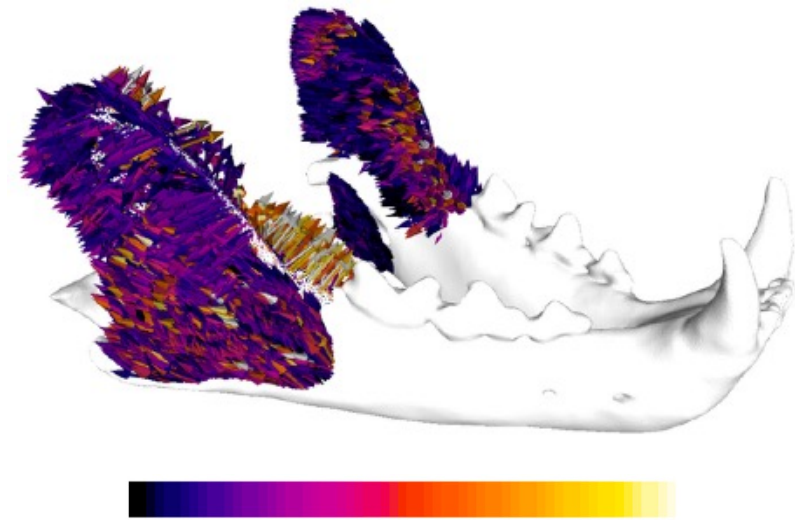


Tangential+normal muscle-traction model

Focal point



Loading scenario



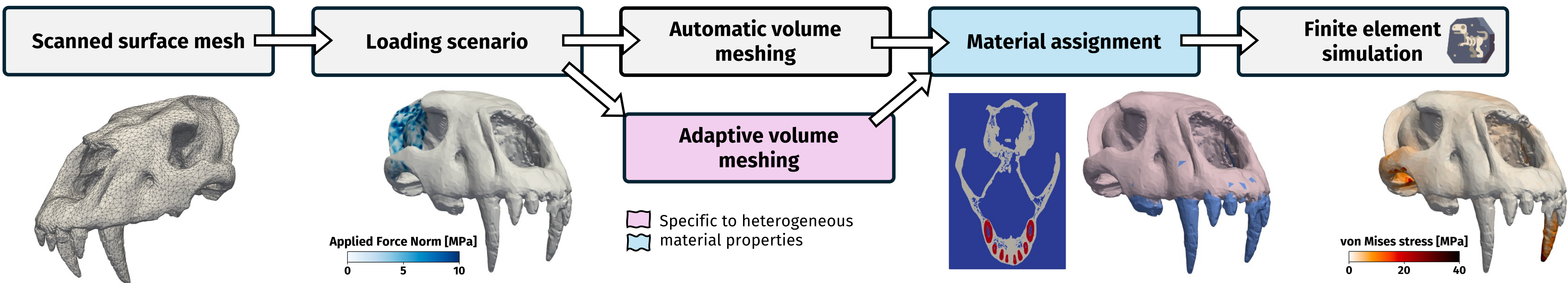
Homotherium serum
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How can Fossils better represent real material variation?

While Fossils already provides an efficient workflow for simulating fossil bones under muscle-induced forces, this work aims to **improve the biomechanical realism of the simulations** by incorporating **heterogeneous material properties** derived from labelled **CT** (Computed Tomography) **scans**.

The essential contribution is a preprocessing strategy for **element-wise material attribution**, where tetrahedral elements receive **discrete material labels** derived from the CT image. As an additional improvement, the workflow also explores **adaptive meshing** near material interfaces, where finer elements are expected to **better capture transitions between materials**.

In this preprocessing pipeline, **Gmsh plays a central role** by generating and controlling the tetrahedral mesh, while also providing the element-level information needed to connect CT-derived material labels to the finite element model.



Assigning material properties

For each tetrahedron generated by Gmsh, the **element barycentre** is mapped into the labelled CT image, and the corresponding image value is used to assign a **discrete material label** (a Gmsh physical group).

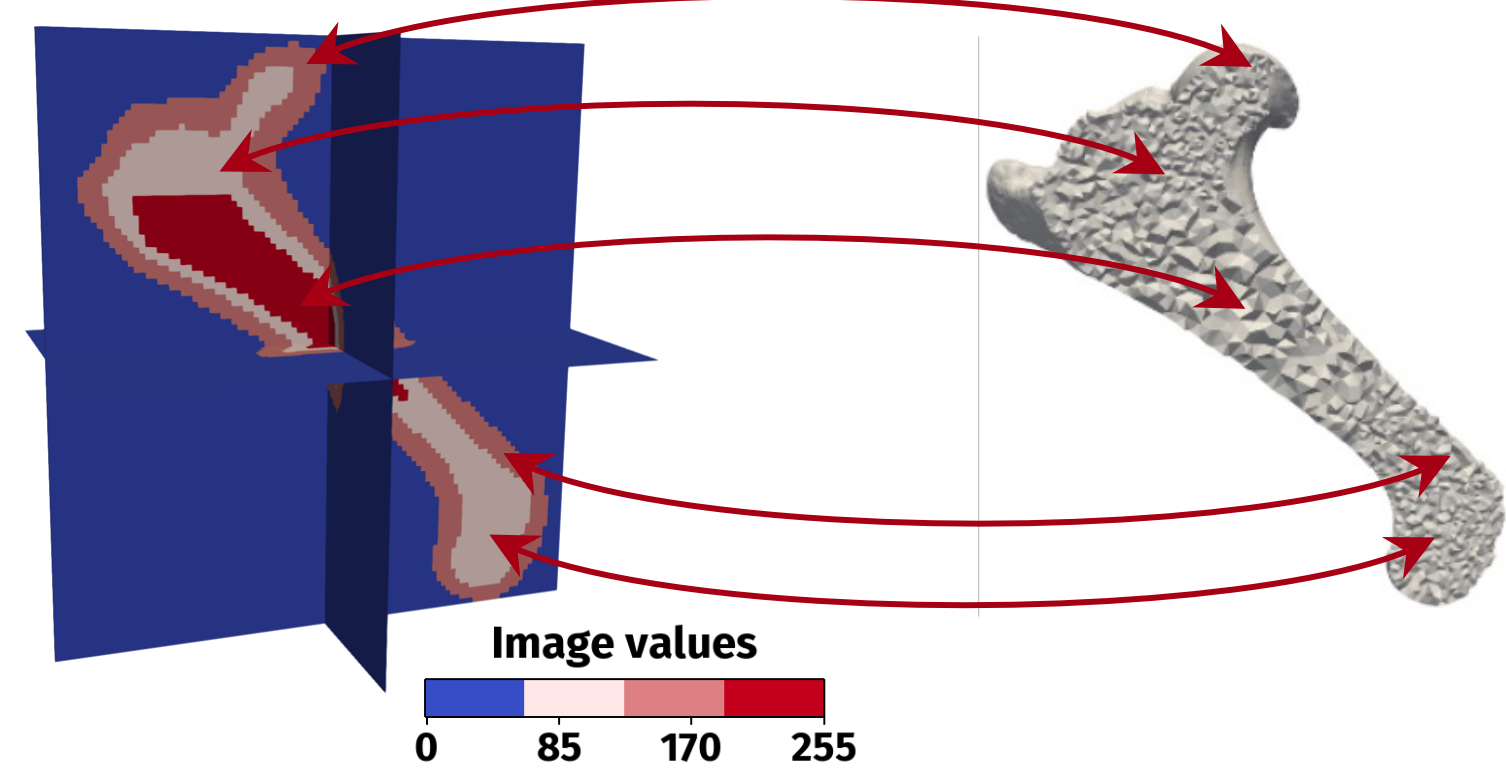
Volume meshing using a Gmsh background mesh

As an additional preprocessing option, the labelled CT scan can also be used to guide **adaptive volume meshing**. A distance-to-material-boundary map is computed, converted into local target element sizes, and exported as a **Gmsh background mesh** used for the volume meshing.

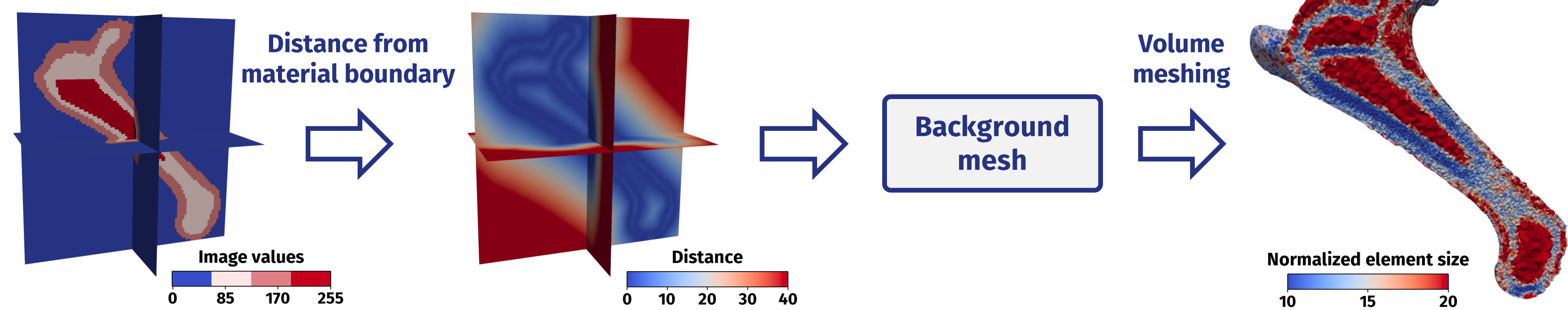


Tapirus indicus
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MATERIAL ASSIGNMENT



ADAPTIVE VOLUME MESHING



STRESS DISTRIBUTION

Homogeneous

Heterogeneous Automatic meshing

Heterogeneous Adaptive meshing

von Mises stress [MPa]

Conclusion and perspectives

This work extends Fossils with a **Gmsh-based heterogeneous modelling pipeline**, combining **adaptive meshing** near material interfaces and element-wise **material assignment** from labelled CT scans. Preliminary comparisons between homogeneous and heterogeneous models show **different mechanical responses**, motivating further investigation into how CT-derived material variation affects biomechanical interpretations of fossil specimens. Future work should therefore focus on **quantitative interpretation** using palaeontological metrics. A further perspective is to compare this approach with the **GenIso meshing tool**, which reconstructs compatible multimaterial interfaces before volume meshing.

References

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