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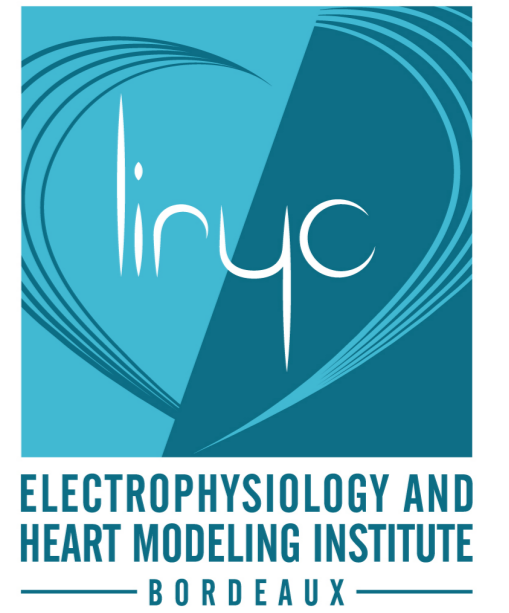
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# Overview on the Cardiac ElectroPhysiology Simulator (CEPS)

Nejib Zemzemi, Yves Coudière, Florian Caro, Marc Fuentes,

INRIA Bordeaux Sud-Ouest, Institut Mathématiques Bordeaux, Institut de Rythmologie et Modélisation Cardiaque

nejib.zemzemi, yves.coudiere@inria.fr, florian.caro@inria.fr, marc.fuentes@inria.fr



## Goals

- Develop a modular code called CEPS (Cardiac ElectroPhysiology Simulator) usefull for doctors and for applied mathematician researchers.
- Develop a paralell code in order to take account multiple scales (from the macroscopic scale to the microscopic scale).
- Develop a kernel framework useful for researchers in medecine and in applied mathematics.
- Develop a parallel code in order to be efficient with clusters like Plafrim, Curie, or personal computer...
- Develop useful tools for installation of the code and validation test cases.

## Actors

A lot of persons work in the CEPS code, see the not exhaustive list below

- Juhoor Mehdi (old ADT), the foundation of CEPS with a lot of contibution of Nejib Zemzemi who contributes on the framework of CEPS.
- Marc Fuentes (SED), to help us on everything on the code (compilation, development,...).
- Pierre Elliott Bécue works with CEPS for simulation at the microscopical scale
- Gerard Antoine, works with CEPS on the implementation of the bilayer atria model in CEPS.
- Florian Caro works on numerical methods and on microscopic scale with PE Bécue.
- Yves Coudière will works on high order Finte Volume mehods, thanks to the framework of CEPS, Those schemes are devoted to be implemented in CEPS.
- Charlie Douanla-lontsi works on high order time numerical schemes with Charles Pierre. Those schemes are devoted to be implemented in CEPS.
- Students and Phd thesis for the future.

## What it is done currently in CEPS

- Mono domain model is developed in CEPS

$$\begin{cases} \chi(C_m \partial_t u + I_{ion}(u, v)) - \operatorname{div}(\sigma \nabla u) = 0 & \text{dans } \Omega_H, \\ \partial_t v - g(u, v) = 0 & \text{dans } \Omega_H, \\ n \cdot \sigma \nabla u = 0 & \text{sur } \partial\Omega_H, \end{cases}$$

where  $v$  and  $u$  denote the unknown vector for the ionic variables and the electric potential. Parameters  $\chi$  and  $C_m$  are physical data and  $\sigma$  denotes the conductivity tensor of the medium.

- About 11 300 lines of C++ (whith header files but without test files)

Language	files	blank	comment	code
C/C++ Header	98	2915	7357	11343
C++	55	1602	3000	7610
CMake	16	74	96	311
SUM:	169	4591	10453	19264

- Validation

– Unit test case.

– Validation test case (comparison between exact solution and numerical solution).

1/16 Test #1: utility.numeric .....	0.19 sec
2/16 Test #2: linearAlgebra.distributedVector .....	2.39 sec
3/16 Test #3: linearAlgebra.distributedHaloVector ...	1.12 sec
4/16 Test #4: linearAlgebra.distributedMatrix .....	1.24 sec
5/16 Test #5: linearAlgebra.linearSystem .....	1.17 sec
6/16 Test #6: geometry.geometry .....	1.18 sec
7/16 Test #7: ode.ionicModels .....	8.58 sec
8/16 Test #8: pde.common .....	0.12 sec
9/16 Test #9: pde.boundaryConditions .....	1.14 sec
10/16 Test #10: pde.assemblers .....	10.00 sec

11/16 Test #11: pde.junctionAssembler .....	3.50 sec
12/16 Test #12: pde.writers .....	1.23 sec
13/16 Test #13: pde.heat .....	35.44 sec
14/16 Test #14: cardiac.problem .....	1.39 sec
15/16 Test #15: cardiac.solver .....	1.07 sec
16/16 Test #16: cardiac.myocardium .....	1.14 sec

- Numerical methods

- $P^1$  finite elements for the spatial discretisation.
- Euler explicit method for the time discretisation.

- Dependancies

- MPI or OpenMP.
- ParMetis for the partitioning of unstructured meshes.
- HDF5, the format of some used meshes.
- PETSc, the library for the resolution of linear systems.

CEPS allows us to develop our own numerical methods (in space and time) in order to be the more efficient as possible.

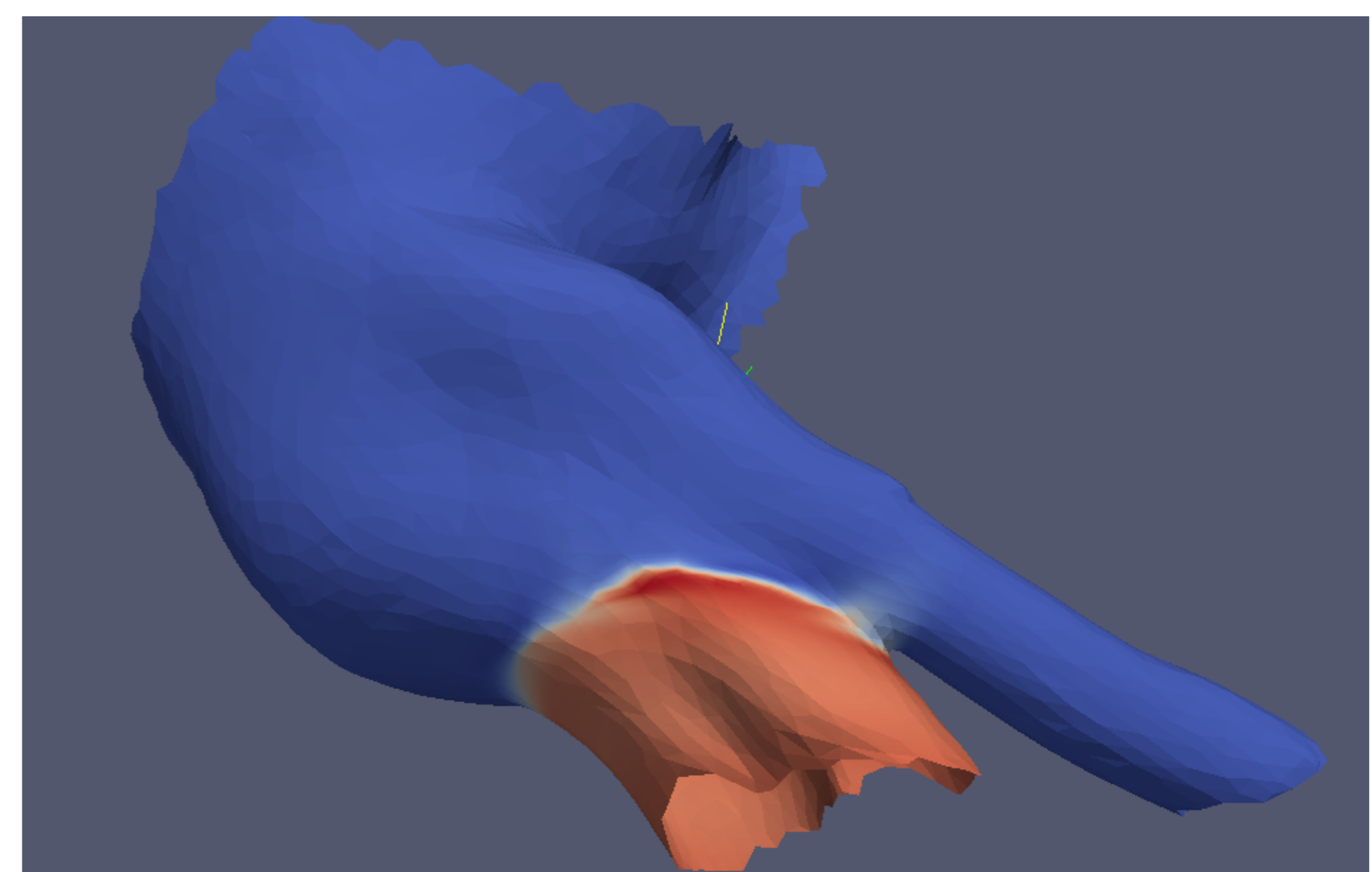


Figure 1: Example of a simulation of the Bilayer Atria model

## Project IDAM (Integration between Data And Models for cardiac electrophysiology)

- Treat pictures from doctors in order to generate meshes usefull for aplied mathematicians.
- Assign realistic tissue parameters for various cardiac structures, field directions of the fibers muscle, gradients apex-base or parameters transmural...
- Use CEPS simulator by using meshes obtain by the previous step
- Import and display simulation results and correlate these results with the experimental data and imaging electrical mapping.
- Development will be done in MedInria with the plugin Music and in collaboration with the Carmen team.

## Perspectives

- Use Scotch instead of Parmetis due to the non reactivity of Parmetis team. Scotch is an equivalent of Parmetis developed at INRIA to operate matrix decomposition.
- Run these tests on the clusters at bigger scales to identify scaling issues.
- Use CEPS to test high order Finite Volume scheme (Y. Coudière) and high order numerical scheme in time (C. Pierre and C. Douanla-lontsi).
- Use CEPS for numerical simulation at the microscopic scale (P.E. Bécue and M. Potse).
- Use CEPS for the development of future research with students.
- Compare macroscopic bi-domain and monodomain model to homogenization-based methods achieved in CARMEN with the microscopic mode developed with P.E. Bécue and M. Potse.
- Integrate Bilayer Atria model in CEPS with A. Gérard and compare obtained results with those obtained by classical models.