The Concept of a Virtual Ring for Mesh Update Methods in Moving Boundary Problems

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As part of the analysis of fluid flow problems, we often encounter situations in which we have to deal with deforming domains. These can either be due to movement of outer boundaries or internal interfaces. Examples are the simulation of packaging machines, melting probes moving through ice, fluid-structure interaction (FSI) problems and others.

Problems including moving boundaries or interfaces impose special requirements on the numerical methods to model the involved motion with respect to both the computational mesh and the solution field. Commonly, a distinction is made between interface capturing and interface tracking methods [1]. In the former approach, one employs an implicit description of the dynamic boundary or interface, which leads to a flexible, yet not quite accurate representation.

The class of interface tracking methods is based on boundary-conforming meshes. This requires an update of the computational mesh to account for the moving boundary. There exist several strategies to modify the mesh according to the change in the position of the interface. These strategies adjust the position of interior nodes based on the prescribed movement of the boundary nodes. As compared to remeshing, this approach is both less costly and more accurate.

A method that, in addition, even allows for topological changes is the Shear-Slip Mesh Update Method (SSMUM) [2]. It is applicable to rotational and translational movement. Here, only elements in a small portion of the mesh are deformed and remeshed by means of a connectivity update, which also circumvents a projection of the solution field and reduces the effort of mutating the mesh.

![Figure 1](image.png)  
**Figure 1.** Sketch of a computational domain closed by the virtual ring in a one-dimensional abstract space.
Based on the SSMUM, the Virtual Ring Shear-Slip Mesh Update Method (VR-SSMUM) [3] has been developed. It is a method that allows to efficiently and accurately handle moving boundary problems. It follows the interface tracking approach and is embedded in the Deforming-Spatial Domain/Stabilized Space-Time (DSD/SST) finite element framework [4]. The main idea is to map the unidirectional and translational movement in the physical domain to a continuous circular movement in a (one-dimensional) abstract space, i.e., along a virtual ring. An augmentation of the moving mesh portion is used, such that it forms the closed virtual ring (see Figure 1). Additionally introduced cells and nodes are deactivated for the solution process. Their sole purpose lies in the mesh deformation.

Even in situations in which the movement is not strictly unidirectional, but also exhibits small transversal components, the concept of the one-dimensional virtual ring can still be applied. We can combine it with another procedure which considers the small deformations, e.g., the elastic mesh update method, which would – taken by itself – fail with respect to the large deformations in the principal direction [5].

When we would like to consider a more arbitrary movement, we can extend the abstract space by another dimension for each additional main direction of motion. Each dimension includes a virtual ring, which in the two-dimensional case leads to a torus on which the computational domain is mapped (see Figure 2).

During the presentation, we will first discuss the mesh update method and its consequences with respect to the space-time finite element method. Furthermore, we will present numerical results for the aforementioned use cases ranging from flow simulations inside packaging machines to FSI problems.

References