Département d'informatique
Unité de formation et de recherche
de mathématique et d'informatique
Université de Strasbourg

Ph.D 2022-2025

3D Modeling, deformation and simulation

Location: The position is to be filled in the IGG Team (Geometric and Graphic Computing) of the ICube Laboratory (Engineering, Computer Science and Imaging Laboratory), in Strasbourg

Application: intention to send to D. Bechmann, professor in computer science,
to be confirmed by CV and cover letter (bechmann@unistra.fr)

Context: doctoral project Déf-RV (Deformations for the simulation and the Virtual Reality) whose financing by the Region GrandEst is acquired for 3 years.

Required skills: The candidate has a master's degree in computer science (with honors) with skills in the field of computer graphics and more specifically in geometric modeling. He or she has the skills to deal with a scientific problem and to develop a 3D application (coding in C++ and graphics).

Subject: The construction of a volume mesh for a given geometric domain is a complex problem and has been addressed for many years. The generation of purely hexahedral meshes for domains of any shape is still an open problem. In the framework of Paul VIVILLE's thesis (defense in 2022), we have developed a processing chain for the generation of hexahedral meshes for domains whose shape can be represented by their skeleton.
In the framework of the work proposed in this thesis, a first task will be to obtain the skeleton from the surface of a 3D object. The targeted skeleton will be a graph composed of segments (1D) and in a second step, composed of segments (1D) and surfaces (2D).

In the context of this thesis project, it is the deformation operations of 3D objects that we want to focus on. Interactive space deformation is a very popular approach for shape modeling tasks. Given a well-defined relationship between a user-controlled tool and the surrounding space, transformations applied to the tool affect any object embedded in that space, regardless of its representation model. In order to provide the user with a tool that offers intuitive control over the deformation, many existing techniques propose to control the locality of the deformation induced by each control point. In the typical workflow, the user first designs the tool, which is then linked to the object in a global process. In this context, the locality offered by each control point is a property that must be satisfied globally by the linking process. This contradiction can lead to a complex binding process that can have a negative impact on the user interaction. Moreover, if the degrees of freedom offered by the tool do not match the users' needs, the whole process has to be restarted. In this project, we propose to use local tools that control the deformation of local subspaces and that can be added, used and deleted during the deformation

session. For their expressiveness, versatility and efficiency, we will propose a formulation based on deformation tools that are independent of the chosen coordinate system, and built to avoid discontinuities between the deformed area and the rest of the surrounding space. Depending on their shape and topology, multidimensional deformation tools can be controlled differently. Since the object coordinates are calculated inside the tools, no computation time or memory will be wasted.
In collaboration with a postdoc of the team, Pauline OLIVIER, this second task will be to establish a library of deformation operations. Space deformation operations typically rely on deformation tools that can be cages encompassing the whole object or a part of it, or skeletons as discussed previously. The automation of the construction of global cages (encompassing the whole object) or local cages (on a part of the object) will be realized in order to facilitate the deformation operations. A work on the deformation operations will also be conceived either through a new model integrating the required properties or by combining different existing models in an appropriate way.

In fine, given an object defined by its surface obtained for example by digitization, all the functionalities mentioned should allow to obtain its skeleton (1D or 2D), to apply the existing chain of treatments to decompose its interior volume into hexahedrons, to deform it to adapt it interactively or automatically. The whole will have to be integrated in CGoGN, the geometric modeling platform of the IGG team of ICube.

Application: The various deformation tools that will be implemented within the framework of the CGoGN software of the GAIA platform, will allow, from an initial volume mesh, for example of the heart, to obtain this mesh over a complete cycle of heartbeat thanks to an adequate deformation sequence.

Indeed, our deformation tools will be designed to be interactive, which allows to test in a few moments if the choice of 3D deformation is relevant or to modify it if necessary, to test others, and to choose in one hour of trial-and-error the best 3D deformation sequence to obtain the sequence of volumetric meshes of the core.

This work will be done in collaboration with specialists in cardiac surgery and mechanical simulation within the framework of the science thesis of Darmesh RAMLUGUN Dharmesh who is a cardiac surgeon at the HUS under the supervision of Professor of Mechanics Yannick HOARAU, and that of Pr Laurent Bonnemains, PU-PH. In this work, a numerical protocol ranging from segmentation of geometries from patient imaging, preparation of the geometry for meshing and numerical simulation of blood flow in this geometry will be developed́ and our future work on 3D deformations will be crucial to obtain the sequence of volume meshes for simulation to analyze these realistic flows to understand the impact of anatomical modification on the evolution of congenital heart disease. According to the initial anatomical shape of the pathology, this digitization will allow us to evolve towards a physical simulation which will bring us a new geometrical vision of surgical management; this dynamic element will be an asset for a modern and patient-adapted management.

These advances will be significant because despite scientific advances, surgery for congenital heart disease represents daily challenges because restoration of perfect anatomy often depends on the degreé of embryologic damage. Although this therapy initially restores functional anatomy in a large majoritý of cases, secondary alterations may progressively appear and compromise normal adult life.

This collaboration is an example of a possible spin-off alreadỳ planned but others may arise as we are open to any simulation and virtual realitý application around our 3D deformation models and tools.