

# Computer Graphics in Surgery Simulation

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## Scientific Background

Medicine is an extremely challenging field of research, which of fundamental importance in human existence. From the early days of computer graphics the medical field has been one of the most important application areas with an enduring provision of exciting research challenges. Conversely, individual graphics tools and methods have become increasingly irreplaceable in modern medicine, where medical imaging systems are only one prominent example.

3D medical imaging systems, such as X-ray (CT), magnet resonance (MR) or nuclear (SPECT) scanners, were revolutionary developments of modern diagnostics which conquered the field starting in the early 70s. These methods gave insight into almost every individual section of the human body and have saved countless lives by early diagnosis of tumors, heart diseases and others.

The data sets, usually defined on equally spaced 3D grids, have been visualized in terms of large sequences of individual slices. The more sophisticated ways of visualizing this new type of volumetric data is by volume rendering. Many different algorithms have been developed for the efficient and realistic rendering of volumes. The variety of approaches ranges from simple back-to-front rendering to sophisticated lighting and shading models implemented via ray tracers. The produced images are highly realistic and ubiquitous.

Besides direct approaches to volume rendering, the geometric reconstruction of anatomic structures has enabled further processing and analysis of medically important features. In this context, data segmentation has proven to be a critical preprocessing step. In addition, higher-level volume data analysis algorithms have allowed the identification of individual anatomic substructures.

Generally, volume data feature extraction and interpretation is a paramount example of the fruitful relationship and convergence of graphics and vision. Many of the graphics and vision methods designed in the early days are presently well established and support advanced applications in medicine, such as radiation and operation planning, education and training and many others.

## Issues in Surgical Simulation

Currently, the most promising technology in the 21st century for surgical training education and preoperative

surgery planning is by using the surgical simulation. During the early stage of surgical training, most of the surgical trainings are practiced on animals, cadavers and human patients. Each of these methods faces challenges and obstacles. For example, the properties of living soft tissues in the cadavers are thoroughly different with the real living tissues in term of anisotropic, nonlinear, time-dependent and viscoelasticity. Meanwhile, patient-based training is the most impractical as it risks the safety of the patient. Another training method is the apprenticeship-based training where novice surgeon observes surgeon operating on a patient, serving a small task then gradually handling the operation alone. This process of learning is time consuming and impractical. Therefore, surgical simulation is introduced.

Surgical simulation is to complement the traditional surgical training methods. With the advances in computer technology, Virtual Reality (VR) is introduced into health care. VR is crucial in the surgical simulation as it combines a convincing representation of soft tissues interacting between the end user and the virtual objects. The virtual environment increases the immersive of the end user. Thus, simulation training should be extended into surgical training.

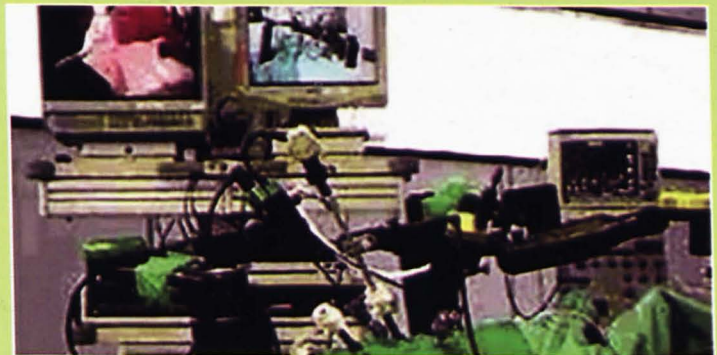


Figure 1 :World's First Robotic Telesurgery.  
Source: <http://news.bbc.co.uk/2/hi/science/nature/1552211.stm>



Although the surgical simulation training is proven to be more useful than traditional surgical training, the assessment of the accuracy of the simulated surgical outcome is still difficult. It deals with the soft tissues of human bodies which are complex, nonlinear, viscoelasticity, anisotropic and time-dependent. For instance, typically to represent an organ geometrically, at least 1500 nodes or roughly 3000 elements are needed. Therefore, a suitable deformable model is essential to represent the exact properties of the soft tissues. Human tissue modeling is one of the most demanding among the potential applications of deformable objects due to the complexity exhibited by the soft tissues. Surgical simulation is also physically-based simulation which involves the deformation of the modeled object. The deformable objects change in size and shape when force is applied, as in the case of the soft tissues.

The main idea on how does a physically-based simulation work is straight-forward. The deformable object is represented by deformable modeling such as the Finite Element Method (FEM), Mass-Spring Model (MSM), Finite Difference Model (FDM), Boundary Element Method (BEM) and others. Firstly, spatial discretization where the deformable object is sampled in mass points. Secondly, identify the forces interactions between the mass points in the deformable object. Basically, the forces are represented by the Newton 2nd Law and the Hooke's Law of the springs. Thirdly, governs a mathematical model which represents the dynamics in the deformation. Fourthly, solve the temporal discretization in a system of ordinary differential equations, ODE which is then solved by using the numerical integration solver. There are several ODEs to solve the discretized system. However, it is crucial to solve the system with a fast converging ODE solver in order to fulfill the requirement such as realistic and real-time for a surgical simulation.



Figure 2: The concept of a liver surgical simulation.  
Source: <http://www.passport-liver.eu/Homepage.html>

## Surgical Simulation

There is a long history of the invention of surgical simulator though it is still new in surgical education. The intent of this invention is to enable the medical students, novice surgeons or the trained surgeon to acquire basic and professional skills in a safe environment. In fact, virtual environment is an environment that does not endanger patient safety.

Figure 2 gives a big picture of how does a surgical simulation work and a basic concept of the interaction between the virtual model represented in the computer visualization and the user from the liver surgical training. It shows the computer-based generated virtual mechanical and interaction modeling. Furthermore, it also shows how a novice surgeon practices through the liver surgical simulation.

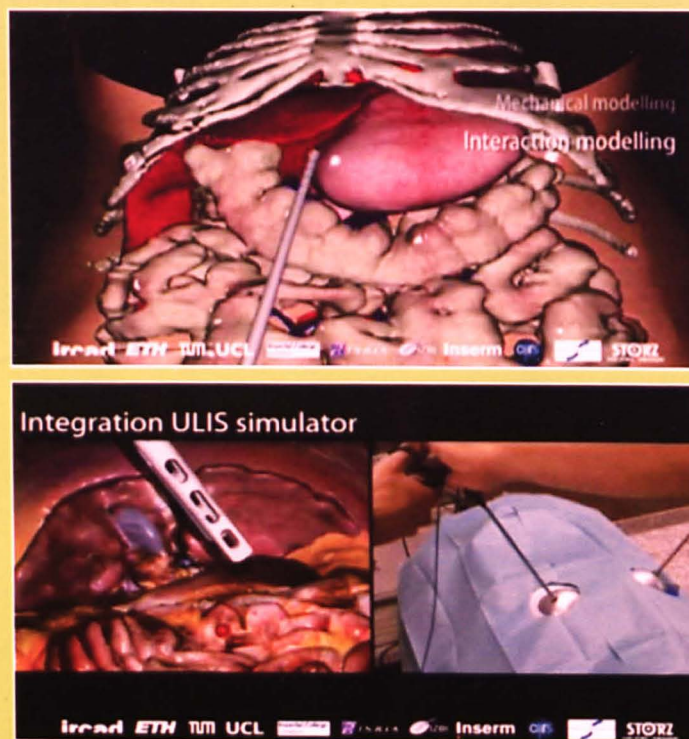


Figure 3: Snapshots from the video "PASSPORT" - Patient Specific Simulation and PreOperative Realistic Training for liver surgery.

## Accomplishment and Challenges of Surgical Simulations

The efforts of surgical simulation with the high-end technologies bring a new generation of professional surgeon equipped with surgical simulator technical skills. There are several tasks accomplished by using surgical simulators, however, challenges remain.

The accomplishments of the surgical simulator are as follows:

- The simulator generates realistic 3D models of anatomy where users can practice several surgical tasks.



- Either for the experienced surgeons or students, surgical simulator plays as a role of the initial assessment in their performance of technical skills.

The challenges that remain in surgical simulator are as follows:

- Improvement of technical fidelity in order to increase the trustworthiness of the patients towards the undergoing surgeries.
- A standardized touchstone to determine the performance of the surgical simulators.
- A wholesome educational curriculum with the compliment of optimized surgical simulator.
- Constricted evaluation of simulations for the effectiveness and stability during the surgical training.

### The Paramount Role of Computer Graphics

The particular attractiveness of highly complex surgery simulation environments lies in the versatility and depth of individual research problems touching or covering almost every important subfield of computer graphics. Therefore, the paramount role of graphics in surgery simulation and briefly sketch some of the major research challenges:

- Modeling of geometry and topology: The basis of any sophisticated surgery simulation system is the efficient mathematical description of the underlying geometry and topology. Here, most of the model has to be described in a full volumetric setting. Sophisticated discretizations and approximation models are essential preprocessing steps for advanced numeric procedures, which compute tissue deformation. Figure 4 shows one of the major challenges in modeling of soft tissue which is topology reconstruction.

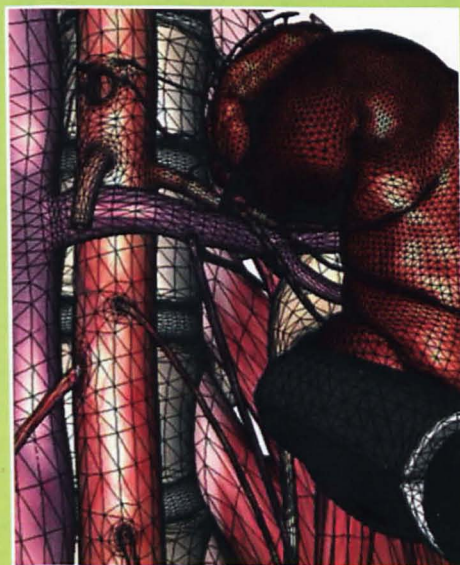


Figure 4: Unique Surgical Simulation Challenges - Modeling of geometry and topology. Source: Roger Smith, Robotic Surgery and Surgical Simulation, Florida Hospital

- Editing of complex structures: Another task is to design powerful editors allowing the user to modify the geometry and topology of anatomic structures. Again mere surface editing is certainly not sufficient for cutting and repositioning of individual pieces of soft tissue. Functions such as a zoom into substructures are highly desirable and enable a surgeon to operate on different scales in the full volumetric setting. Therefore, elaborate data structures have to be designed giving efficient access to, and maintaining individual primitives of the underlying approximation. Furthermore, these data types will have to maintain all necessary parameters of the physics-based models, which in turn must interact with the editor in real time.
- Simplification and adaptation of physical models: One of core challenges in surgery simulation is to understand and simplify the physics of the simulation process. The quest for real-time update rates in visual and mechanical feedback forces the development of sophisticated solutions, which have to balance computational complexity with accuracy through the use of graphics processing unit (GPU) hardware in order to accelerate the envisioned algorithms.
- Image generation: Generally, fast rendering algorithms are irreplaceable in surgery simulation. However, with advanced volumetric approximations new types of unstructured graphics primitives will be generated in surgical simulation with appropriate hardware support. Thus both surface and volume rendering of higher order primitives will be of great interest. Nonetheless, the required visual quality, depends highly on the application context.
- System Design and Layout: Computer graphics researchers will undoubtedly be the principal designers of future surgery simulation systems. Thus, besides the mere development, tuning and tailoring of individual algorithms graphics research will also have to cover overall systems layout and optimisation. In particular, global design issues, such as the interactions of editor, rendering, simulation engine and force feedback, are of fundamental importance in highly interconnected, complex systems and must also be considered by graphics researchers.

### Summary

In summary, from the earliest days, the medical field has been one of the most appealing areas for computer graphics research. Being the chief engineer of next generation's medical training and simulation systems, computer graphics will help to improve our present health system. Thus it will provide a significant contribution particularly to our society, generally to modern human life.