Enhancement of a Preprocessor for the Simulation of Human Bones

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Abstract

A preprocessor capable of visualizing computed tomography (CT) scans and extracting a specific volume of interest, such as a femoral bone, was developed. The preprocessor modeled the load surfaces as a spherical caps in combination with a force vector. The entire model was exported in specialized data formats.

Motivation

Within the scope of current research in biomedical engineering, numerical tools for the simulation of human bones are developed. In future, orthopedic surgeons may use such tools, for instance, to predict and improve the mechanical performance of the total hip replacements.

Existing simulation tools, however, are lacking a preprocessor capable of an interactive and efficient way of numerical modeling of the boundary conditions. Currently, this is done manually by individual scripting.

Figure 1: Hip implant

A preprocessor was to be developed allowing for an easy definition of the load surfaces and Neumann (force) boundary conditions. First developments were supposed to use the simulation of a human femur as an example. However, the modeling concept can be applied to any bone.
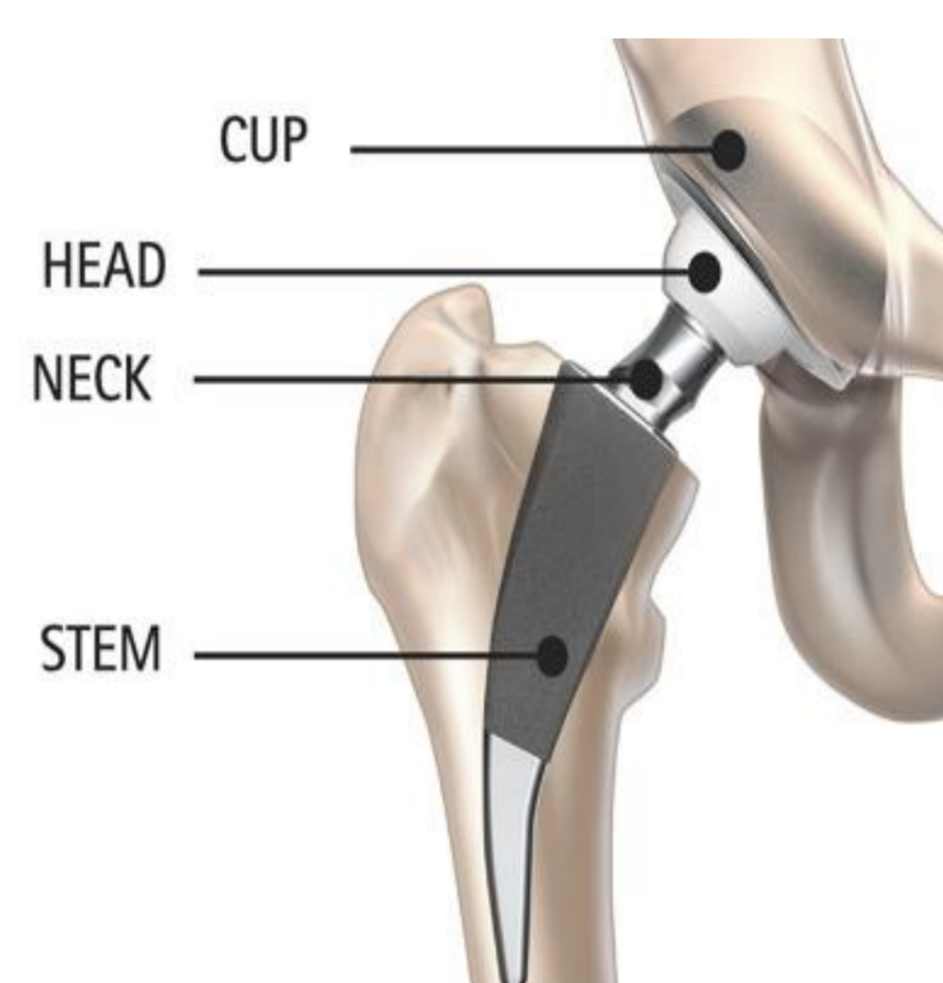
Solution approach

The preprocessor is based on three preexisting C++ libraries:

- **ITK** to read the CT scans;
- **VTK** to visualize the data;
- **Qt** to setup the graphical user interface.

Typically, one is only interested in a specific part of the overall skeleton, e.g. the femur. Following that, the preprocessor was to allow the definition of the volume of interest (VOI) before modeling the load surfaces:
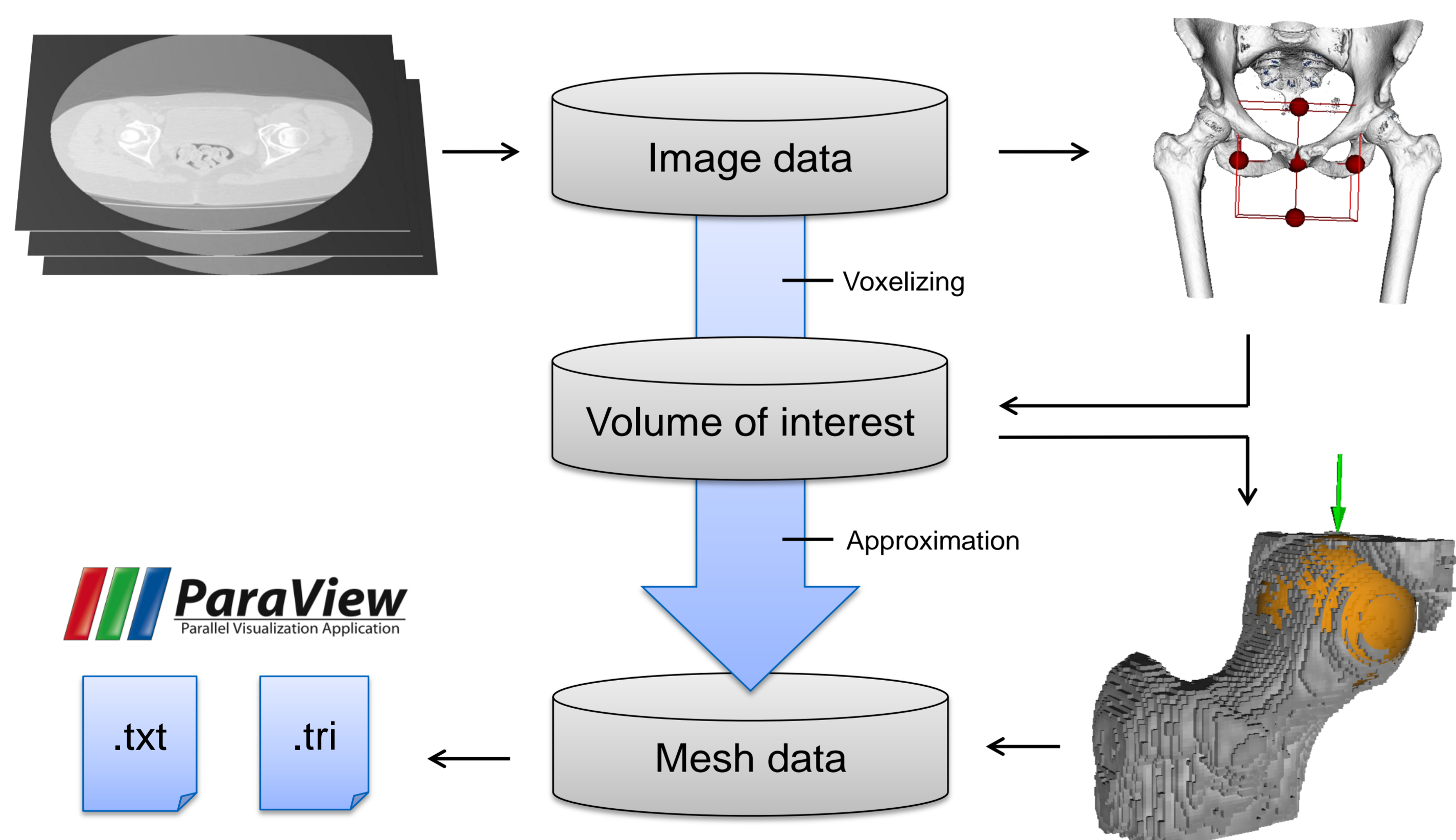
Figure 2: Process chain implemented in the software

Applied methods

To visualize CT scans as a 3D model, two powerful rendering algorithms provided by VTK are applied in the software:

- Marching Cubes: polygonal iso-surface according to scalar values;
- Ray-Casting: volume model by mapping scalar values of CT-scans to color and opacity values.

The advantage of these methods is the fast processing with low memory requirements. This enables the visualization of large data sets, e.g. an entire patient.

The drawback of these rendering approaches is that individual voxels can not be inspected. In order to cope with that, the VOI is visualized by means of a detailed voxel model which is build as indicated in figure 3:
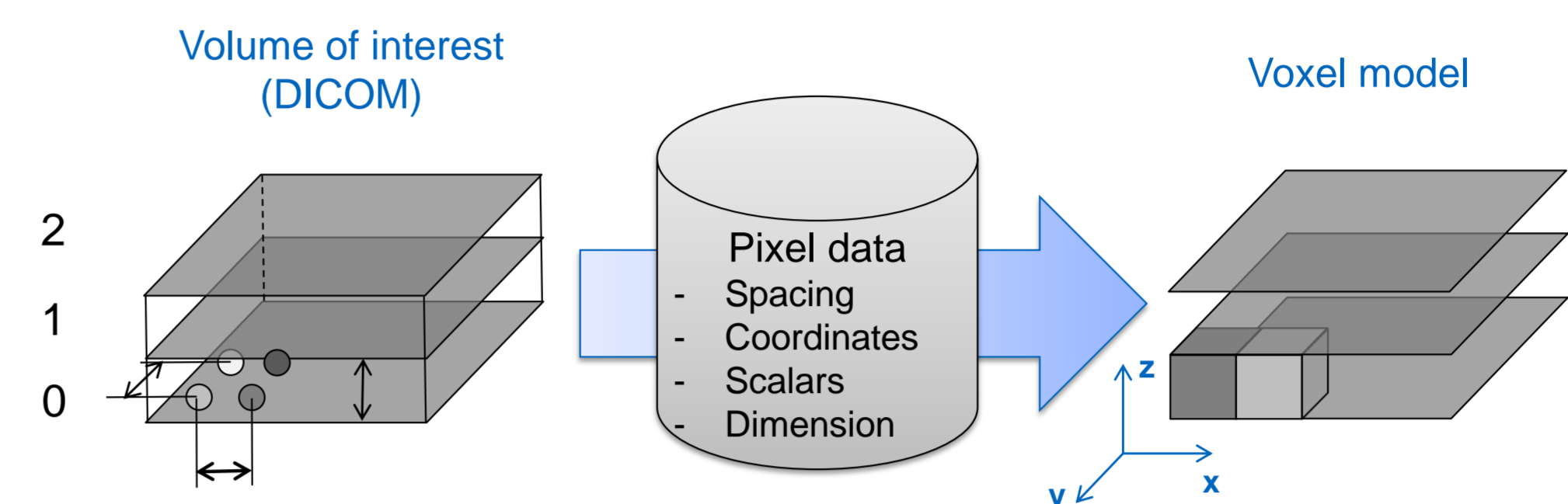
Figure 3: Rendering of a voxel model

Force boundary conditions are modeled by:

1. Approximating the load surface with a triangular-meshed spherical cap;
2. Defining a force vector in the spherical coordinates;
3. Determining the pressure load by dividing the force vector magnitude by the projected area of the spherical cap relative to the force vector.
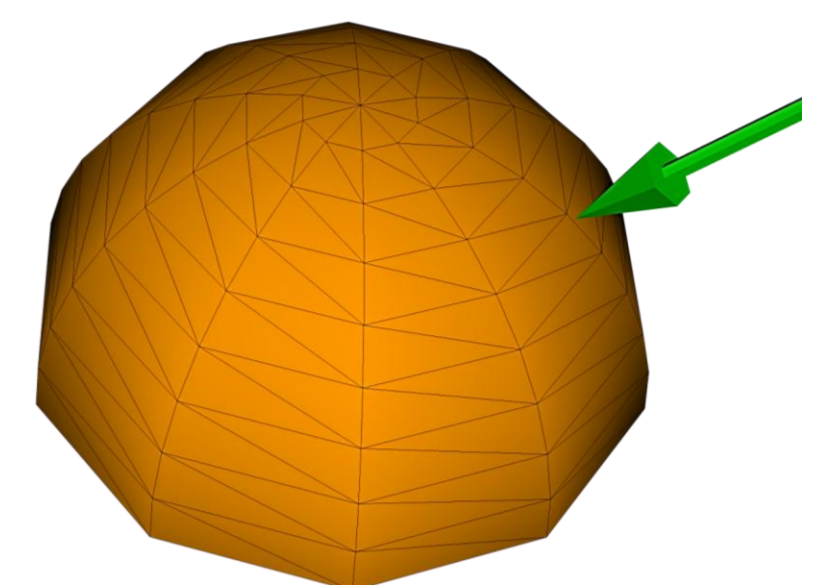
Figure 4: Meshed sphere cap and load vector

Software features

The software´s capability comprises the following principal features:

- Extracting the VOI by an interactive positioning of the bounding box;
- Thresholding the extracted data allowing for a detailed investigation of a femoral bone structure in terms of corresponding Hounsfield units;
- Interactive modeling of the force boundary conditions within an anatomic setting;
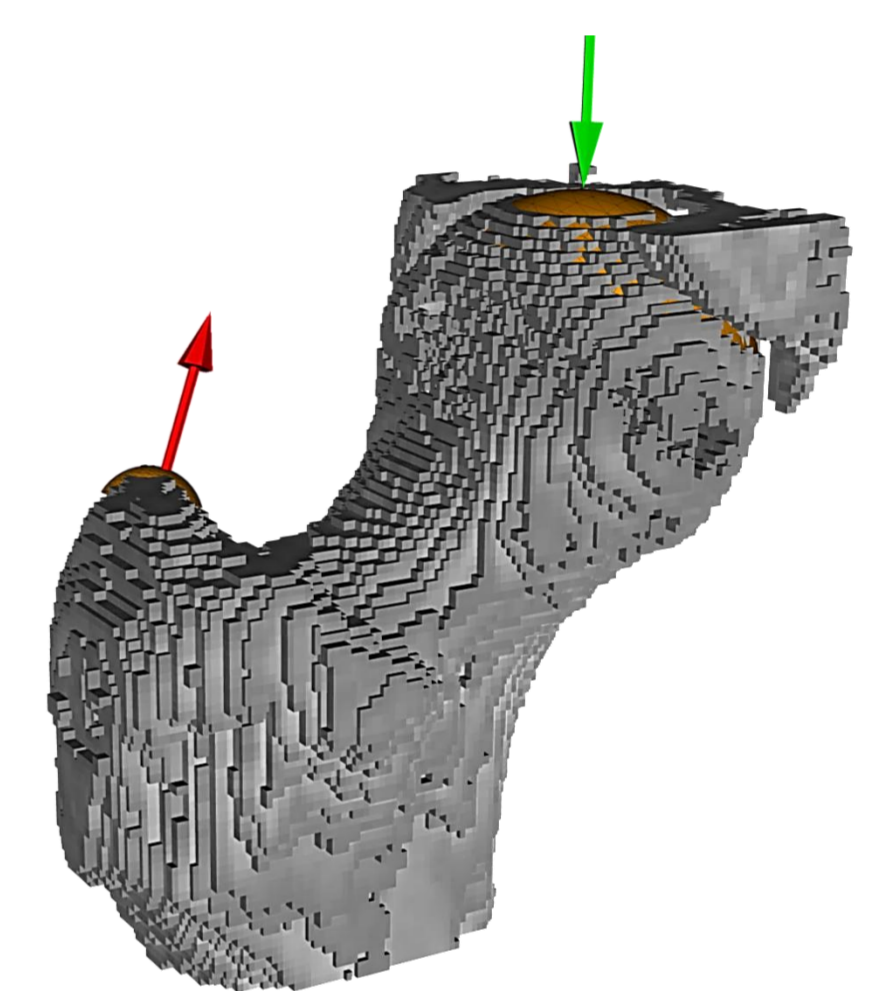- Exporting data in several formats.

Figure 5: Load surface with applied BC´s using a model threshold of 250 HU

Besides that, various functionalities facilitating the overall usability are implemented, for example virtual measurements, render options and a tool to investigate a possible finite cell mesh.
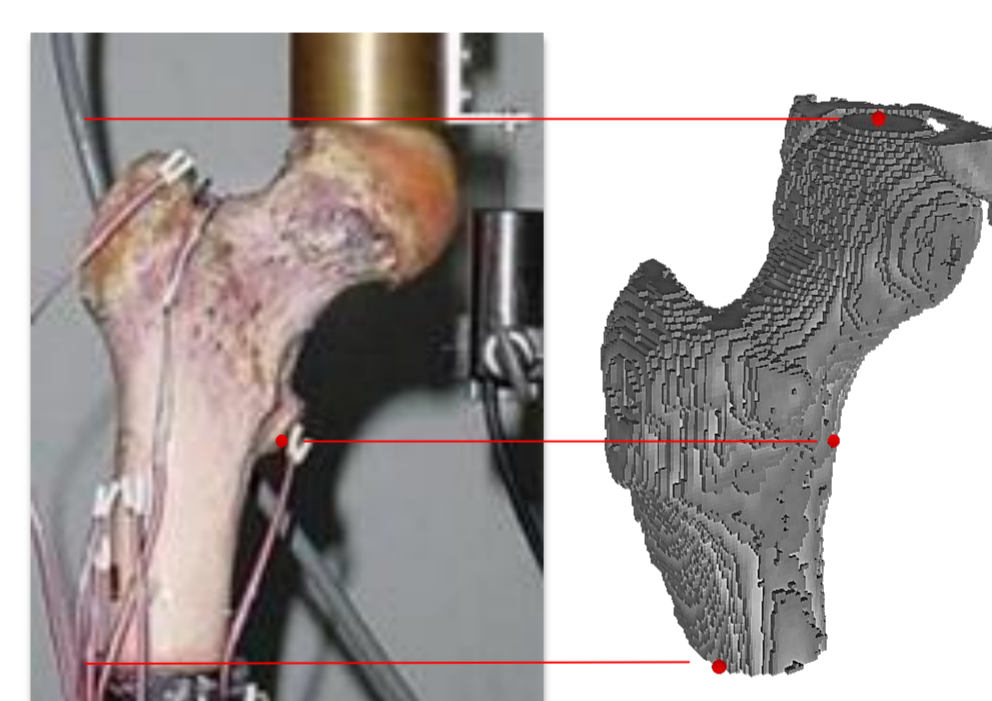
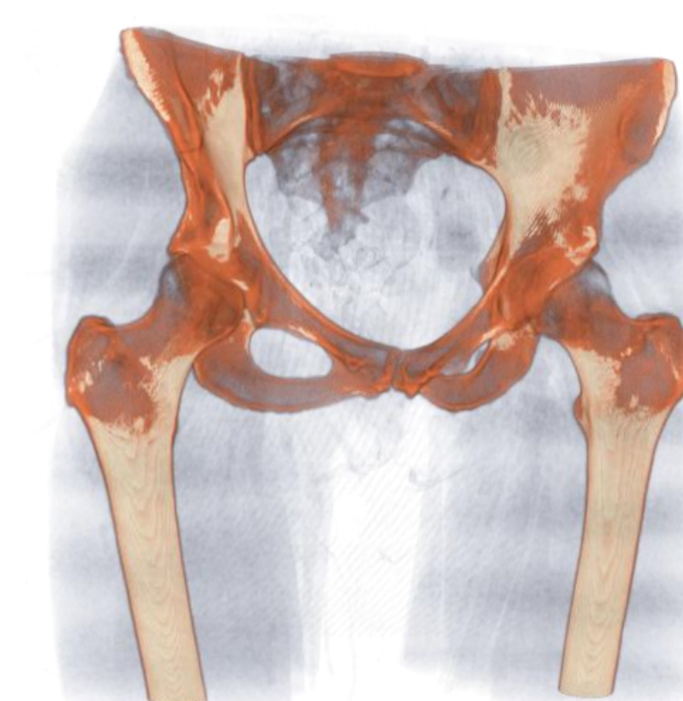Figure 6: Virtual measurements can be carried out and compared to physical tests

Figure 7: Switching the rendering is possible, e.g. to a ray casting volume representation
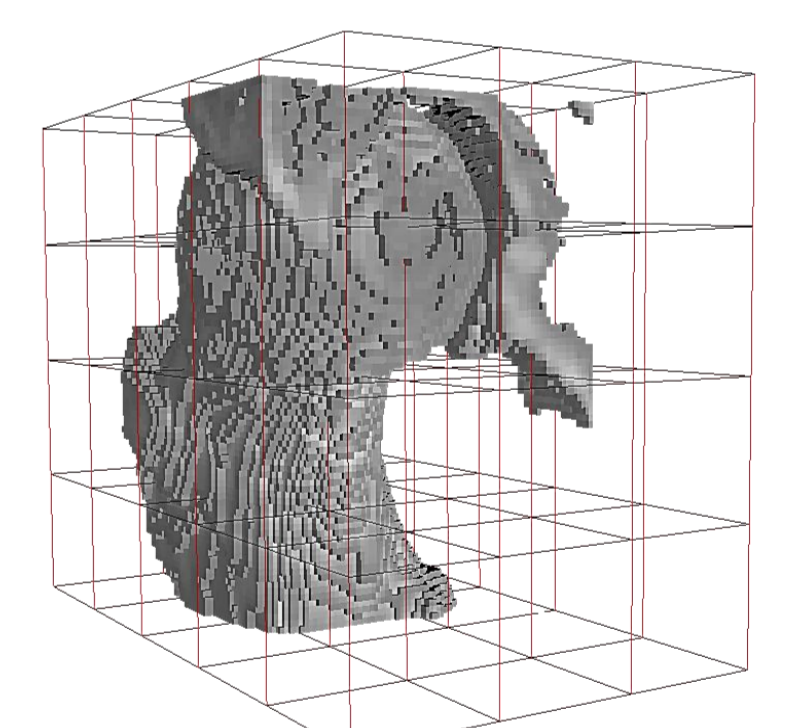
Figure 8: Dimensions of a possible finite cell grid are assessable

Conclusions / Outlook

In the scope of this project a preprocessor was developed, allowing an easy modeling of anatomic load scenarios w.r.t. the femur in general and its joint connection to the pelvis in particular. The preprocessor comprises:

- A 3D visualization and data processing of a series of CT scans;
- A modeling of the load surfaces and the application of Neumann BCs;
- A data export and a highly interactive GUI.

The software will facilitate the simulation of human bones by speeding up the modeling procedure. Moreover, it provides a basis for further function developments, e.g. towards an enhanced approximation of the load surfaces.

References

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