



**HAL**  
open science

## **C.E.P.S.: an efficient tool for cardiac electrophysiology simulations**

Mehdi Juhoor, Yves Coudière, Nejib Zemzemi

► **To cite this version:**

Mehdi Juhoor, Yves Coudière, Nejib Zemzemi. C.E.P.S.: an efficient tool for cardiac electrophysiology simulations. Workshop LIRYC, Oct 2013, Bordeaux, France. hal-00925834

**HAL Id: hal-00925834**

**<https://inria.hal.science/hal-00925834>**

Submitted on 8 Jan 2014

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



# C.E.P.S : an efficient tool for cardiac electrophysiology simulations

MEHDI JUHOOR, YVES COUDIÈRE, NEJIB ZEMZEMI

mehdi.juhoor@inria.fr, yves.coudiere@inria.fr, nejib.zemzemi@inria.fr



## PROVIDE A UNIQUE PLATFORM FOR CARDIAC ELECTROPHYSIOLOGY RESEARCH

### ABOUT THE PROJECT

Being developed at INRIA Bordeaux, CARMEN team

Main goals:

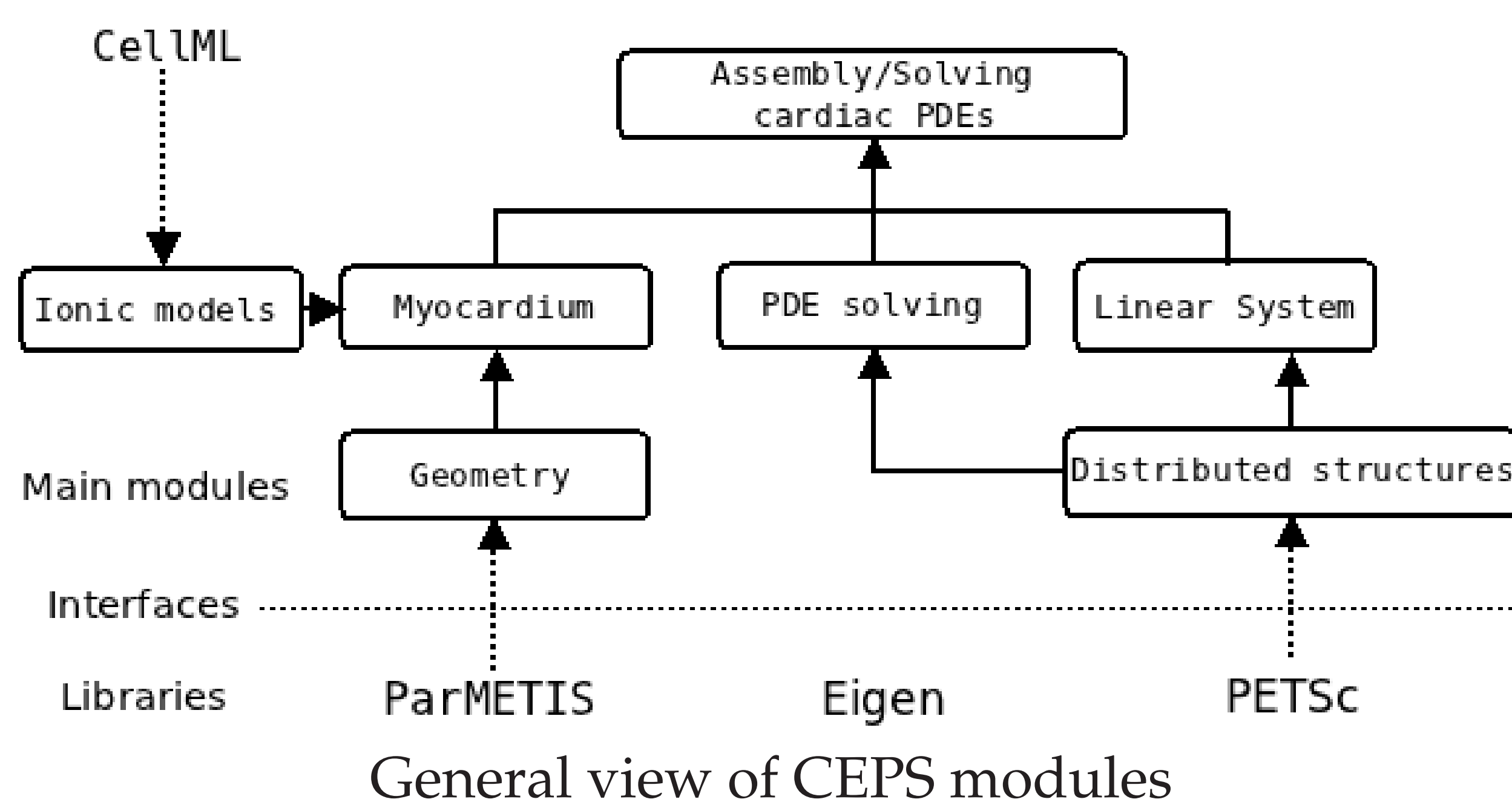
- Simulating the electrophysiology of the heart from cell ionic activity to body surface.
- Modelization of forward problem and solving of inverse problem in cardiac electrophysiology

### CODE DESIGN

- Highly specialized code
- Ready to run on HPC platforms
- Enable high-order numerical methods
- Easily add new PDE/ODE systems
- Make use of efficient and well-known libraries

## GENERAL ARCHITECTURE

### MODULES



### DESIGN

C++ code, aiming for:

- genericity
  - efficiency
  - readability
  - portability
- Documentation generation via Doxygen

Using alternative libraries is possible through interface implementation  
Produced code fully tested with CxxTest and continuous integration through Jenkins

## COMPUTATIONAL DOMAINS

### MOTIVATION

Compute on major structures of the heart in a single simulation :

- ventricles
- atria
- conduction system network

Express the coupling between these structures to account for the conduction of the electrical impulse.

### DISCRETIZATION

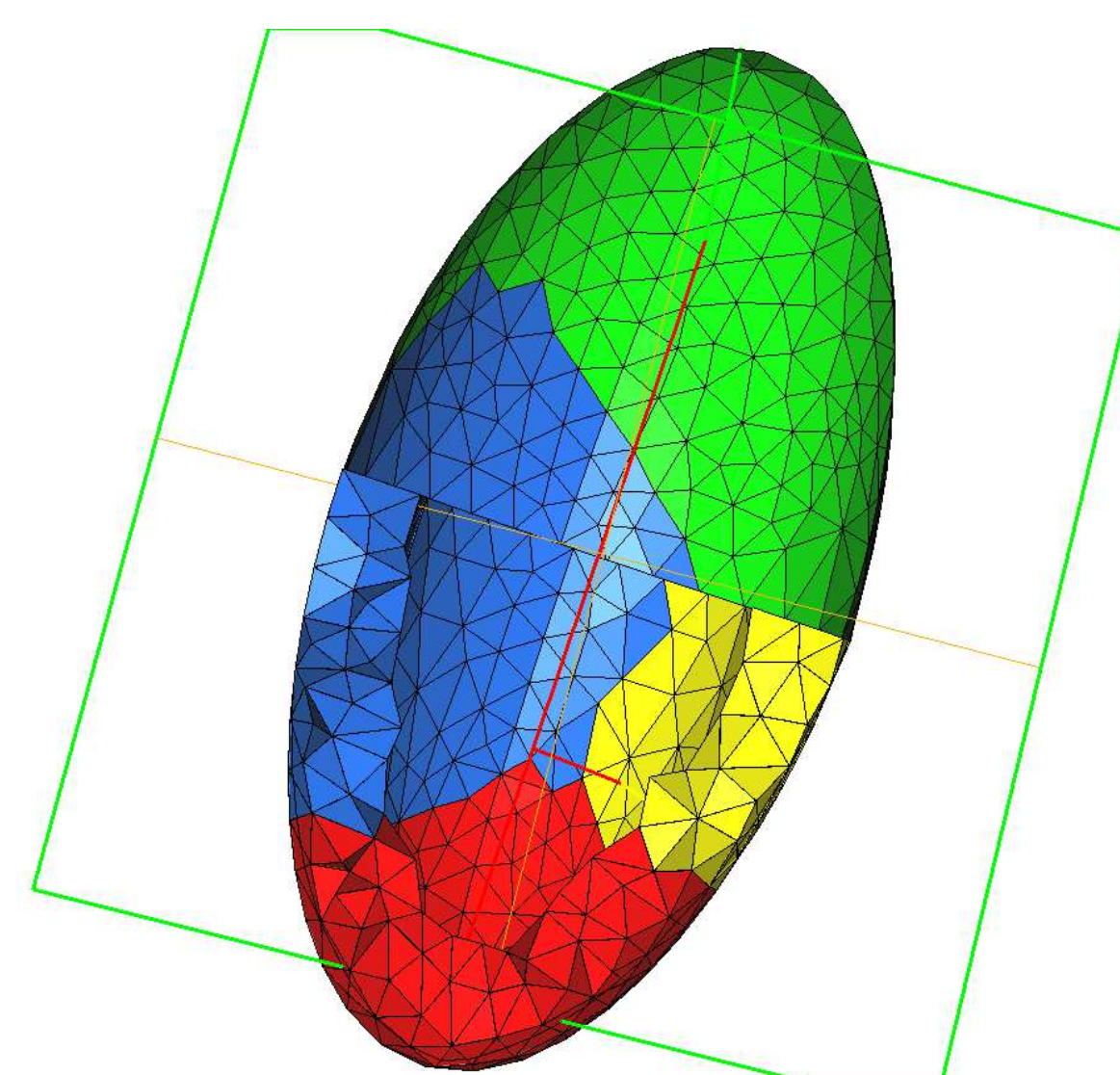
Each structure is represented in 3D space by a mesh

- volumic (ventricles/thorax)
- surfacic (atria)
- cable (fibers of conduction system)

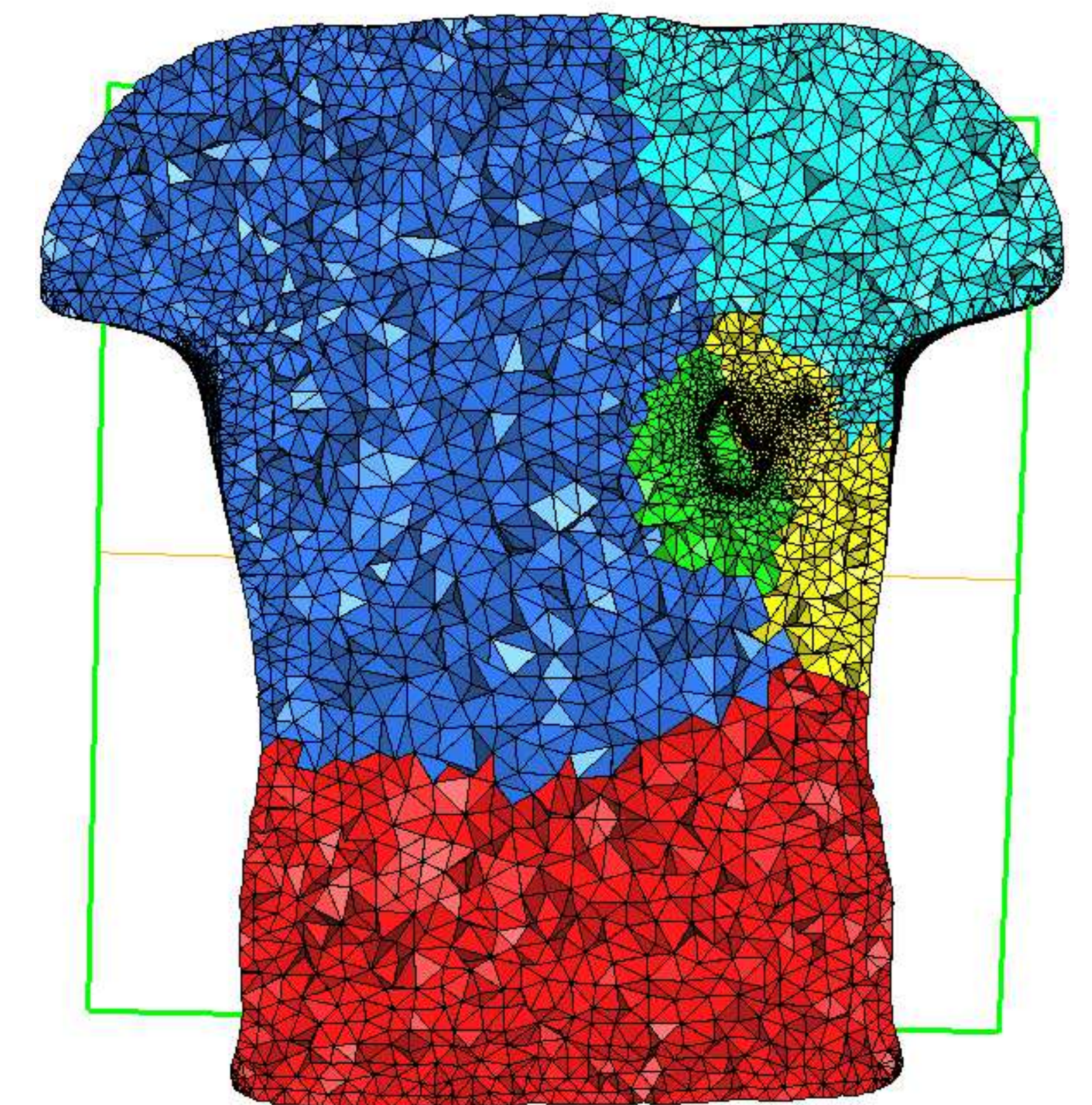
Partitioning of the geometry in order to:

- achieve load balancing
- minimize communications
- reduce computing time

### GEOMETRY EXAMPLES



Volumic, surfacic and cable elements in a single partitioned geometry. Each process is assigned a color.



Volumic geometry of heart and torso.

## PARALLEL IMPLEMENTATION

### COMPUTATIONAL CHALLENGES

Accurate models are increasingly complex  $\Rightarrow$  expensive computations

Computing time increases with:

- problem size
- fine space/time discretization
- accurate numerical methods
- electrophysiological ionic models

### IMPLEMENTATION

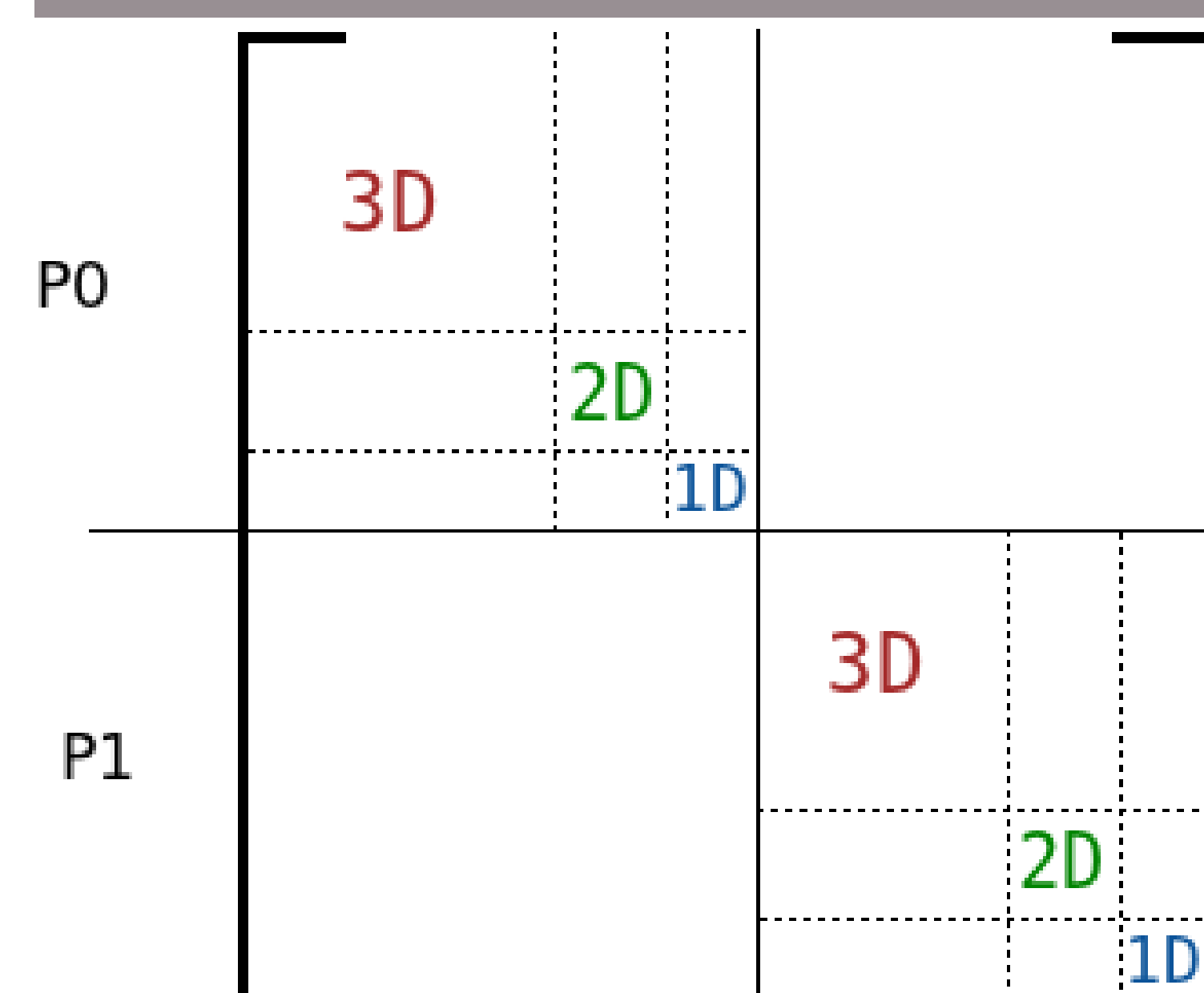
Parallel computing design of each component of the code

- Mesh partitioning: ParMETIS[2]
- Linear system solving: PETSc[1]
- I/O: HDF5[3]

High level of abstraction, transparent way of manipulating distributed data structures.

## PROBLEM DISCRETIZATION

### MATRIX STRUCTURE



Discretization of cardiac PDEs lead to linear systems in the form  $Ax = b$

This figure shows the parallel structure of distributed matrix  $A$  for multi-dimensional geometries

Coupling between elements of different dimension will be expressed in this matrix

## NEXT STEPS

### SHORT-TERM

Implementation of:

- ionic models
- multi-dimensional coupling
- assembly/resolution of monodomain/bidomain equations

### LONG-TERM

Integration with other LIRYC tools

- CARP (Edward J. Vigmond)
- CardioViz(Imaging)
- ...

## REFERENCES

- [1] Satish BALAY et al. *PETSc Web page*. <http://www.mcs.anl.gov/petsc>. 2013.
- [2] George KARYPIS. *ParMETIS Web page*. <http://glaros.dtc.umn.edu/gkhome/metis/parmetis>. 2013.
- [3] THE HDF GROUP. *Hierarchical data format version 5*. 2000-2010. URL : <http://www.hdfgroup.org/HDF5>.