

MICROCARD: Numerical modeling of cardiac electrophysiology at the cellular scale

Introduction

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EuroHPC
Joint Undertaking

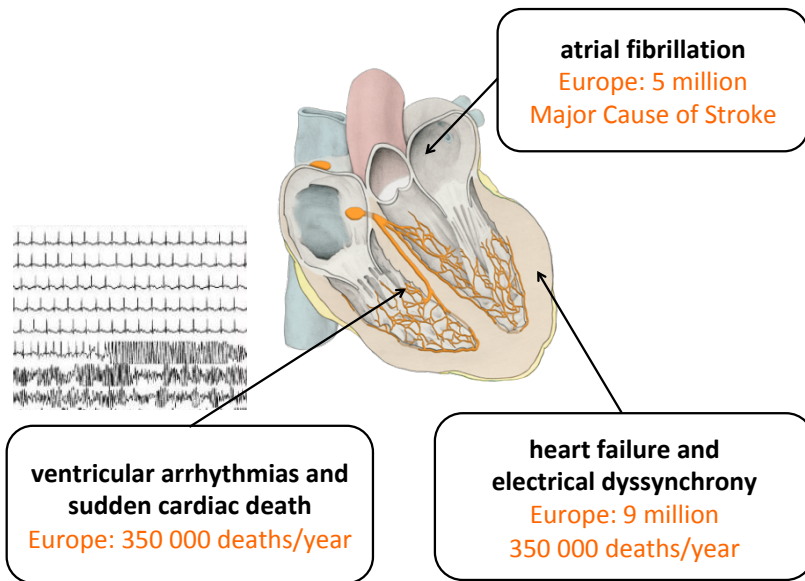


This project has received funding from the European High-Performance Computing Joint Undertaking EuroHPC (JU) under grant agreement No 955495. The JU receives support from the European Union's Horizon 2020 research and innovation programme and France, Italy, Germany, Austria, Norway, and Switzerland.

Our cause

Our challenge

- cardiac disease is the #1 cause of death in Europe and half of these deaths are caused by electrical malfunctions
- structural muscle damage is crucial in most of these



Cardiac muscle has a unique structure and electrophysiology

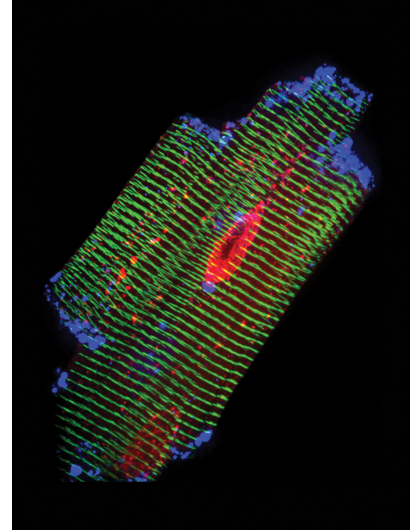
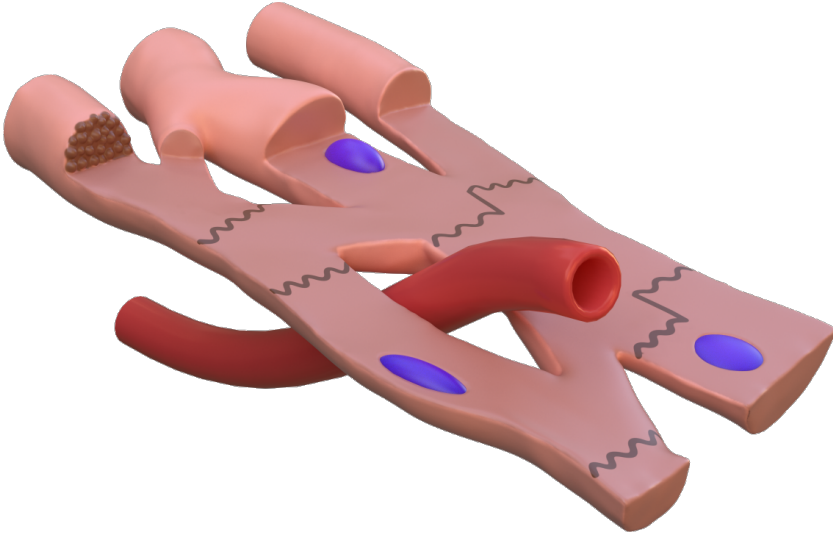
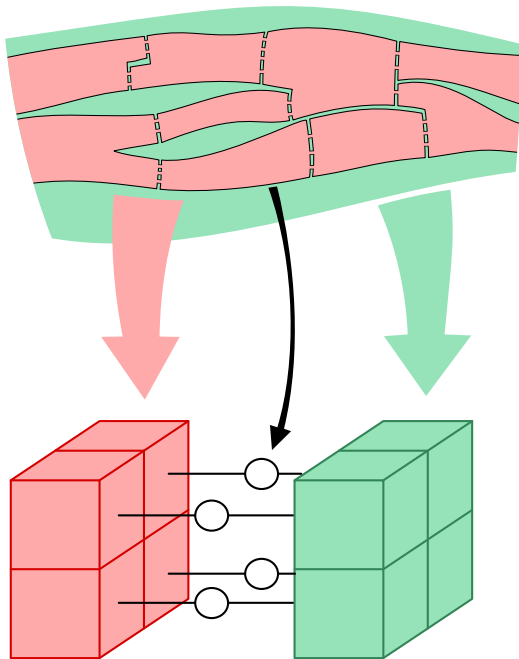


illustration Dana Hamers Scientific Art

The present: bidomain model

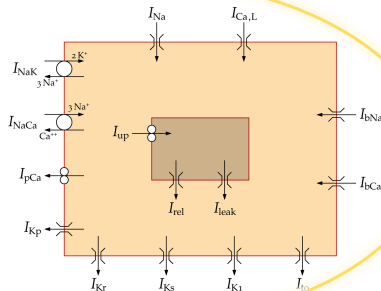


$$\begin{cases} \nabla \cdot (\mathbf{G}_i \nabla \phi_i) = I_m \\ \nabla \cdot (\mathbf{G}_e \nabla \phi_e) = -I_m \end{cases}$$

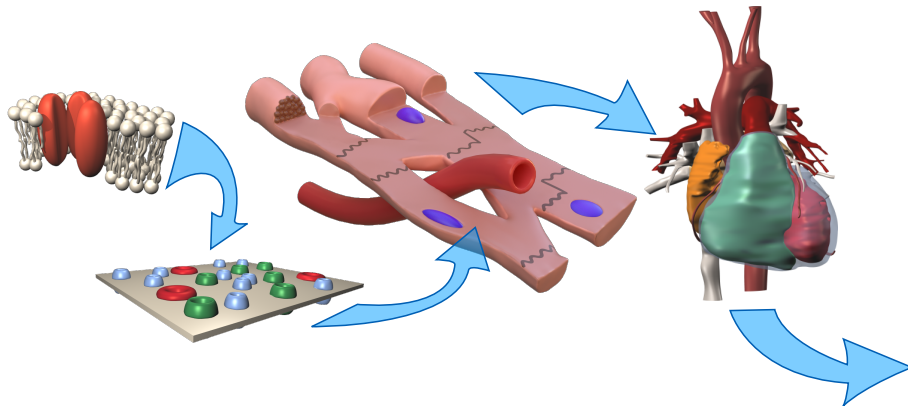
$$V_m = \phi_i - \phi_e$$

$$I_m = \beta C_m \frac{\partial V_m}{\partial t} + I_{\text{ion}} + I_s$$

membrane:
20-50 ODEs
per node



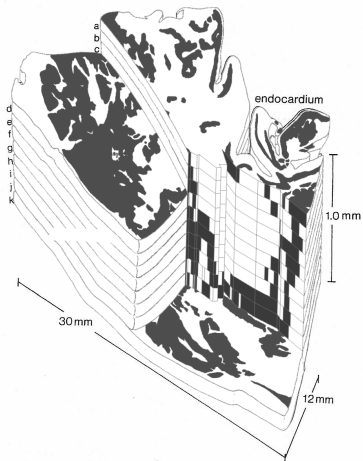
The present in cardiac electrophysiology: bidomain model



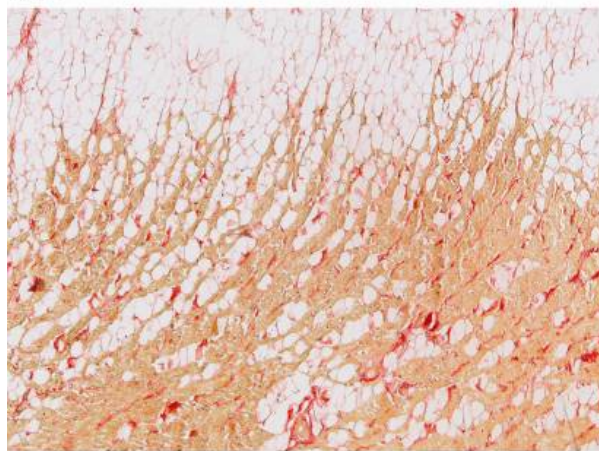
The present: bidomain model

Limitations of the bidomain model

- no notion of individual cells
- cannot represent damaged tissue
- damaged tissue is everywhere (ageing, infarction scars, cardiomyopathies, ...)



De Bakker et al. *JACC* 15:1594-1607 (1990)

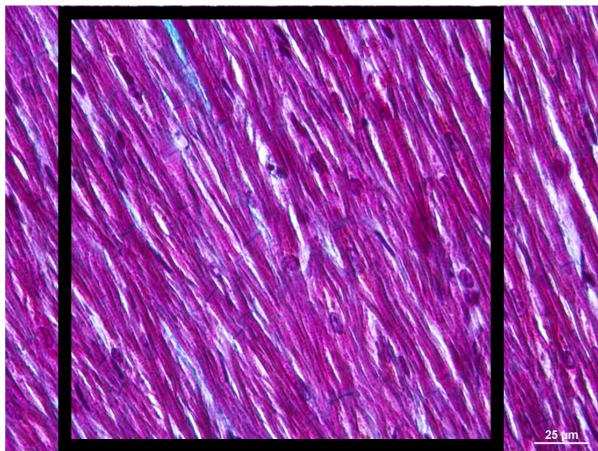


Hoogendijk et al. *Heart Rhythm* 7:238–248 (2010)

Solution: Build a model in which individual cells are discretized

before

about 200 cells per model element

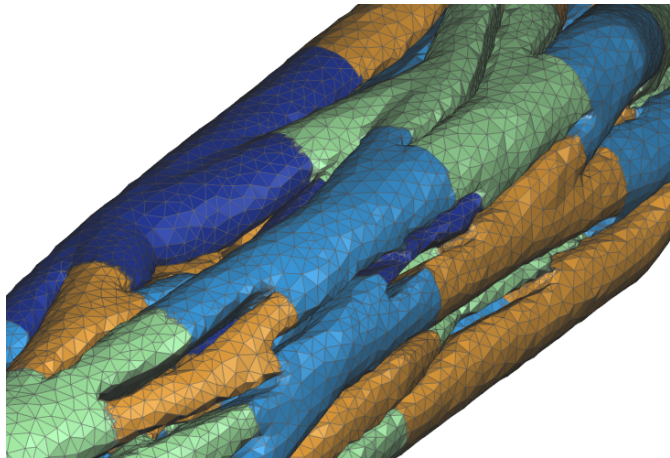


200 μm

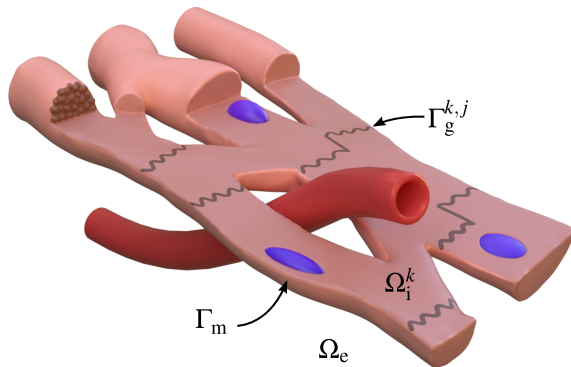
micrograph courtesy of Dr David Benoist, IHU Liryc

after

about 1000 model elements per cell

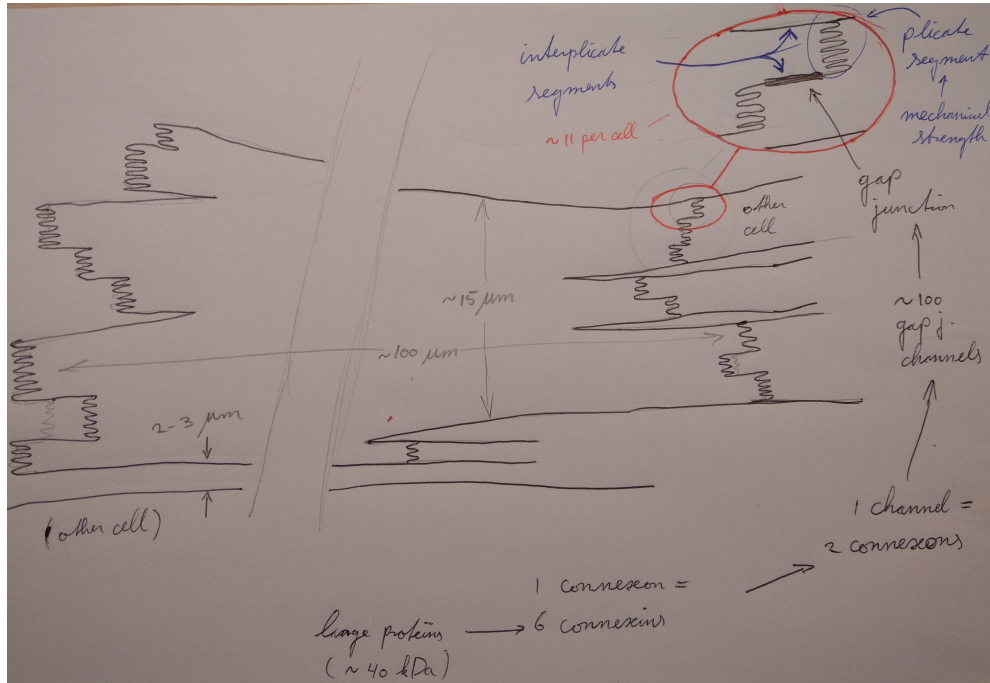


A more complicated model formulation

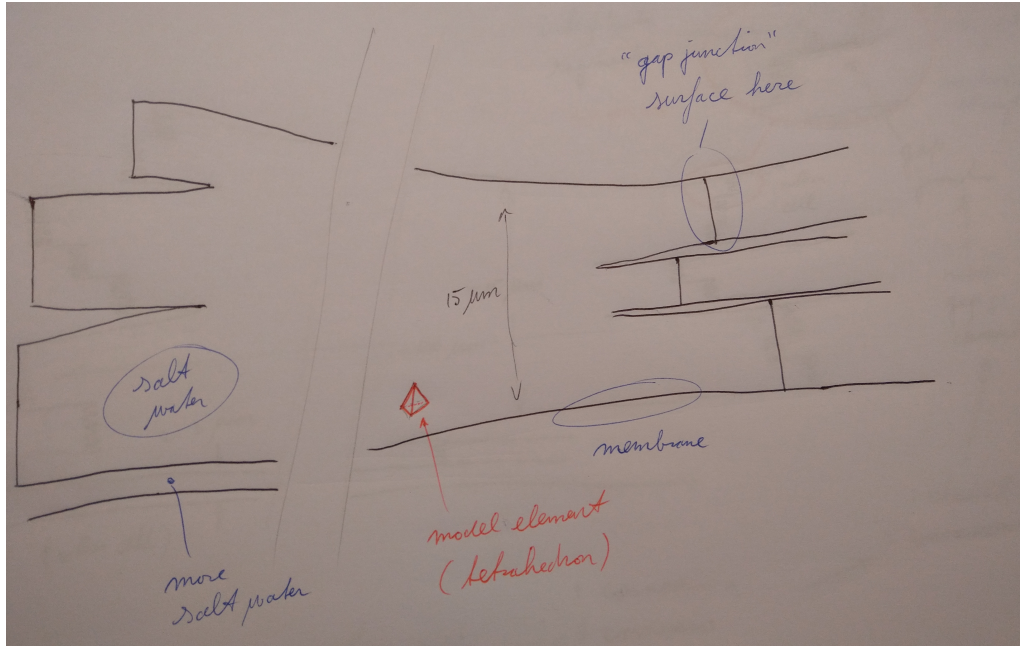


$$\left\{ \begin{array}{ll} \nabla \cdot (G_i^k \nabla \phi_i^k) = 0, & \text{on } \Omega_i^k, \\ \nabla \cdot (G_e \nabla \phi_e) = 0, & \text{on } \Omega_e, \\ V_m^k = \phi_i^k - \phi_e, & \text{on } \Gamma_m^k, \quad (\text{Transmem. voltages}) \\ -G_i^k \nabla \phi_i^k \cdot \mathbf{n} = G_e \nabla \phi_e \cdot \mathbf{n} = C_m \partial_t V_m^k + I_{\text{ion}}(V_m^k, \mathbf{y}), & \text{on } \Gamma_m^k, \quad (\text{Transmem. currents}) \\ -G_i^k \nabla \phi_i^k \cdot \mathbf{n} = G_i^j \nabla \phi_i^j \cdot \mathbf{n} = \kappa(\phi_i^k - \phi_i^j), & \text{on } \Gamma_g^{k,j}, \quad (\text{Gap junctions}) \\ \partial_t \mathbf{y} = \mathbf{F}(V_m, \mathbf{y}), & \text{on } \Gamma_m^k \end{array} \right.$$

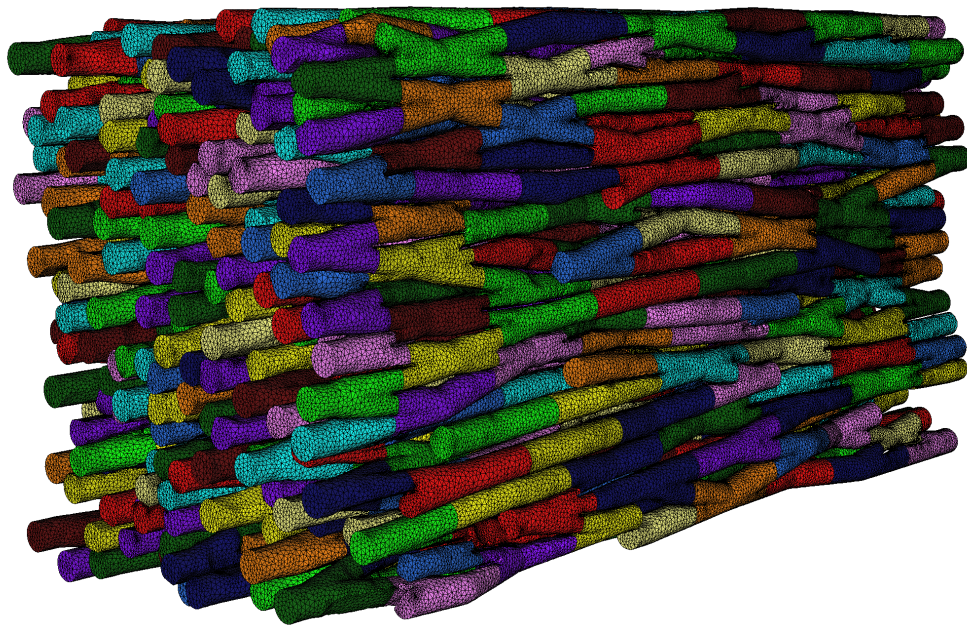
An interesting geometry



An interesting geometry

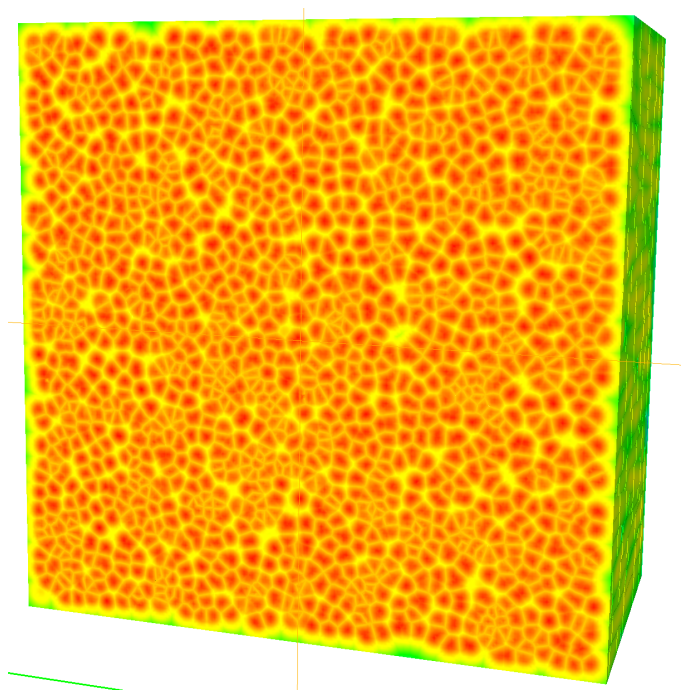


An interesting geometry



An interesting geometry

1 mm³
7538 cells
271 million tetrahedra
15 GB storage



Our problem

- equations that are hard to solve on a large scale (numerical science)
- very large computations will require exascale hardware
 - very high parallelism
 - heterogeneous hardware (CPU, GPU, ...; SIMD, RISC, ...)
 - need resilience to hardware failures
 - need to mitigate energy consumption
- realistic physiology (biomedical engineering)
- realistic anatomy (image segmentation)
- will need much more powerful meshing software (informatics)

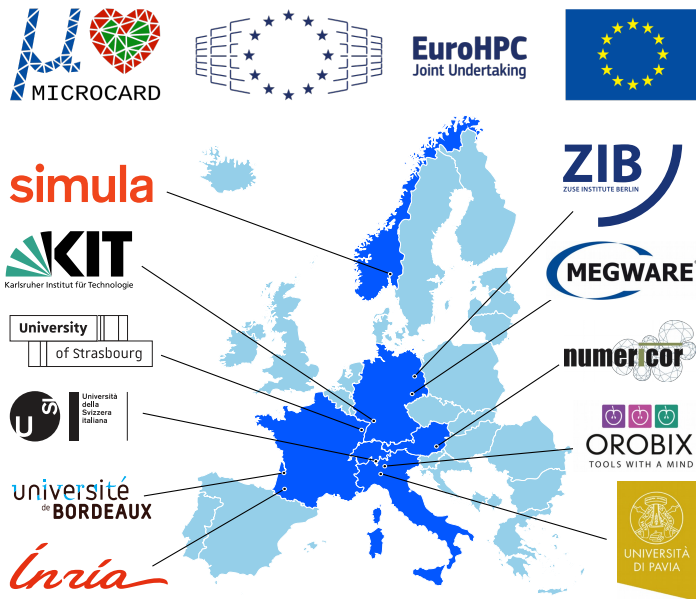
Solution

- A EuroHPC grant for a multidisciplinary collaborative project →



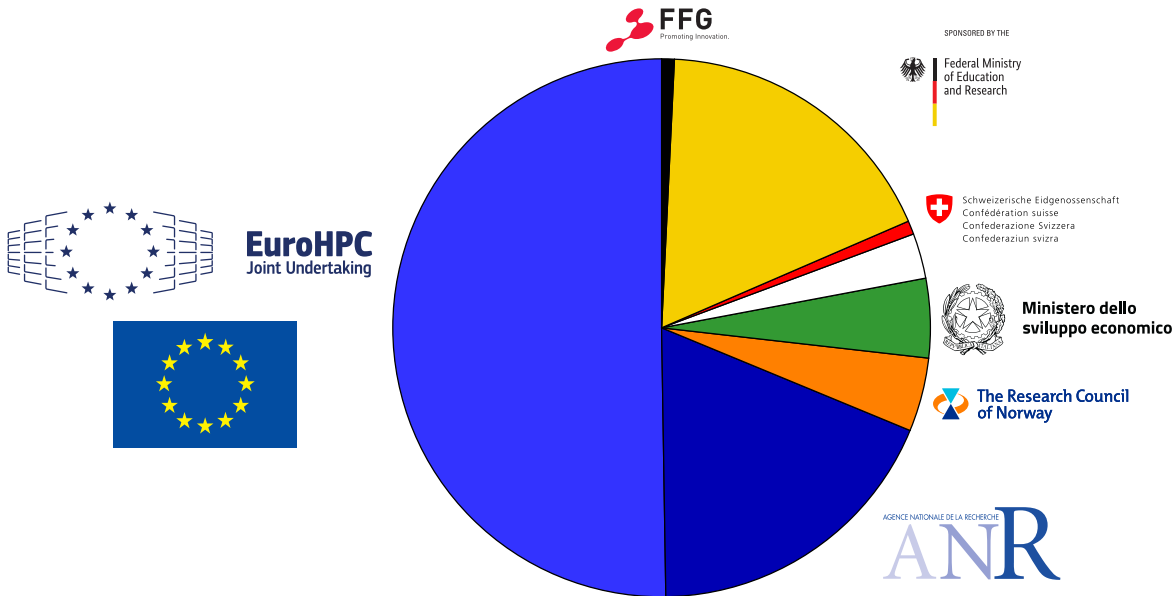
The project

The MICROCARD project

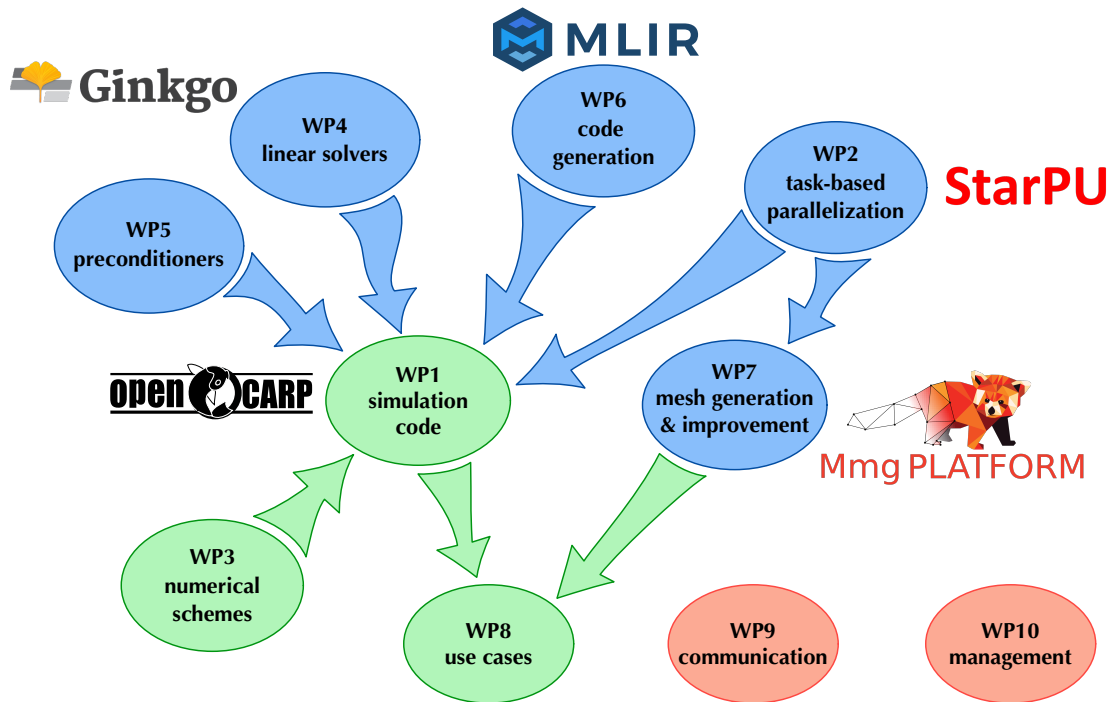


Funding

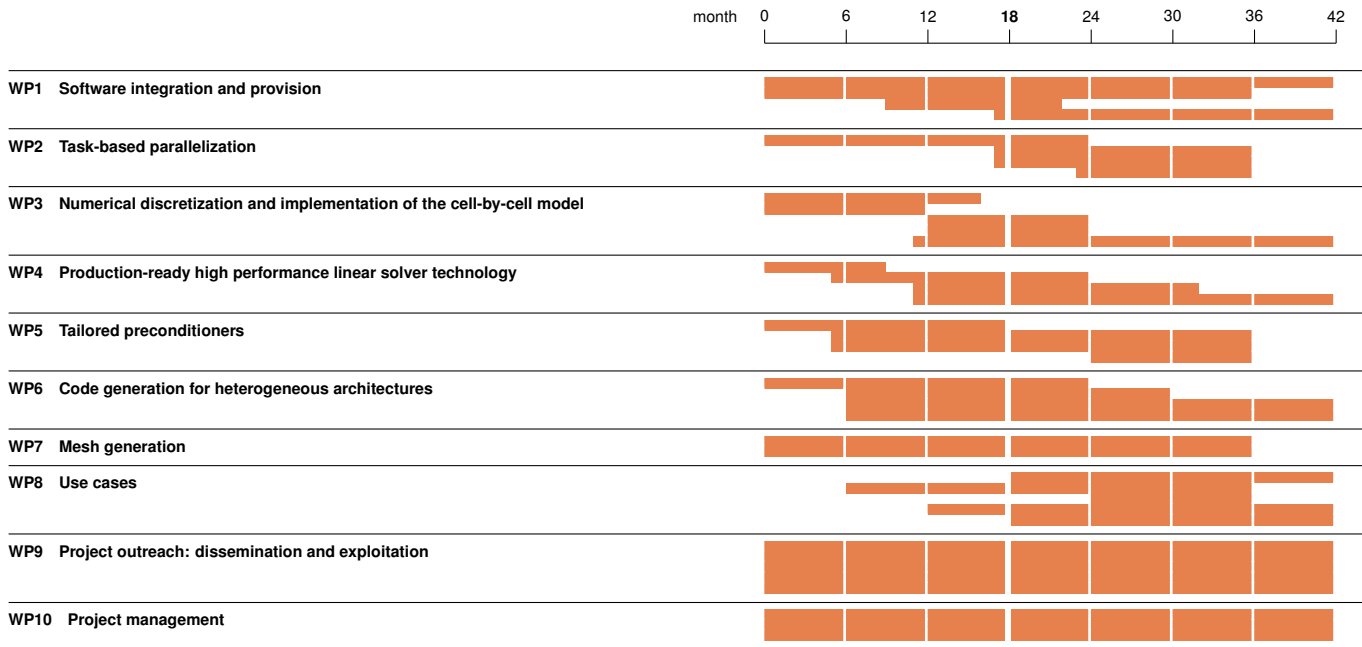
5.8 M€ total (2.7M€ from the JU)



Project outline



Timeline



Summary of staff effort

Participant Nr	name	WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8	WP9	WP10	Total PM
1	UBx	6	33	50			39	75	55	11	14	283
2	Unistra	4	3		2		69				1	79
3	Simula	8			8		8		24		1	49
4	UPavia	2			20	54		4		2	1	83
5	USI	4		28		12			12		1	57
6	KIT	53			46	25			25	13	2	164
7	ZIB	4	2	48		30					1	85
8	MW	12			3							15
9	NC	12								6		18
10	ORO	3	6					36	3		1	49
total		108	44	126	79	121	116	115	119	32	22	882

Organization

Management team



Andréa Alexander project manager



Mark Potse scientific coordinator



Yves Coudière scientific and technical manager

End-user Advisory Board



Larissa Fabritz
Professor of Cardiovascular Sciences
University of Birmingham



Carol Ann Remme
Associate Professor Basic and Translational Electrophysiology
Amsterdam University Medical Center



Eva Rog-Zielinska
Head of 4D Imaging Section
Institute for Experimental Cardiovascular Medicine, Freiburg



Mèlèze Hocini
Cardiologist, deputy director, Liryc
University Hospital Bordeaux

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UBx



Vincent Loechner

UniStra



Xing Cai

SIMULA



Luca Pavarino

UniPV



Rolf Krause

USI



Axel Loewe

KIT



Martin Weiser

ZIB



Axel Auweter

MEGWARE



Aurel Neic

Numericor



Luca Antiga

Orobix

Executive Board



Mark Potse
SC, WP9,10



Algiane Froehly
WP7



Hermenegild Arevalo
WP8



Aurel Neic
WP1



Yves Coudière
WP10



Hartwig Anzt
WP4



Axel Loewe
WP1, WP9



Vincent Loechner
WP2,6



Nico Mittenzwey
MEGWARE



Rolf Krause
WP5



Amina Guermouche
WP2,6



Edward Vigmond
WP8



Simone Scacchi
WP4



Martin Weiser
WP3



Luca Pavarino
WP5



Luca Antiga
WP7



Simone Pezzuto
WP3

Career moves affecting the project



Simone Pezzuto (USI) → assistant professor at U. Trento



Hartwig Anzt (KIT) → associate professor at U. Tennessee



Amina Guermouche (UBx) → assistant professor (MdC) at Bordeaux INP



Denis Barthou (UBx) → industry; WP2 will be led by **Amina Guermouche**



Achievements

Dissemination overview

- accelerated ionic models in openCARP (500 users)
- Ginkgo providing GPU acceleration in openCARP
- improvements in Mmg
- 9 journal papers
- 21 invited lectures
- 16 other conference contributions
- >350 followers on LinkedIn

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Numerical modeling of cardiac electrophysiology at the cellular scale

MICROCARD is a European research project to build software that can simulate cardiac electrophysiology using whole-heart models with sub-cellular resolution, on future exascale supercomputers. It is funded by EuroHPC call Towards Extreme Scale Technologies and Applications.

Summary

Cardiovascular diseases are the most frequent cause of death worldwide and half of these deaths are due to cardiac arrhythmia, disorders of the heart's electrical synchronization system. Computer models are essential to understand the behaviour of this complex system and its diseases. These models are already very sophisticated and widely used, but currently they are not powerful enough to take the heart's (2 billion!) individual cells into account. They must therefore assume that hundreds of cells are doing approximately the same thing. Due to this limitation, current models cannot reproduce the events in aging and structurally diseased hearts, in which reduced electrical coupling leads to large differences in behaviour between neighbouring cells, with possibly fatal consequences.

If we want to model the heart cell by cell, we face a mathematical problem that is 10,000 times larger, and also harder to solve. We will need larger supercomputers than those that exist today, and a lot of inventiveness to solve our problem efficiently on these future machines.

The purpose of the MICROCARD project is to develop software that can solve this problem on future exascale supercomputers. We will develop algorithms that are tailored to the specific mathematical problem, to the size of the computations, and to the particular design of these future computers, which will probably owe most of their compute power to ultra-parallel computing elements such as Graphics Processing Units. We will not content ourselves with a "proof of concept", but will use the code that we develop to solve real-life problems in cardiology. Therefore the project includes computer experts, mathematicians, and biomedical engineers, and collaborates with cardiologists and physiologists.

Funding

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LinkedIn: @project MICROCARD
Twitter: @P_Microcard

Latest news

Open positions

We are looking for an engineer and a postdoc to work on meshing tools and a research software engineer to work on software integration.

MICROCARD is touring Europe

In June, the MICROCARD project was presented at the Teratec Forum 2022 on 14 and 15 June in Paris, and at the HiPEAC meeting in Budapest on June 20-22.

We will also present results at the ECCOMAS meeting in Oslo, the ISC High Performance meeting in Hamburg, and the CMBE meeting in Milan.

Leading the way in European supercomputing

MICROCARD is one of nine European supercomputing projects showcased in this brochure issued by CORDIS.

[more news](#)

Agenda

Monday 27 June
15:00-18:00 Workshop

Thank you!



EuroHPC
Joint Undertaking

