# 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**

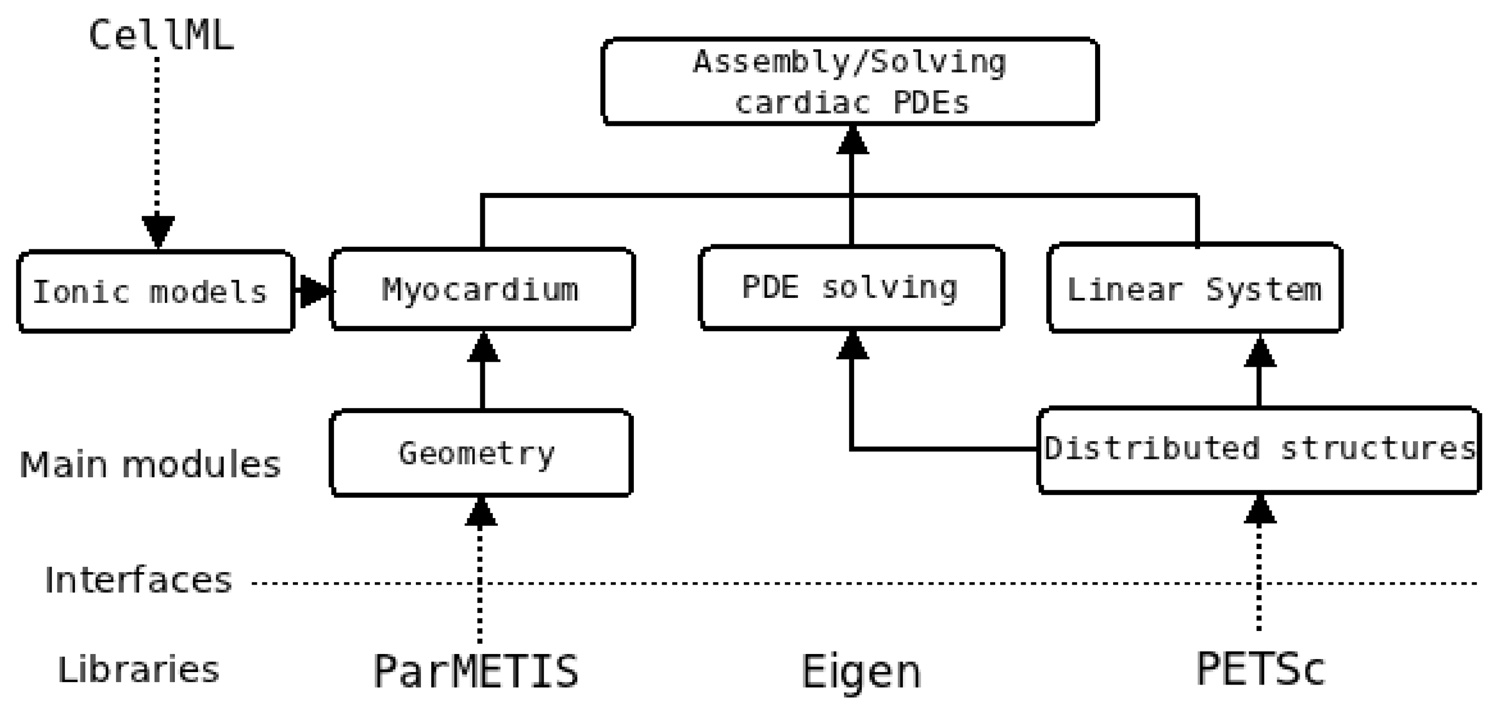
– **Enable high-order numerical methods**

– **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

## PARALLEL IMPLEMENTATION

### COMPUTATIONAL CHALLENGES

**Accurate models are increasingly complex** ⇒ 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.

## 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)

– ...

## 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)

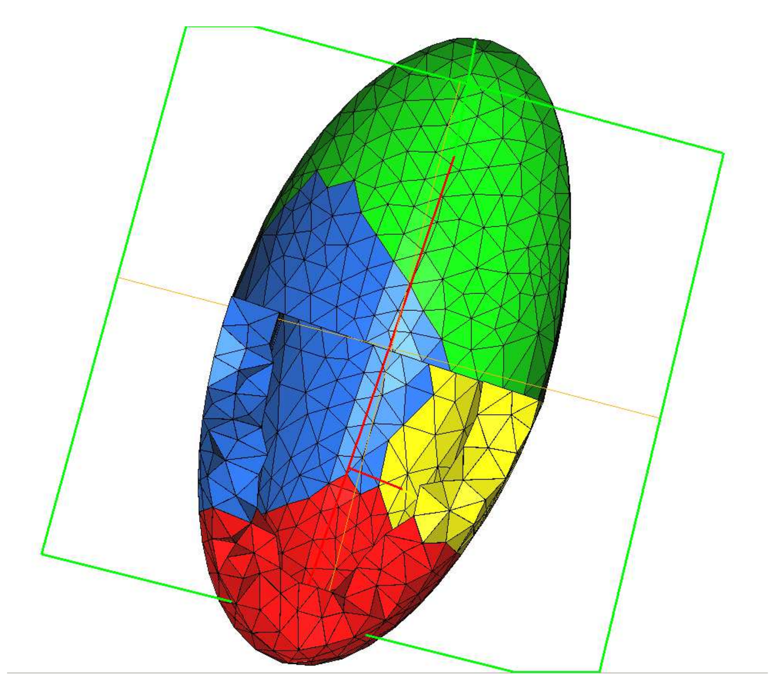
**Partitioning of the geometry in order to:**

– achieve load balancing

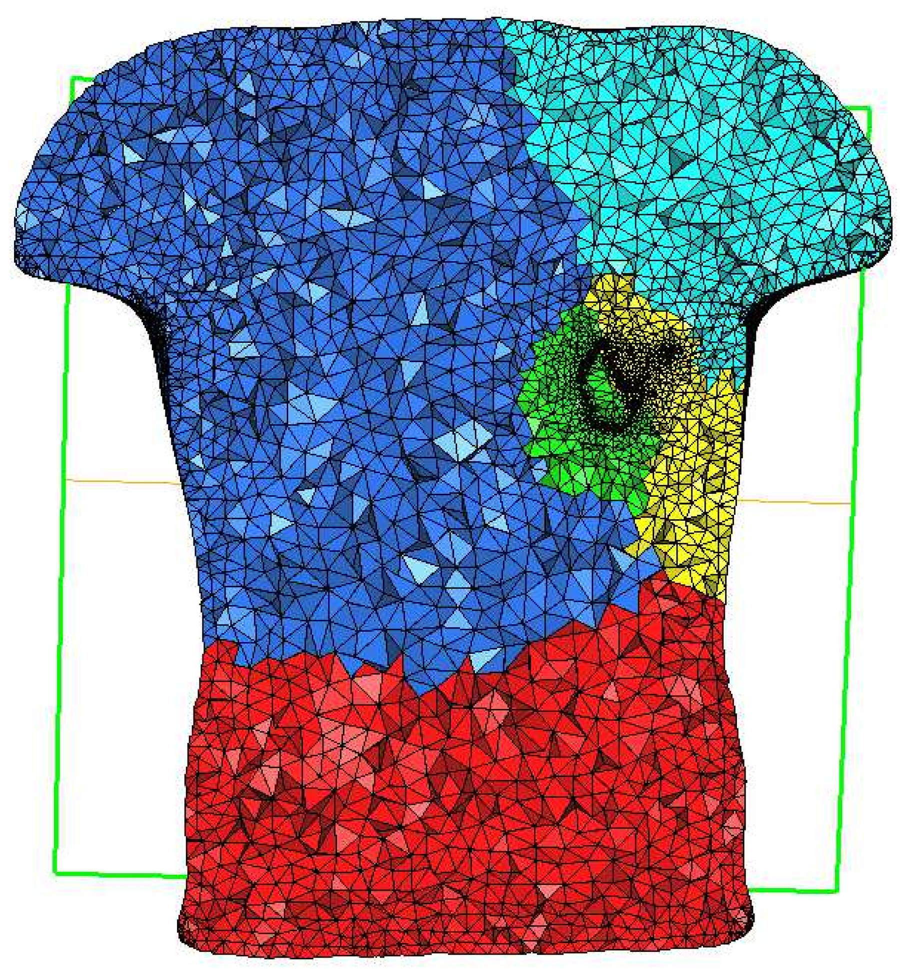
– minimize communications

– reduce computing time

### GEOMETRY EXAMPLES



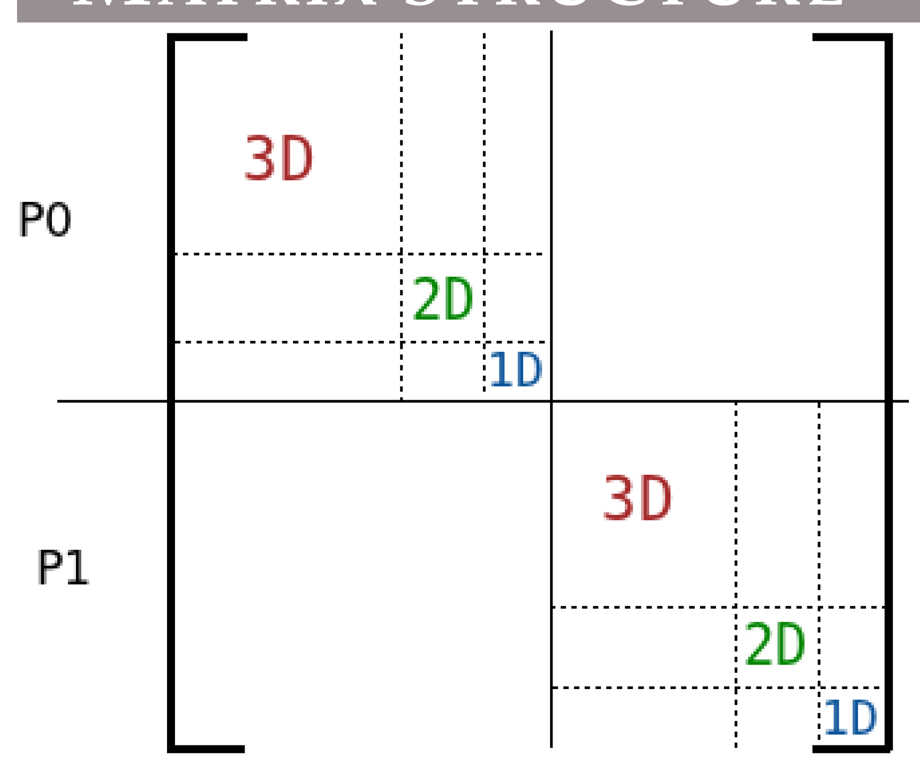
Volumic, surfacic and cable elements in a single partitioned geometry. Each process is assigned a color.



Volumic geometry of heart and torso.

## 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

## 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.