Numerical modeling of cardiac electrophysiology at the cellular scale

Reporting

Project Information

MICROCARD

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Project website

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Project closed

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EU contribution
€ 2 777 053,32

Coordinated by
UNIVERSITE DE BORDEAUX
France

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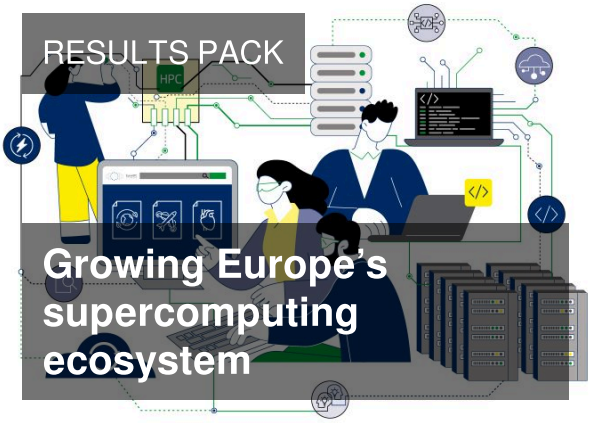


23 July 2024

4 July 2022

Periodic Reporting for period 1 - MICROCARD (Numerical modeling of cardiac electrophysiology at the cellular scale)

Reporting period: 2021-04-01 to 2022-09-30

Summary of the context and overall objectives of the project

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. This system, based on electrical connections between the cells and myriads of molecular-scale current generators in each cell membrane, is so complex that it can only be understood with the help of computer models.

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 neigbouring cells, with possibly fatal consequences. But if we want to model the heart cell by cell, we face a mathematical problem that is ten thousand 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 main 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 (GPUs).

In addition, MICROCARD will develop the geometrical models of cardiac tissue that it needs to perform simulations, as well as the software needed to create these enormously large and complex models. For this purpose MICROCARD analyses large microscopy datasets provided by others.

Finally, we will use the code that we develop to investigate cardiac arrhythmia, in collaboration with cardiologists and physiologists.

Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far

The first 18 months of the project were characterized by the construction of building blocks, a prototype implementation of the cell-by-cell model, and the design of an exascale-ready code that will integrate these building blocks. Functionality that we need has been added to the existing software libraries on which the project builds, and is already available for others to use. Examples are recent releases of the ParMmg code (https://mmgtools.org) the Ginkgo linear algebra library (https://github.com/ginkgo-project/ginkgo) and the openCARP cardiac simulation software (https://opencarp.org).

In addition we worked on the interpretation of imaging data to construct tissue geometries, and we developed a code that can produce artificial geometries that are much larger than would be possible with microscope images.

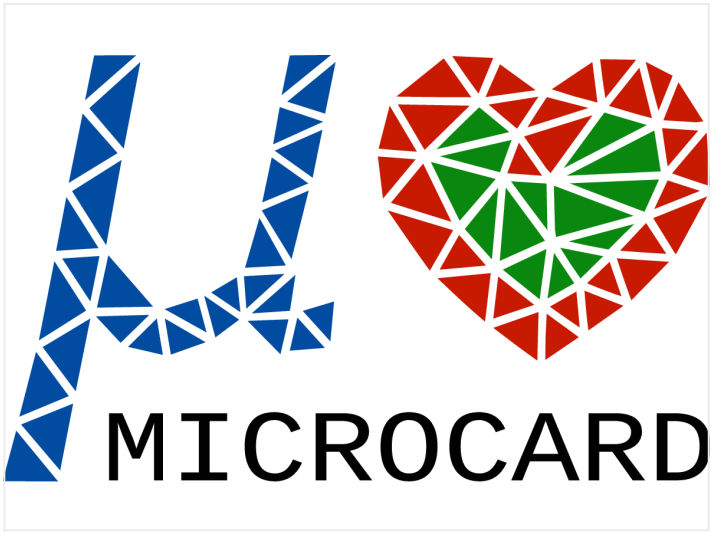
We further worked on alternative numerical approaches to the mathematical problem, methods to distribute computational work on millions of processors, and strategies to reduce the energy consumption of our code.

The project has supported the publication of 8 journal papers so far, and as many presentations at scientific conferences. We have also participated in events aimed at a larger audience. We regularly post news about our project on our website and on social media.

Progress beyond the state of the art and expected potential impact (including the socio-economic impact and the wider societal implications of the project so far)

An achievement that we are especially proud of is the development of a tool that accelerates the computation of the electric currents that are produced by the cardiac cell membranes and that make the heart beat. The physiological systems that produce these currents are extremely complex, and therefore the current produced by each cells is captured in a system of hundreds of mathematical equations, together called a "membrane model". The tool that we developed takes such a model, written in a special human-friendly language, and translates it to efficient computer code. It can do so for a variety of different processors (CPUs and GPUs), producing the code that works most efficiently for each of them. The dedicated code produced in this way turned out to be three times faster, on average, than existing codes. Even better, it was more than 10 times faster for the more complex membrane models, which represent the physiology in greater detail. This tool will be used in our project, but can also be used separately. It allows researchers to run their code faster and to use less energy, but also brings more realistic simulations within reach.

Currently there is only one working exascale computer in the world. Using these extremely powerful machines will be difficult, especially for end users who are not experts in the intricacies of these machines. The MICROCARD project will help one important application, simulation of the heart, to benefit from these machines. We expect that this will also help related fields, such as brain research, to make better use of future exascale supercomputers, and we hope that these will be examples to the entire medical field.



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