Multiscale/multiphysics modeling of ocular physiology: the eye as a window on the body

Giovanna Guidoboni[*], Lorenzo Sala[†], Marcela Szopos[§], Christophe Prud'homme[†], Riccardo Sacco[**] and Alon Harris[††]

[*] Departments of Electrical Engineering and Computer Science, Department of Mathematics
University of Missouri, 201 Naka Hall, Columbia (MO) 65211, USA
e-mail: guidobonig@missouri.edu

[†]Université de Strasbourg, CNRS, IRMA UMR 7501
7, rue René-Descartes 67084 Strasbourg Cedex, France

[§]Laboratoire MAP5 (UMR CNRS 8145), Université Paris Descartes
45 rue des Saints Pères, 75270 Paris Cedex 06 FRANCE

[**] Dipartimento di Matematica, Politecnico di Milano
Piazza Leonardo da Vinci 32, 20133 Milano, Italy

[††]Department of Ophthalmology, Indiana University School of Medicine
Glick Eye Institute, 1160 W. Michigan St, Indianapolis (IN) 46202, USA

ABSTRACT

Vascular anomalies related to alterations in blood flow, vessel structure and vascular function are involved in the pathophysiology of many diseases, including cardiovascular diseases, diabetes and neurodegenerative disorders. Oftentimes, the vascular-implicated damage goes on silently for many years without detection in various organs, including brain and kidneys. Thanks to its accessibility via noninvasive measurements, the eye offers a very unique opportunity for vascular assessment. However, structural and functional vascular features in the eye are the results of complex interactions between factors that *(i)* are specific to the eye, e.g. intraocular pressure; *(ii)* are associated with other organs, e.g. intracranial pressure; and *(iii)* depend on systemic conditions, e.g. blood pressure. The complexity of the mutual interactions among these multiscale components make it extremely difficult to single out the relative contribution of each factor experimentally. To address this challenge, we have been developing a high performance computing platform that *(i)* enables an integrated view of multimodal ocular imaging data; and *(ii)* processes the integrated data by individualizing the analysis method to the patient's specific clinical conditions. This platform is based on Feel++ [1], a finite element C++ library to solve partial differential equations (PDEs), which has been interfaced with OpenModelica [2], a freeware targeted to deal efficiently with ordinary differential equations (ODEs). The PDE/ODE coupling required by the need of accounting simultaneously for local and nonlocal factors is dealt via *(i)* operator splitting for the time discretization, which provides modularity of the solution algorithm while preserving the physical energy at the discrete level [3]; and *(ii)* Hybridizable Discontinuous Galerkin (HDG) method for the PDE discretization, which ensures conservation of fluxes of mass and linear momentum at the discrete level [4].

REFERENCES

[1] Prud'Homme C et al.. *Feel++: A Computational Framework for Galerkin Methods and Advanced Numerical Methods.* ESAIM: Proceedings, EDP Sciences. 2012; 38: 429-455.

[2] *https://openmodelica.org/*. Open Source Modelica Consortium; Linkping, Sweden.

[3] Carichino L et al.. *Energy-based operator splitting approach for the time discretization of coupled systems of partial and ordinary differential equations for fluid flows: the Stokes case.* J. of Comput. Physics, 2018; 364: 235-256.

[4] Prada D. *A hybridizable discontinuous Galerkin method for nonlinear porous media viscoelasticity with applications in ophthalmology.* PhD Dissertation. Purdue University. 2016