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Modular Integration of Biomedical Simulation and Medical Image Computing

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Biomedical simulation is a highly complex problem and a relatively young research discipline. Various attempts in the past years were made to establish common platforms for development and research both in medical imaging and analysis as well as biomedical simulation. While several solutions emerged in the former case, only a few solutions are available for the latter case. Attempts to design platforms combining both research disciplines so far suffered from the complexity of the problem and hence not least from missing acceptance by the research community. Consequently, biomedical simulation platforms are very specific to their original topic in an isolated manner and do not allow for easy integration in a bigger medical context as it would be necessary as the experience showed in the medical imaging domain. Without a higher degree of integration into a common platform and clinical research workflow it is hard or even impossible to validate any results made in this research area. A specifically challenging prerequisite for biomedical simulations exist in surgery with the need to simulate topological changes of tissue. Hence, a non-specific, modular solution enabling topological changes for any simulation approach is highly desirable.

The main objective of this work was to design and apply modular concepts and methods to improve the current situation. Therefore, it was divided into two parts:

- A novel approach for separating simulation methods from topological changes of geometry by extending modularity to the fundamental design of according algorithms.
- The integration of SOFA as modular biomedical simulation framework into a broader medical workflow by embedding it into MITK, an established medical imaging based solution.

The conceptual separation of thin shell elements as an example of a sophisticated simulation method from topological changes of anatomical geometry lead to a novel joining approach, which allows to implement surgical low-level procedures, e.g., incising and suturing, independent from the simulation model. This modular simulation system can therefore instantaneously benefit from further improved simulation methods in the future without the requirement of any modifications or adaptions. It was further shown that thin shell elements are an appropriate method for the real-time simulation of blood vessel walls as they allow to accurately represent deformed tubular structures with a relatively low element count.

The essential requirements and feature requests for a combined medical imaging and biomedical simulation platform were elaborated and achieved by the careful and software quality centric integration of SOFA into MITK. This novel platform help to overcome several facets of the high complexity of the research discipline by enabling collaborative and iterative research on a common basis. New methods can be contributed to or established within a well-defined environment and results can be easily reproduced and verified. The direct accessibility of medical imaging modalities allows for more sophisticated possibilities in evaluation of simulation methods.

Both contributions allowed to rapidly create proof of concept applications by mainly using and combining already present functionality of the common platform. Instead of developing highly specific biomedical simulation approaches, new achievements can be made by combining or extending already established simulation approaches.

This work accelerates the translation of biomedical simulation methods into a clinical setting for further evaluation and medical research. In the medium to long term it enables the development of patient-specific, predictive therapy and intervention planning.