Cutting in real-time in corrotational elasticity and perspectives on simulating cuts

Hadrien Courtecuisse, Pierre Kerfriden and Stéphane P. A. Bordas,
[†]Cardiff University, School of Engineering, Institute of Mechanics and Advanced Materials
The Parade, CF24 3AA, Cardiff, Wales, United Kingdom
stephane.bordas@alum.northwestern.edu, kerfridenP@cardiff.ac.uk, hadrien.courtecuisse@gmail.com

Key words: surgical simulation, cutting, multiscale, model reduction, domain decomposition, XFEM, meshless

ABSTRACT

We focus here on the simulation of surgical acts of types similar to cutting and needle insertion in soft tissue, in real time (500Hz), where the scale of the surgical instrument is several orders of magnitude smaller than that of the organ.

We provide review of the state of the art and make propositions (Fig. 1) to address some of the main difficulties in this area:

- complex geometries - implicit boundaries, XFEM, meshless, advanced meshing

- multiple scales (large gradients) - domain decomposition and model reduction [4]

- error control and adaptivity [1]

- parallel implementation Graphical Processing Units (GPUs) [2, 3]

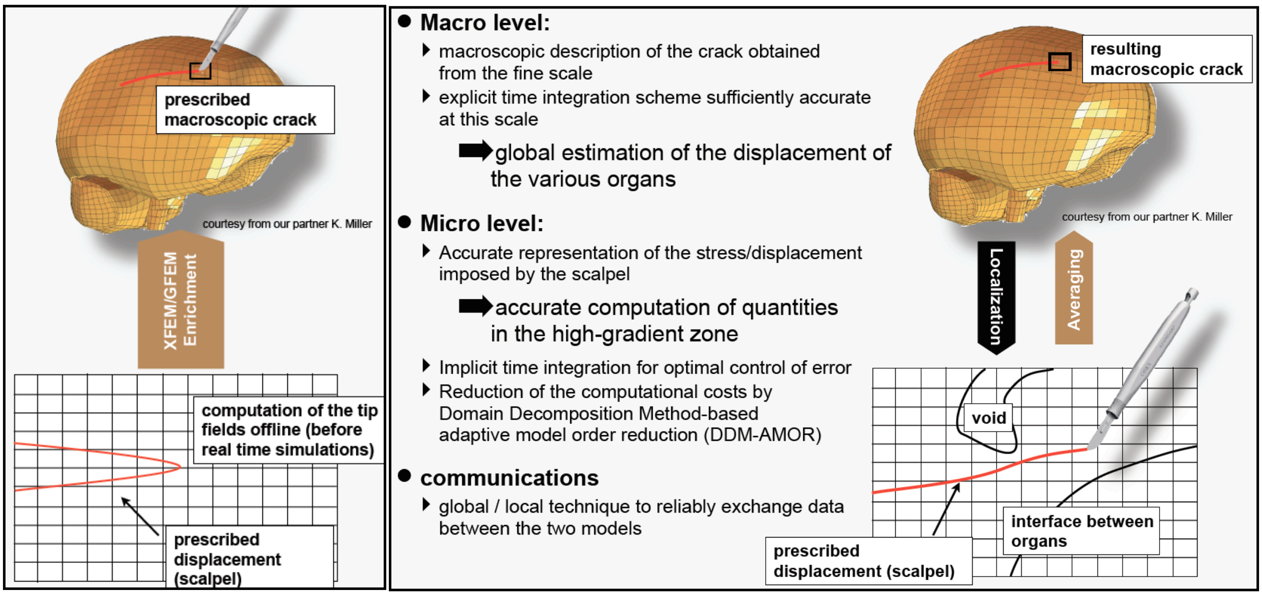

Figure 1: Two proposed methods for the multiscale simulation of cutting: [Left: two scale description] Macroscopic crack problem enriched with microscopic fields around the virtual scalpel through XFEM. Enrichment functions obtained by solving a local (micro) problem. [Right: Global/Local (Macro/Micro)]semi-concurrent multiscale method: the macroscopic crack is obtained through a microscopic simulation. Coarse scale: geometry and material properties of the brain represented crudely (away from the cut), the cut is incorporated without remeshing using XFEM. Fine scale ("micro") representation of the geometry (zoom) in the vicinity of the cut with implicit representation of the cut and internal organ boundaries by the XFEM, implicit representation of the interfaces (perfect bonding or contact) between organs and of the voids: regular meshes are sufficient thanks to enrichment. (Note: micro is used here abusively to denote a scale 10 to 1000 times smaller

than the macroscopic scale (mm).

We then describe a series of contributions in the field of real-time simulation of soft tissue biomechanics. These contributions address various requirements for interactive simulation of complex surgical procedures. In particular, we present results in the areas of soft tissue deformation, contact modelling, simulation of cutting, and haptic rendering, which are all relevant to a variety of medical interventions. The contributions we describe share a common underlying model of deformation and rely on GPU implementations to significantly reduce computational expense.

References

[1] Wu X., Downes M.S., Goktekin T., and Tendick F.. Adaptive nonlinear finite elements for deformable body simulation using dynamic progressive meshes. Computer Graphics Forum, 20(3), (2001).

[2] Joldes G.R., Wittek A., Miller K. Real-time nonlinear finite element computations on GPU- application to neurosurgical simulation Computer Methods in Applied Mechanics in Engineering in press. (2010)

[3] Courtecuisse H., Junga H., Allard J., Duriez C., Lee D.Y., Cotin S. GPU-based real-time soft tissue deformation with cutting and haptic feedback Progress in Biophysics and Molecular Biology (2010)

[4] Kerfriden P, Passieux J C, Bordas S, Local/Global model order reduction strategy for the simulation of localised failure, International Journal for Numerical Methods in Engineering , 89 (2) (2012) 154-179

Acknowledgment of S. Bordas for the financial support of The European Research Council Starting Independent Research Grant (ERC Stg grant agreement No. 279578)