Advanced Volume Rendering Techniques for Medical Applications

Verbesserte Darstellungsmethoden für Volumendaten in medizinischen Anwendungen

J. Georgii[1], J. Schneider[1], J. Krüger[1], R. Westermann[1], M. Eder[2], L. Kovacs[2]

[1] Computer Graphics and Visualization Group
Institut für Informatik,
Technische Universität München
Boltzmannstraße 3, 85748 Garching bei München

[2] Abt. f. Plastische und Wiederherstellende Chirurgie
Klinikum rechts der Isar,
Technische Universität München
Ismaningerstraße 22, 81675 München

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Purpose

Interactive visual analysis of a patient's anatomy by means of computer-generated 3D imagery is crucial for diagnosis, pre-operative planning, and surgical training. Hence, computer-aided visualization has established itself in medical applications. Recent advances in consumer class graphics hardware (GPUs) allow a number of new, high-quality visualization modes, while at the same time reducing the financial costs. However, as computing capacities continue to grow, so does the size of acquired datasets, leading to a barrage of information. Consequently, the task of visualization is not limited anymore to producing images at interactive rates, but also includes the guided extraction of significant features to assist the user in the data exploration process. Furthermore, an effective visualization module has to perform problem-specific abstraction of the dataset, leading to a more compact and hence more efficient visual representation.

Moreover, many medical applications, such as surgical training simulators and pre-operative planning for plastic and reconstructive surgery, require the visualization of datasets that are dynamically modified or even generated by a physics-based simulation engine. Since the simulation is usually performed on an unstructured finite element grid, novel algorithms including correct visibility ordering have to be applied.

Method

To deal with the barrage of information present in today's medical datasets, we present a focus+context technique that builds on a GPU-based volume raycaster. The system extracts two or more feature layers (at least one focus and one context) and performs a compositing step to produce the final image. This allows surgeons to view a clearly defined region of interest without sacrificing the positional cues of the surrounding material.

The challenge of visualizing unstructured grids is to obtain a visibility ordering of the rendering primitives. This ordering is necessary to provide the user with correct depth cues. For larger datasets, this ordering cannot be achieved at interactive rates, since the underlying data is continuously deforming. Therefore, we extend the GPU-based raycaster to operate on dynamic, unstructured finite element grids. This opens new data modalities to be simulated and visualized. For instance, plastic surgeons can now effectively examine how tissue will be stressed during and after operations.

Results

The GPU-based raycasting approach delivers high quality images at highly interactive frame rates (see Figure 1). Although multiple feature layers have to be extracted, the extremely fast compositing step allows latency-free modification of focus+context parameters. This provides surgeons with the rapid visual feedback needed to explore the dataset conveniently. By providing different shading modes, e.g. for skin and bones, intuitive visualizations can be achieved as shown in Figure 2.

With the ability to render dynamic datasets, we can even visualize internal properties such as tissue stress interactively during simulation as illustrated in Figure 3. This kind of visualization has a great potential in surgical training environments as it shows the tissue stress induced by the operations of the surgeon.

Conclusion

We presented several novel visualization modes and demonstrated how they can support surgeons in specific situations.

Firstly, the focus+context approach efficiently provides positional cues in addition to a clearly defined focus region. This can be used for still images to communicate certain features to both medics and patients, as well as to support surgical planning processes. Modes that easily convey distances between feature layers (such as bone and skin) are included, along with the possibility to mix layers with traditional volume rendering.

Secondly, since visualization of unstructured and dynamic grids is now possible at interactive rates, physics-based simulations can provide surgeons with immediate visual feedback. The visualization of novel modalities such as tissue stress can greatly assist surgeons in training and pre-operative planning.

References

1. J. Georgii, R. Westermann: „A Generic and Scalable Pipeline for GPU Tetrahedral Grid Rendering“, IEEE Transactions on Visualization and Computer Graphics (Proceedings of IEEE Visualization 2006) , Vol.12, No.5, Sept./Oct. 2006, *to appear*

2. J. Georgii, R. Westermann: „A Multigrid Framework for Real-Time Simulation of Deformable Bodies“, Computers & Graphics, Vol.30, No.3, 2006

3. J. Krüger, J. Schneider, R. Westermann: „An Interactive Context Preserving Hotspot Visualization Technique“, IEEE Transactions on Visualization and Computer Graphics (Proceedings of IEEE Visualization 2006) , 12(5), Sept./Oct. 2006, *to appear*

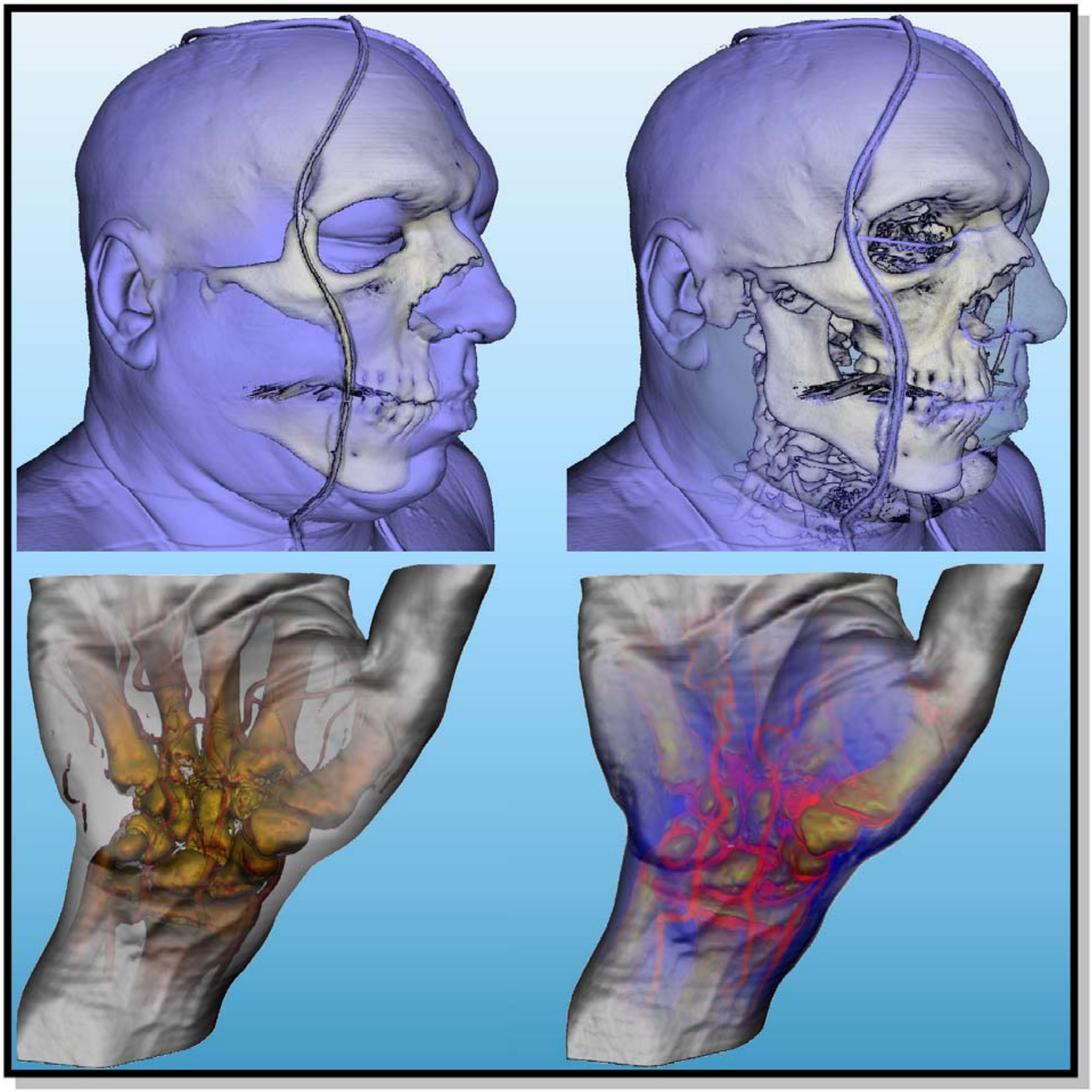

Figure 1: To demonstrate the high visual quality of our approach, we show two data sets. Top: The Visible Human (male) head is shown using two different methods to emphasize the location of bone relative to the skin. Bottom: Two different renderings of a hand are compared. To the left, only iso-surfaces have been used, while to the right a volumetric tissue-layer (blue) was included.

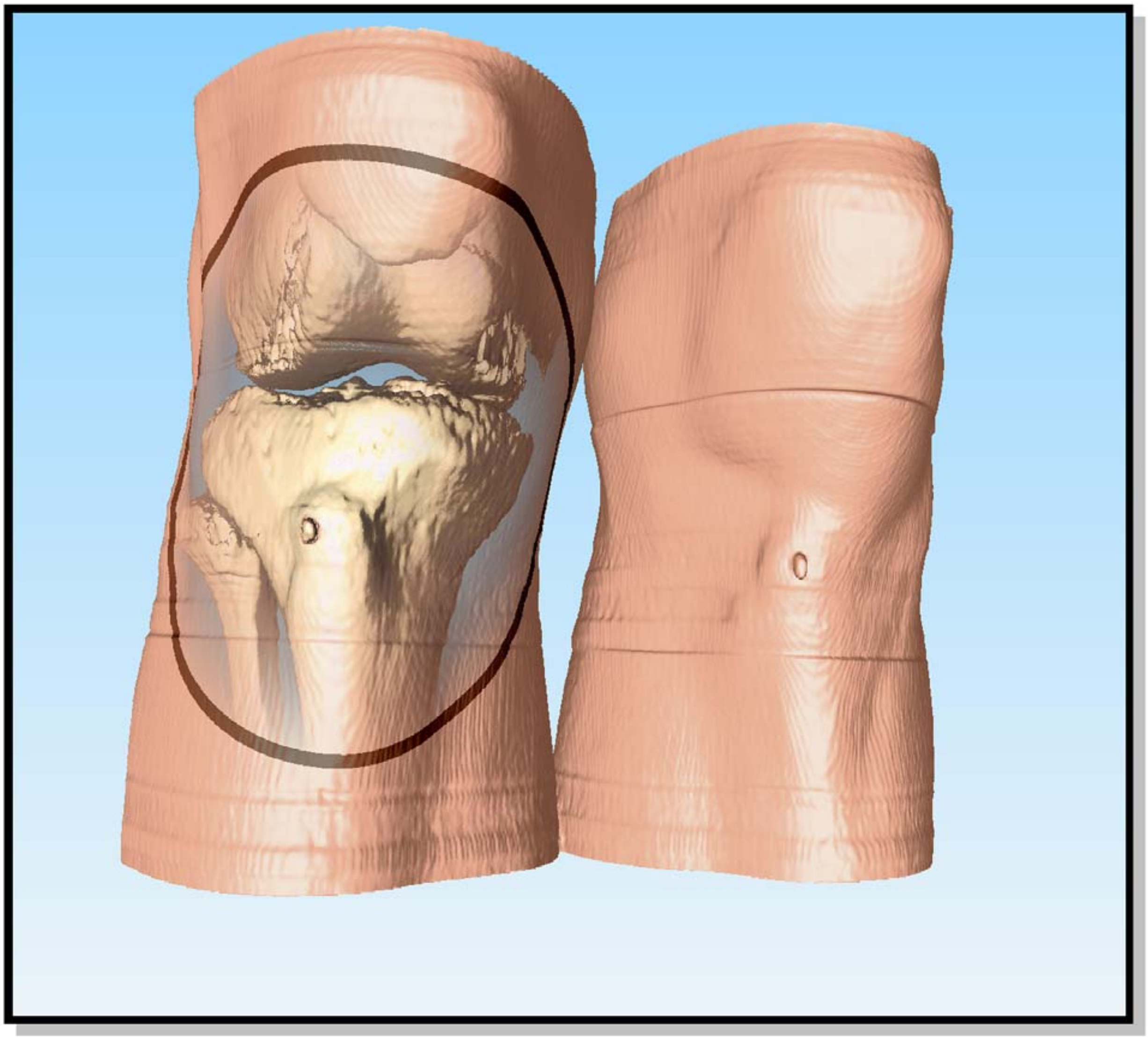

Figure 2: We demonstrate that our system produces highly intuitive visualizations. To achieve a natural understanding of the materials present in this data set, skin and bone shaders have been integrated to highlight the joint between femur and tibia. Due to the combination of focus+context and shaders, it is immediately clear - especially to non-experts - that the region of interest is a right knee-joint.

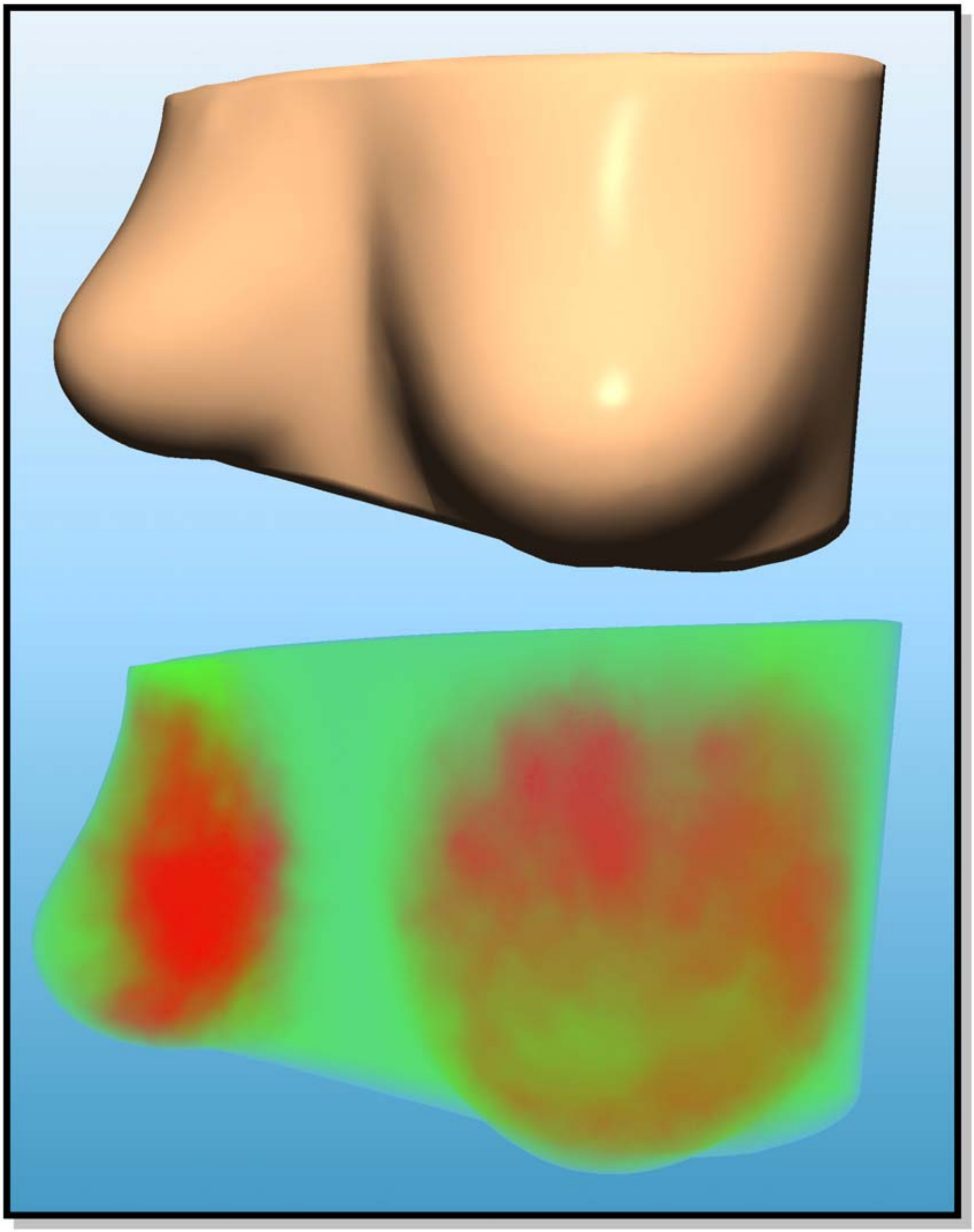

Figure 3: We demonstrate the rendering of a dynamically deformed breast model. Top: The outer surface of the volumetric model used for the physics-based simulation of gravity is shown. A shader to compute shadows is used to improve positional perception. Bottom: Visualization of internal properties. The underlying dynamic, unstructured grid was rendered by means of tetrahedral volume rendering. Red indicates high tissue stress, while green marks undeformed regions. Such a visualization can assist in plastic and reconstructive surgery planning.