



Parallel Cardiac Electrophysiology Modeling Framework

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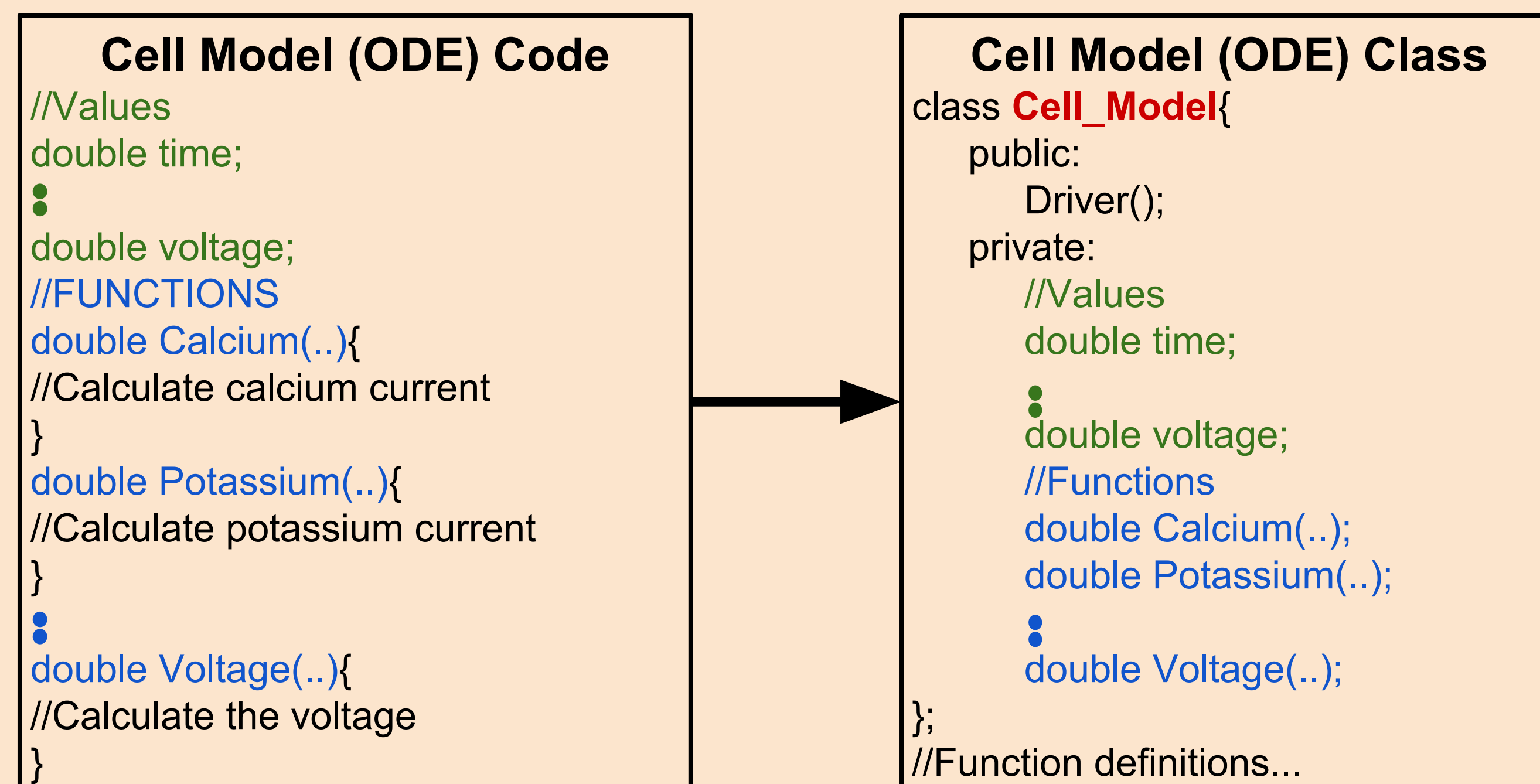


Overview

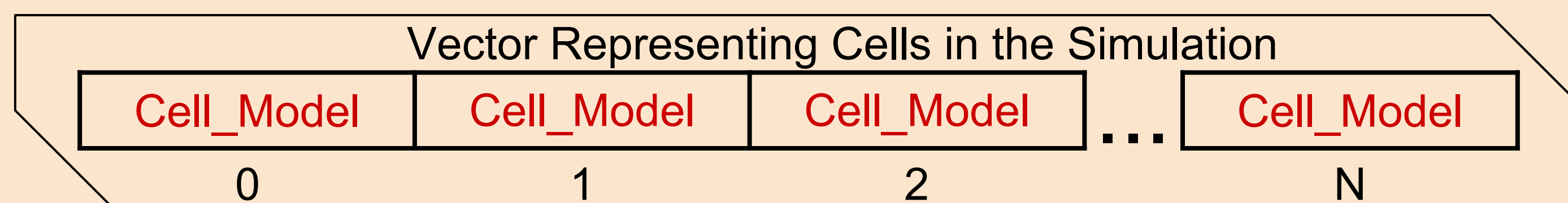
- Cardiovascular diseases are the leading cause of death worldwide. Using computer simulations to quickly and accurately model the dynamics of the heart provides a platform for developing methods to better detect and treat heart disease.
- We provide a fully parallel heart electrophysiology modeling framework designed to run on the HPC platforms, including **NICS Darter**. The framework is capable of evaluating various cardiac electrophysiology models in conjunction with a realistic three-dimensional heart structure.

Methods

- Obtain a cell model written in C++ and refactor it into a C++ class.



- Generate a vector of instances of the C++ class.

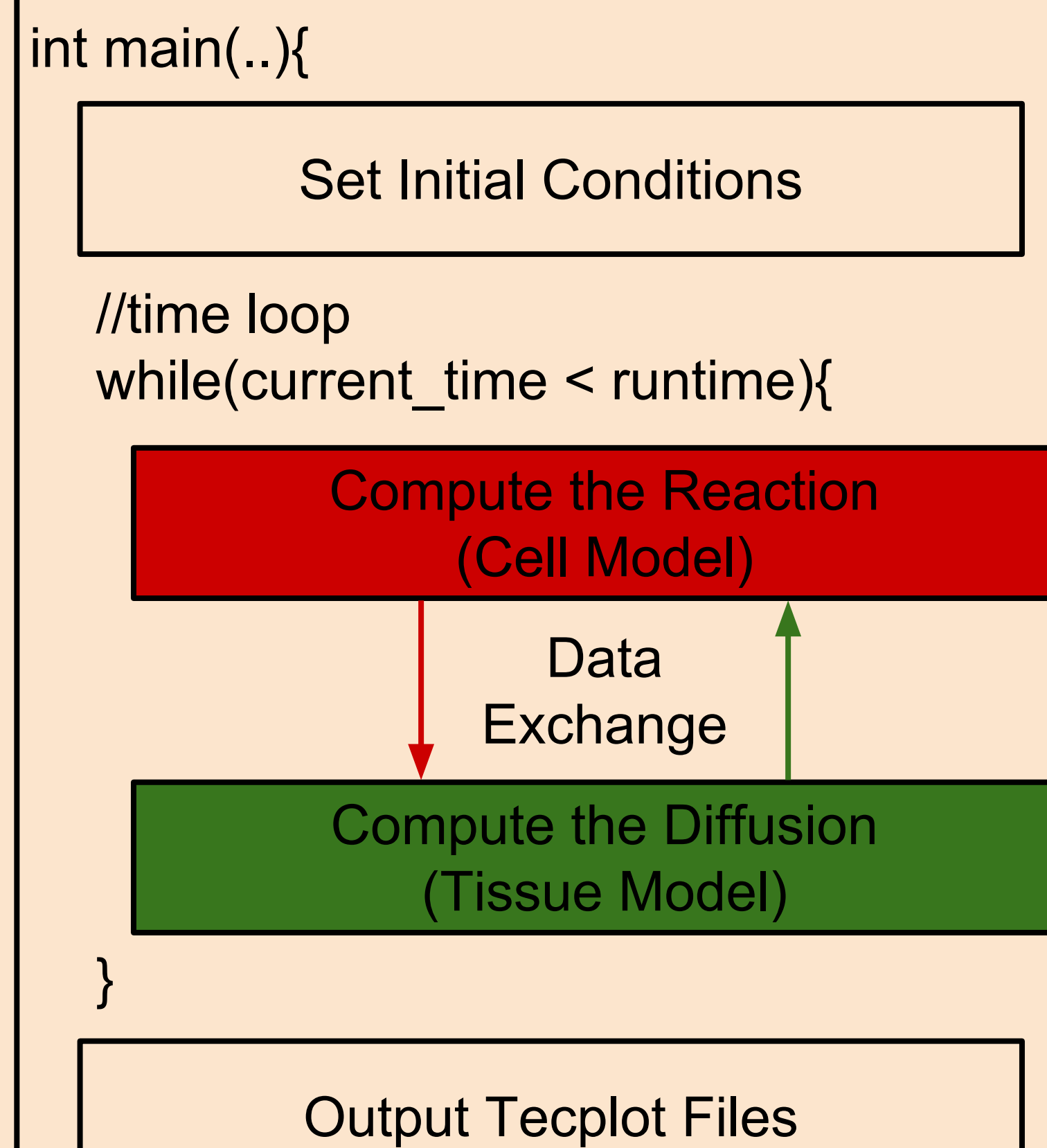


- Compute the voltage of the cell at each timestep.

Key Advantages

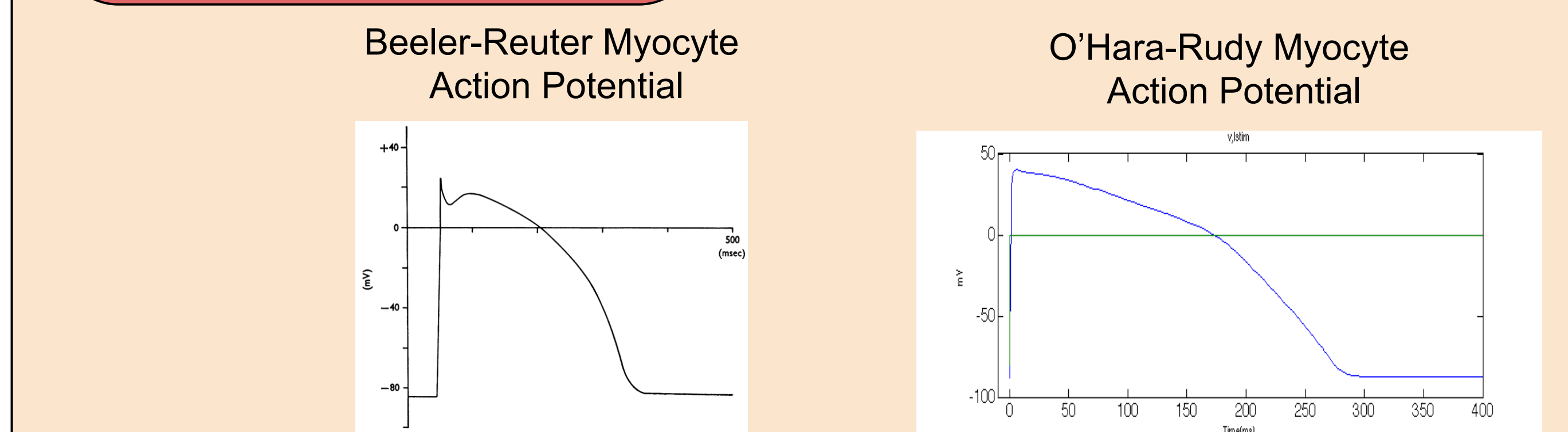
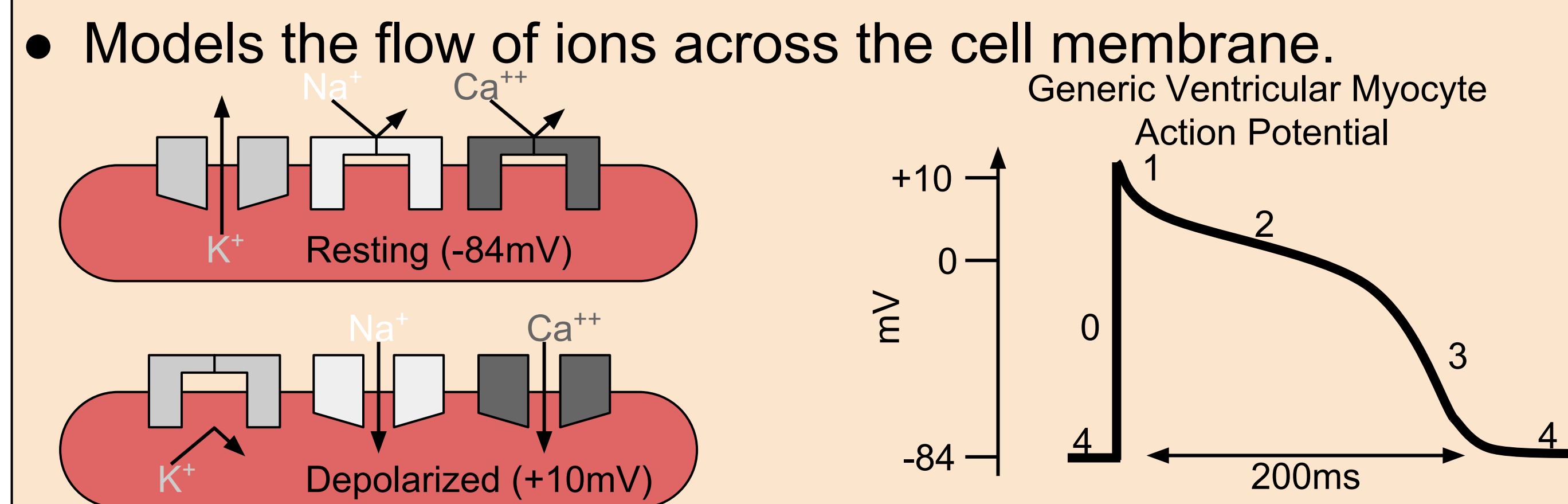
- Scalable
 - Built to run on HPC platforms.
 - Allows for variable node sizes.
- Built on Trilinos
 - A leader in solving large-scale, complex multi-physics engineering and scientific problems.
- Built to run under the openDIEL
 - Distributive Interoperable Executive Library
 - Facilitates communication between loosely coupled simulations.
- Allows for alternative cell models to be easily integrated into the system.
 - Now supports O'Hara-Rudy and Beeler-Reuter models.

Cardiac Modeling (PDE & ODE) Code



Cardiac Modeling Overview

The Cell Model & Governing Equations



- The ionic currents and ultimately the action potential is found by solving a system of ODE using the Finite Element Method (FEM).

Beeler Reuter Voltage Calculation

$$\frac{dV}{dt} = -\frac{i_{k1} + i_{x1} + i_{Na} + i_{Ca} - i_{external}}{C_m}$$

$\frac{dV}{dt}$ = change in voltage with respect to time
 i_{k1} = potassium current
 i_{x1} = second potassium current
 i_{Na} = sodium current
 $i_{external}$ = external stimulus
 C_m = membrane conductivity

The Monodomain Tissue Model & Governing Equation

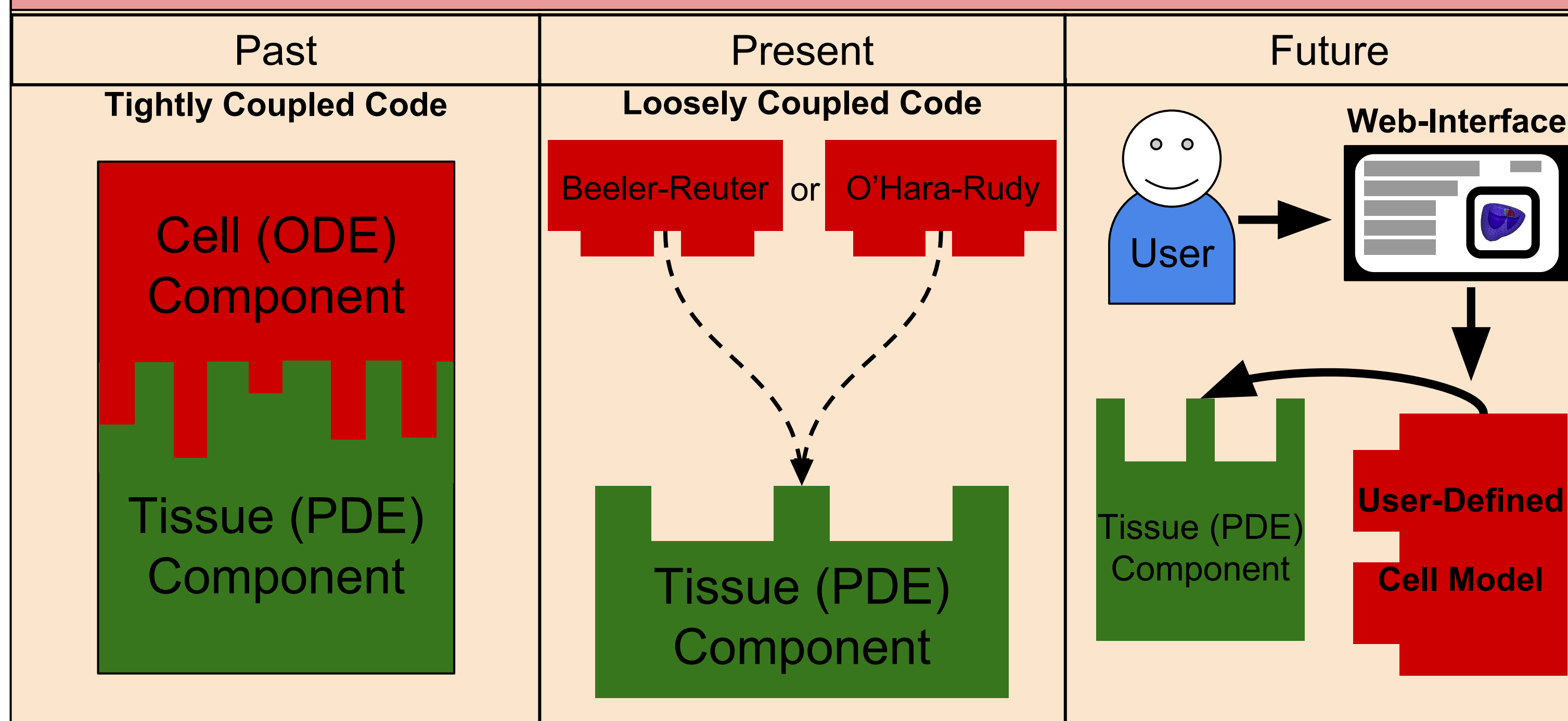
- A cardiac tissue electrical model simulates how cell membrane currents interact with neighboring cells.
- The monodomain model is used instead of the bidomain model because it is less computationally demanding.

Monodomain Equation

$$\frac{\lambda}{1 + \lambda} \nabla \cdot (M_i \nabla v) = \chi (C_m \frac{\partial v}{\partial t} + I_{ion})$$

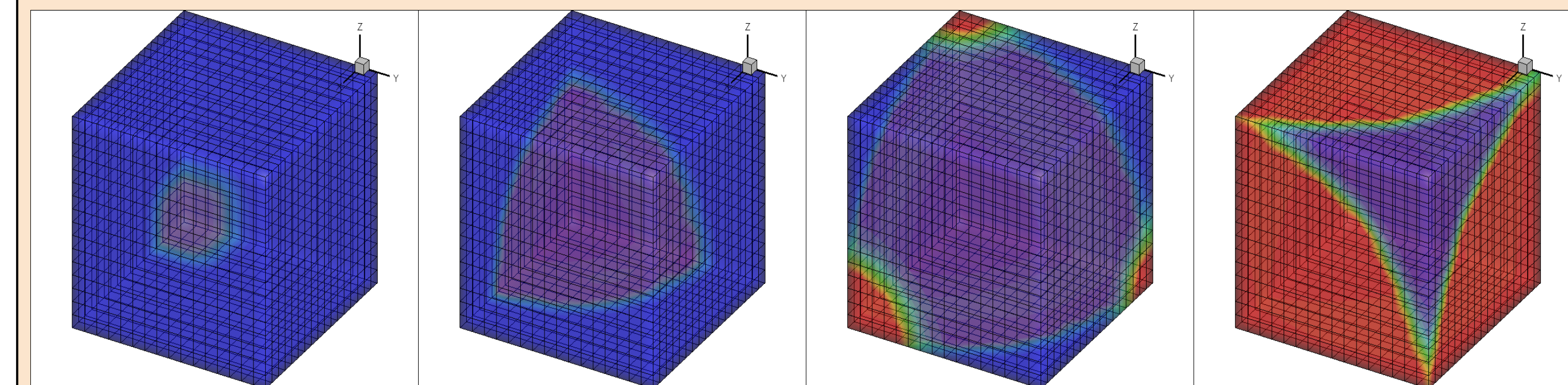
M_i = intracellular conductivity
 C_m = membrane conductivity
 χ = intra to extracellular conductivity ratio
 I_{ion} = transmembrane ionic current
 χ = membrane surface area

State of the Framework

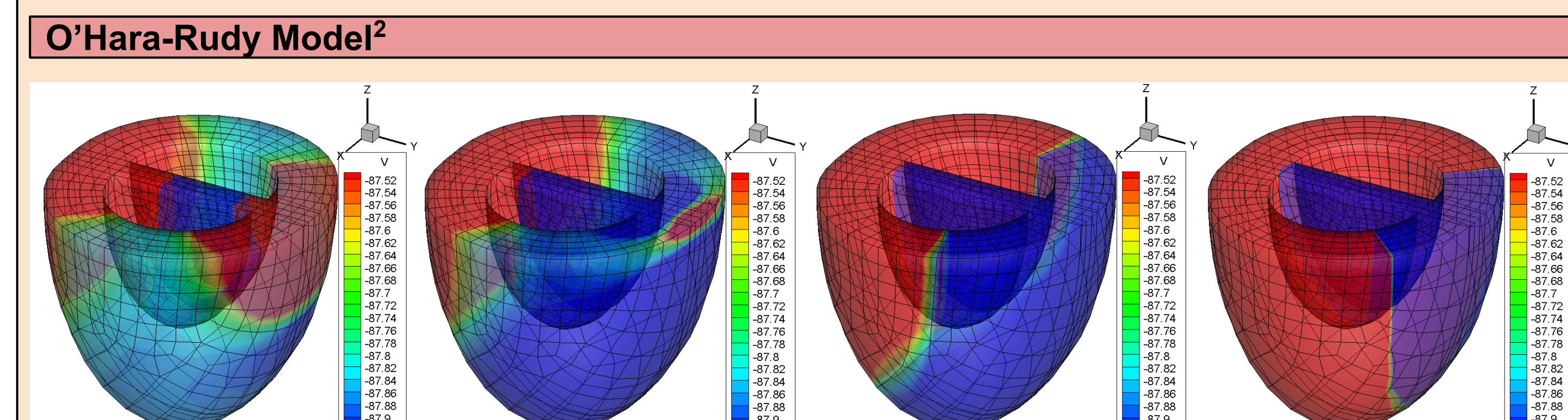
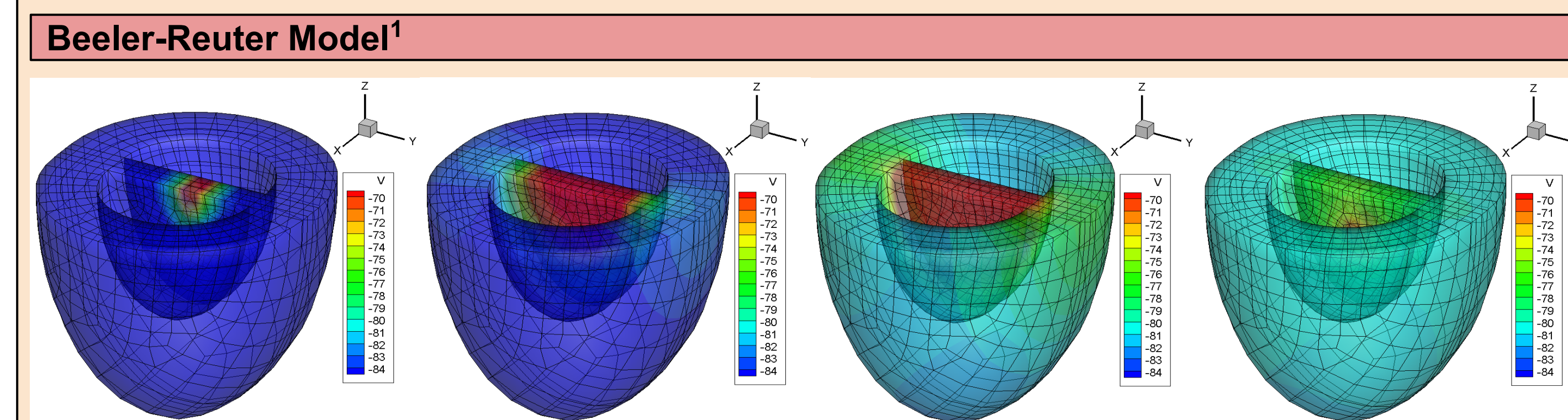


Results

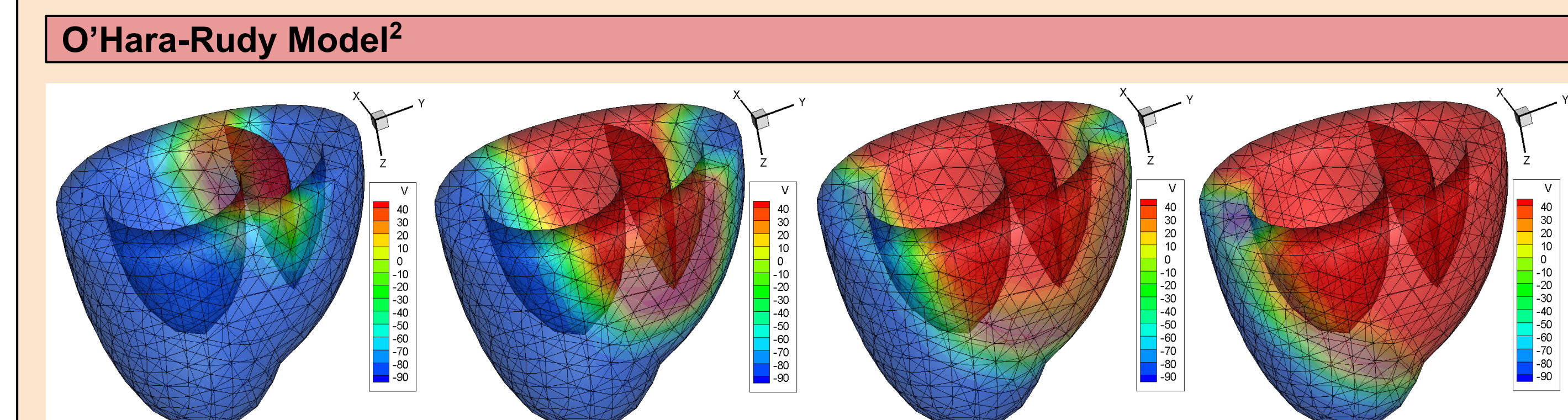
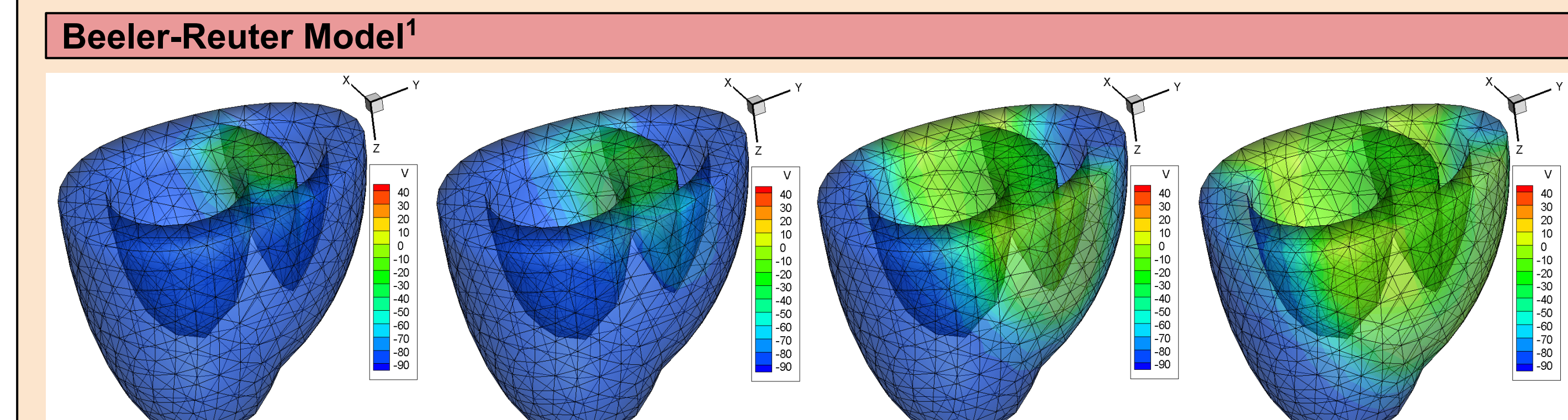
Cube Tissue Test Model



Symmetric 2-Ventricle



Asymmetric 2-Ventricle



References

- Beeler, Go W., and H. Reuter. "Reconstruction of the action potential of ventricular myocardial fibres." The Journal of physiology 268.1 (1977): 177-210.
- O'Hara, Thomas, et al. "Simulation of the undiseased human cardiac ventricular action potential: model formulation and experimental validation." (2011).

Acknowledgements

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