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► **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://hal.inria.fr/hal-00925834>**

Submitted on 8 Jan 2014

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

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## PROVIDE A UNIQUE PLATFORM FOR CARDIAC ELECTROPHYSIOLOGY RESEARCH

### ABOUT THE PROJECT

Being developed at INRIA Bordeaux, CARMEN team

Main goals:

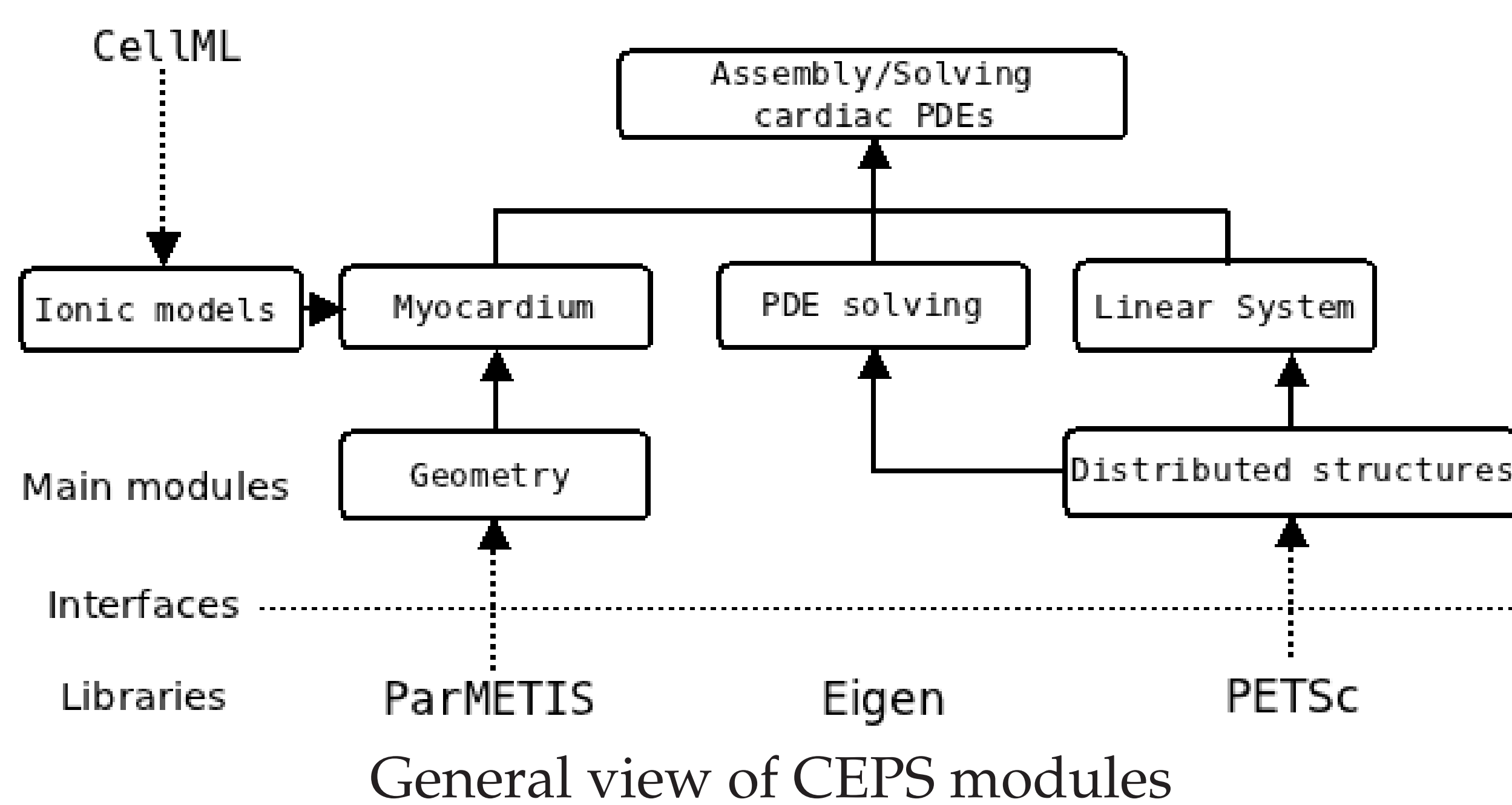
- Simulating the electrophysiology of the heart from cell ionic activity to body surface.
- Modelization of forward problem and solving of inverse problem in cardiac electrophysiology

### 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



General view of CEPS 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

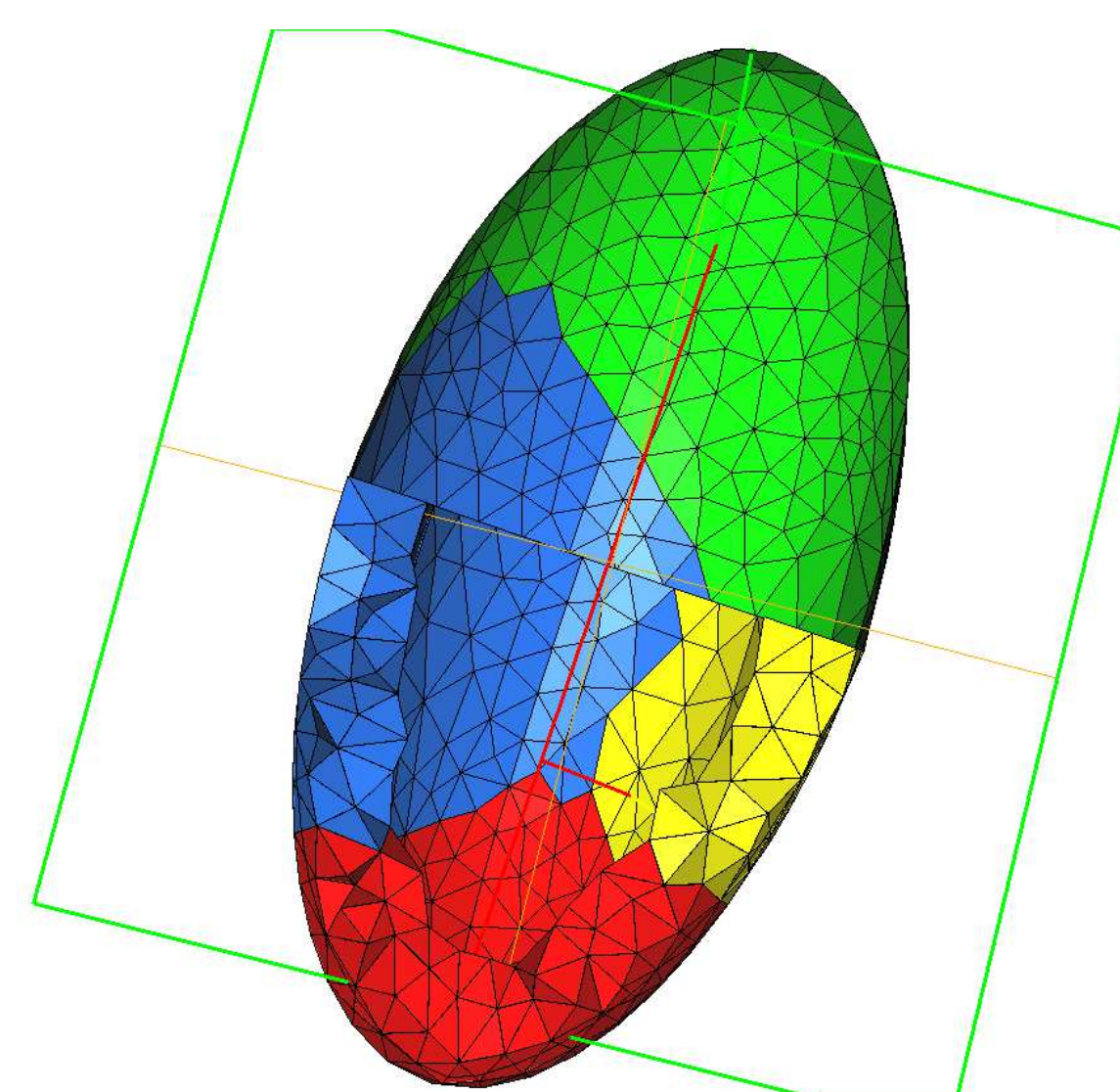
Each structure is represented in 3D space by a mesh

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

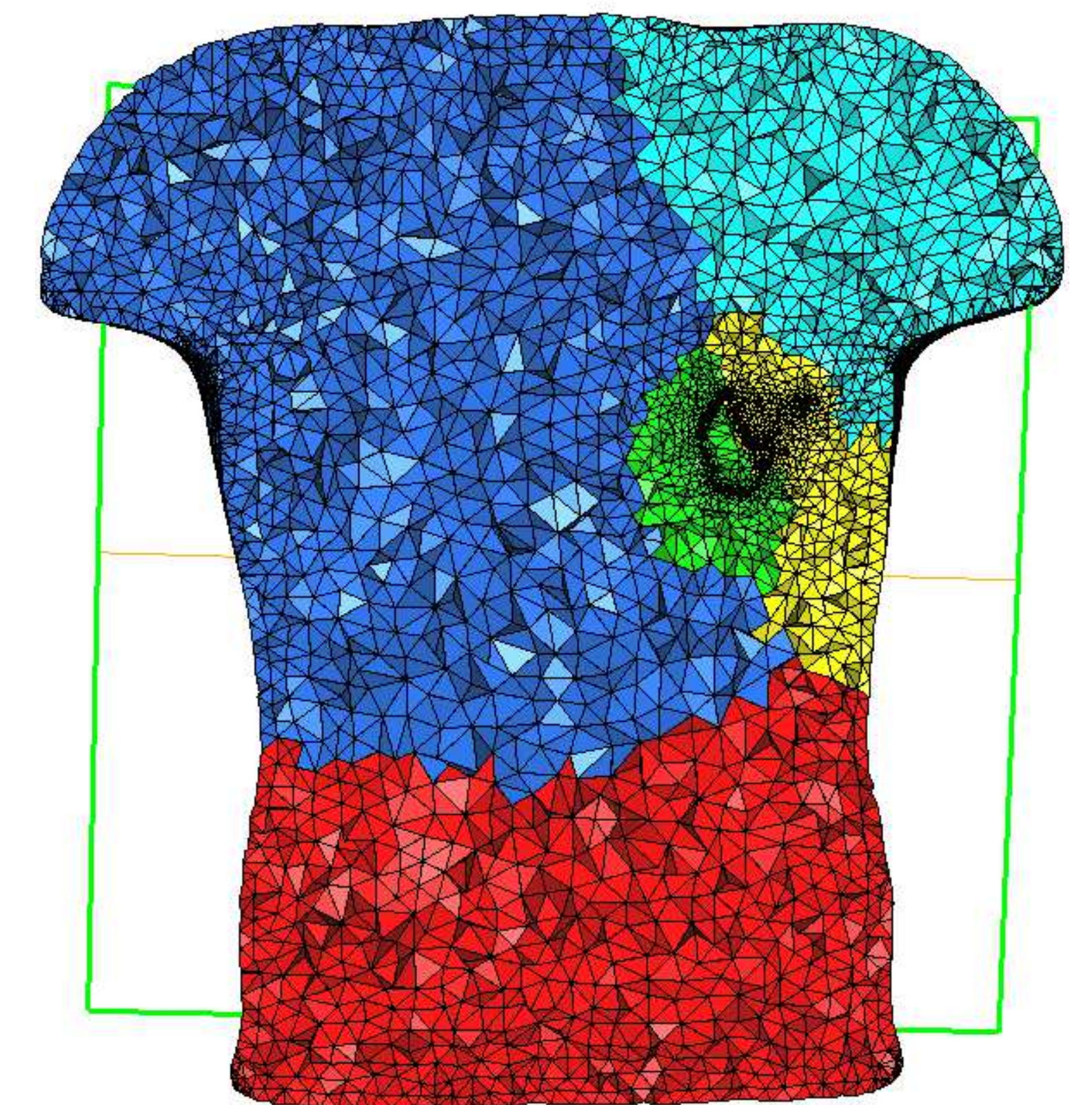
Partitioning of the geometry in order to:

- 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

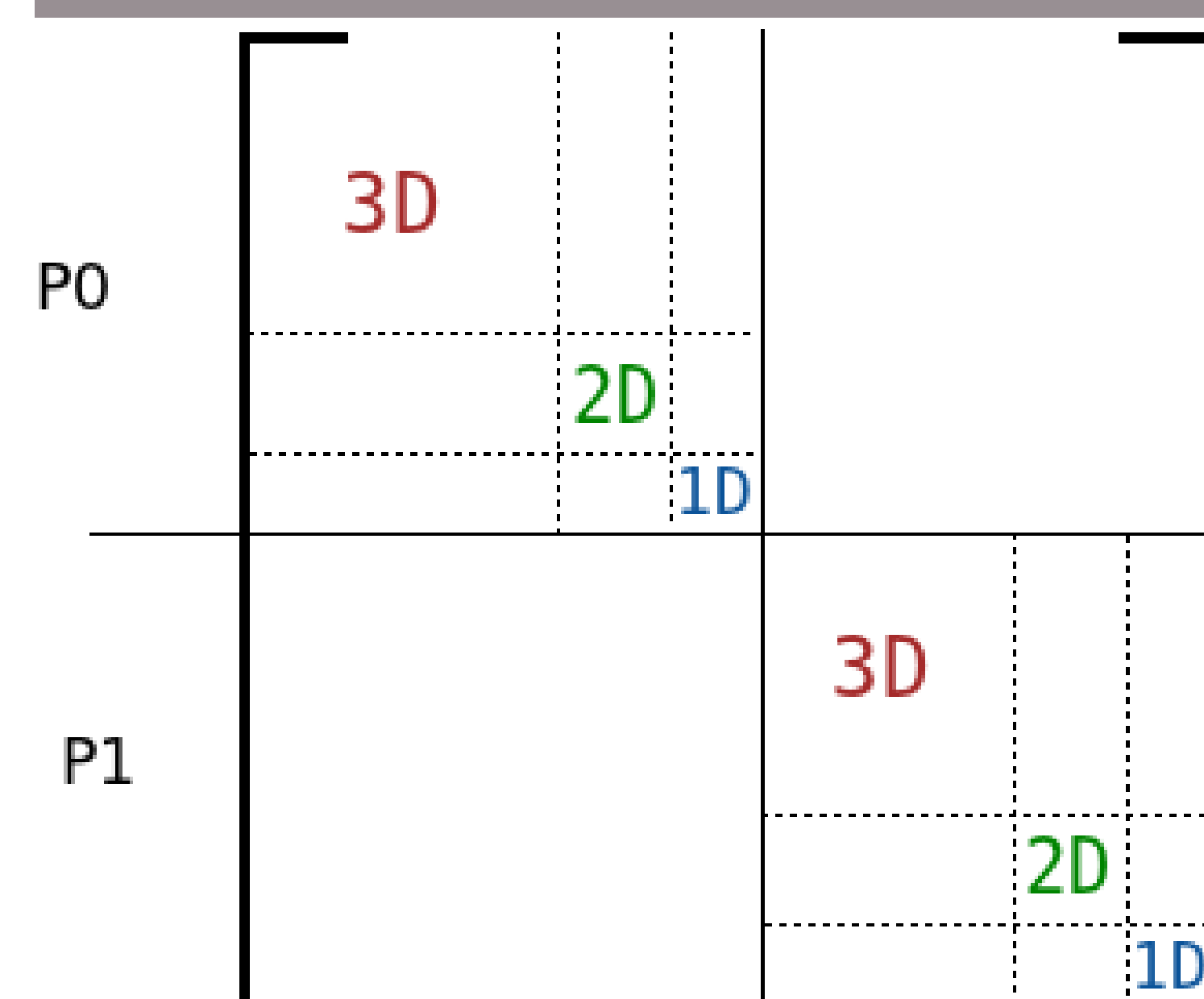
Parallel computing design of each component of the code

- 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>.