LifeV Project 2005 Report

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Contents

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1 Description

LifeV is a joint development project between École Polytechnique Fédérale de Lausanne(CMCS), Politecnico di Milano(Italie – MOX) and INRIA(France – REO) which started in 1999/2000. The author of this report leads this project since November 2003 which comprises now about 30 registered developers and contributors ranging from senior researchers to PhD students.

LifeV is primarily a finite element (FE) library providing implementations of state of the art mathematical and numerical methods. It serves both as a research and production library. It has been used already in medical and industrial context to simulate fluid structure interaction and mass transport.

LifeV has applications in many domains like fluid dynamics, structure dynamics, heat transfer, fluid structure interaction or transport in porous media. One of the major goal of LifeV is to provide an implementation for the haemodynamic testcases (fluid structure interaction, mass transport and multiscale simulation) proposed by the Haemodel project.

2 Recent Advances in the Context of Haemodynamics

2.1 Multiscale and Multiphysics

LifeV is mainly developed in two areas: multiphysics and multiscale simulation. The effort is being not only supported by the Haemodel project but also partly by the three research groups (REO, CMCS and MOX).

We work on defining a proper computational framework for multiscale and multiphysics. In particular, we try to define interfaces for the various coupling systems either multiscale or multiphysics — fluid-structure interaction, mass transport, 0D-1D, 1D-1D, 0D-3D or 1D-3D. — In medium long term, we wish to be able to assemble easily these components in a distributed/parallel environment.

The fluid structure framework has been designed such that it is easy to incorporate new fluid-structure coupling algorithms thanks to the work of G. Fourestey, M Fernandez and C. Prud'homme. It has been successfully tested with two new coupling strategies [11] and [24, 23].

Regarding mass transport, several medical applications have been developed by Martin Prosi using the various solvers available in LifeV, see [18, 17, 26]

Concerning the multiscale framework, it is still very much in infancy though good progress has been made. It started with the postdoctoral work by V. Martin, see [14], who implemented a 1D solver for one and two tubes. This work is being extended by M. de Luca and T. Passerini to a network of 1D tubes using a graph representation (with the Boost Graph Library[1]) as proposed by C. Prud'homme. A. Moura contributed an implementation of the first results of her research concerning multiscale/multiphysics coupling (3DFSI[2]-0D and 3DFSI-1D) with compliant vessels, see [15, 6]. There have been also a contribution by C. Vergara, see [15], concerning the proper imposition of flow rates when coupling domains with different scales and the validation of the algorithm should be soon contributed to LifeV thanks to the work of C. Vergara and A. Veneziani, see [1].

2.2 From Medical Images To Computational Meshes

There is also an effort in generating computational meshes from medical images in order to provide realistic geometries (eventually with pathologies) to the simulation kernel, see [13]. However, there remains many issues such as generated mesh quality, handling of large datasets or robust image segmentation before the effort can produce a useful tool.

3 More General Advances

LifeV has also made progress in more general areas

- Stabilisation methods, see [3, 4], thanks to the implementation effort by M Fernandez and C. Winkelmann.
- A discontinuous Galerkin implementation has been contributed by D. Di Pietro [16]
- A new mathematical kernel is being developed by C. Prud'homme and is already in use in CMCS that should allow for *(i)* seamless 1-2-3D simulations *(ii)* high order(hp/spectral) numerical methods *(iii)* a programming syntax very close to the mathematical one for variational formulations, see [21].

4 LifeV in Use

LifeV is mainly used of course in the context of haemodynamics but not only.

[1] `http://www.boost.org`

[2] FSI: Fluid Structure Interaction

4.1 Numerical Simulation of 3D Shear-Thinning Blood Flow in Axisymmetric Vessel Stenosis

M Prosi at MOX, T. Bodnar and Joao Janela at the university of Lisbon collaborated on non-newtonian fluid simulation using LifeV. M. Prosi and T. Bodnar compared the numerical results obtained with two different codes, LifeV on unstructured grids and a finite volume code on structured grids, see [2]. The initial results seem promising and in accordance with results already published on this benchmark.

4.2 Influence Of The Aortic Arch Geometry On High Blood Pressure

Y. Maday, N. Poussineau and M. Szopos for Paris VI, and Damien Bonnet and Phalla Ou at Necker Hospital are starting a collaboration to study the influence of the aortic arch geometry on high blood pressure. Some initial results using the fluid-structure interaction framework in LifeV are already confirmed (at least qualitatively) by what medical doctors observe using MRI.

4.3 Numerical Simulation Of The Flow In An Abdominal Aortic Aneurysm (AAA)

Anne-Virginie Salsac (UTC Compiegne) is collaborating with M.A. Fernandez (REO) and P. Le Tallec (Ecole Polytechnique) on the 3D numerical study of the blood flow in an AAA. The numerical results in a rigid wall configuration have been compared to the experimental study with PIV (particle image velocimetry) measurements, carried out by A.-V Salsac during her PhD work. Numerical simulations are now being performed with compliant walls, in order to quantify the influence of the wall motion on the flow and on the hemodynamic stresses.

4.4 Numerical Simulation Of The Electrical Activity Of The Heart

Muriel Boulakia (REO) is working with M.A. Fernández and J.-F. Gerbeau (REO) on the numerical simulation of the action potential propagation in the heart. One of the objectives of this study concerns the numerical simulation of the electrocardiogram (ECG), by coupling the cardiac action potential with the thorathic potential.

4.5 Drug Release From A Stent Into The Arterial Wall

Mathematical modeling of the drug release from a drug eluting stent into the arterial wall. Development of appropriate pharmacokinetic models, numerical simulation and experimental valitation.

Collaborating partners: MOX - Modeling and Scientific Compution, Department of Mathematics, Politecnico di Milano (M.Prosi, P.Zunino, L. Formaggia, S. Minisini)

LaBS - Bioengineering Department and Laoratory of Biological Structure Mechanics, Department of Bioengineering, Politecnico di Milano. (G. Dubini, F. Migliavacca, F. Gervaso)

Dipartimento di Chimica - Department of Chemistry, University of Bologna. (N. Roveri, B. Palazzo)

4.6 Flow Rates Estimates From The Doppler Measures

Flow rates estimates from the Doppler measures of the maximum velocity based on CFD simulations: for this problem an extensive use of the Lagrange multiplier technique has been exploited, see [22].

4.7 Aneurisk Project

Collaboration: MOX - Dipartimento di Matematica; LaBS - Dipartimento di Ingegneria Strutturale e Bioingegneria, Politecnico di Milano; Azienda Ospedaliera - Ospedale Niguarda Ca' Granda, Milano; Scuola di Neurochirurgia - Università degli Studi di Milano; Istituto di Ricerche Farmacologiche Mario Negri (IRFMN), Bergamo.

In the framework of the Aneurisk[3] project whose goal is to develop statistical and numerical tools to evaluate and predict the risk of rupture of cerebral aneurysms, LifeV is giving a fundamental contribution. We simulated the haemodynamics of the Circle of Willis (using 1D solver) and we are going to study the fluid-dynamics of blood inside aneurysms (geometries reconstructed from medical images). Extensive numerical simulations will be carried out in order to find a morphological and fluid-dynamical classification of cerebral aneurysms, see [12].

5 Research Dissemination

The research accomplished with the aid of LifeV is disseminated in various ways. The list of publications at the end of the report shows for the year 2005 about

[3] http::www2.mate.polimi.it:8080/aneurisk

twenty articles, reports, conference proceedings and talks. Also, we maintain a website http://www.lifev.org whose aim is to document and illustrate the progress made by the LifeV project.

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