M. Teschner

Advances in Real-Time Surgery Simulation and Training with Applications in Craniofacial Surgery

This presentation focuses on current developments in the area of real-time soft-tissue modeling which is employed for generalized surgery simulation and training. Based on efficient approaches for deformable modeling, collision handling, and the simulation of surgical instruments, a generalized real-time surgical simulator has been implemented. The simulator can process a variety of anatomical scenarios which are represented by volumetric tetrahedral meshes. First applications have been realized in craniofacial surgery, orbital reconstruction, and hysteroscopy. Software presentations will illustrate the achievements.
The efficient and realistic processing of soft tissue, i. e. the simulation of geometrically complex deformable objects, is one of the most important problems in real-time surgery simulation. In order to realize basic capabilities of a surgery simulator, a number of challenging problems have to be addressed, including deformable modeling, collision detection, and collision response. This presentation discusses efficient models and algorithms for these three simulation components. Further, it discusses the interplay of the components in order to implement an interactive system for interacting deformable objects.
A versatile and robust model for geometrically complex solids is employed to compute the dynamic behavior of deformable objects. The model considers elastic and plastic deformation. It handles a large variety of material properties ranging from stiff to fluid-like behavior. Due to the computational efficiency of the approach, complex environments consisting of up to several thousand primitives can be simulated at interactive speed.
Collisions and self-collisions of dynamically deforming objects are detected with a spatial subdivision approach. The presented algorithm employs a hash table for representing a potentially infinite regular spatial grid. Although the hash table does not enable a unique mapping of grid cells, it can be processed very efficiently and complex data structures, such as octrees or BSPs, are avoided.
Collisions are resolved with a penalty approach, i. e. the penetration depth of a colliding primitive is processed to compute a force that resolves the collision. The presented method considers the fact that only sampled collision information is available. In particular, the presented solution avoids non-plausible collision responses in case of large penetrations due to discrete simulation steps. Further, the problem of discontinuous directions of the penalty forces due to coarse surface representations is addressed.

All presented models and algorithms process tetrahedral meshes with triangulated surfaces. Due to the computational efficiency of all simulation components, complex environments consisting of up to several thousand tetrahedrons can be simulated at interactive speed. For visualization purposes, tetrahedral meshes are coupled with high-resolution surface meshes.

The presented components have been integrated into an interactive simulation environment which can be used for surgical simulations. First applications in craniofacial surgery, orbital reconstruction, and hysteroscopy have been realized. Software demonstrations illustrate the capabilities of the implemented simulations. Further, the directions for future developments in the context of real-time surgery simulation will be discussed.