



HAL
open science

CEPS: a cardiac electrophysiology exploration tool for new mathematical models and methods

Michael Leguèbe, Yves Coudière, Loïc Calvez, Valentin Pannetier, Charlie Douanla-Lontsi, Anđela Davidović, Pierre-Elliott Bécue, Mehdi Juhoor, Nejib Zemzemi

► To cite this version:

Michael Leguèbe, Yves Coudière, Loïc Calvez, Valentin Pannetier, Charlie Douanla-Lontsi, et al.. CEPS: a cardiac electrophysiology exploration tool for new mathematical models and methods. *Journal of Open Source Software*, 2025, 10 (114), pp.8910. <10.21105/joss.08910>. <hal-05313674>

HAL Id: hal-05313674

<https://inria.hal.science/hal-05313674v1>

Submitted on 23 Apr 2026






HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.


L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization




CEPS: a cardiac electrophysiology exploration tool for new mathematical models and methods

Michael Leguèbe ^{1,2,3}[¶], Yves Coudière ^{2,1,3}, Loïc Calvez¹, Valentin Pannetier^{2,3}, Charlie Douanla-Lontsi^{2,3}, Anđela Davidović ^{2,3}, Pierre-Elliott Bécue^{2,3}, Mehdi Juhoor^{1,3}, and Nejib Zemzemi ^{1,2,3}

¹ Centre Inria de l'Université de Bordeaux, France ² Université de Bordeaux, France ³ IHU Liryc, France
 Corresponding author

DOI: [10.21105/joss.08910](https://doi.org/10.21105/joss.08910)

Software

- [Review](#) 
- [Repository](#) 
- [Archive](#) 

Editor: [Henrik Finsberg](#)  

Reviewers:

- [@axel-loewe](#)
- [@cdaversin](#)
- [@kylebeggs](#)

Submitted: 02 July 2025

Published: 14 October 2025

License

Authors of papers retain copyright and release the work under a Creative Commons Attribution 4.0 International License ([CC BY 4.0](#)).

Summary

Cardiac activity is regulated by the propagation within the heart muscle of an electric action potential (AP), which follows a specific synchronized pattern in normal conditions. Defects in the tissue or metabolic changes can lead to pathological propagations and cardiac arrhythmias, which are a major cause of death around the world.

Electrophysiology simulation tools at tissue scale are required to better understand the normal and pathological function of the heart, and could also be used as design tools for new medical devices and therapies.

Statement of need

CEPS stands for Cardiac ElectroPhysiology Simulator. The goal of this software is to freely provide a set of models and advanced numerical methods as a base for research on new models and methods to solve cardiac problems. CEPS focuses on the electric function of the heart: mechanical models that simulate muscle contraction or blood flow are not part of the software.

Developed since 2012 in the Inria CARMEN team, CEPS is designed as an exploration tool: computational efficiency is not its primary aim, contrary to other electrophysiology software that are more suited to production such as openCARP ([Plank et al., 2021](#)), Propag ([Potse, 2018](#)) or CHASTE ([Cooper et al., 2020](#)). Nevertheless, CEPS runs on parallel architectures with a level of performance which is reasonable for academic studies of direct problems. A strong effort on the clarity of the implementation, documentation and software quality assurance has been conducted to ease the use of CEPS and to make contributing relatively accessible, even for students that are freshly trained in applied mathematics and/or programming.

Main features

CEPS is a C++ code, parallelized with MPI using domain decomposition. CEPS runs simulations on 1D, 2D and 3D simplicial meshes (segments, triangles, tetrahedra). Several meshes of different dimension can be given at the same time and coupled. The solvers for partial differential equations are based on Lagrangian finite elements. The software should be compatible with any Linux distribution and macOS. Windows users can run CEPS in Windows Subsystem for Linux. CEPS is developed and tested via continuous integration on Ubuntu machines.

On top of the standard *monodomain*, *bidomain* and *bidomain-with-bath* models of electrophysiology, CEPS offers several features, that were the product of our research:

- *Current-lifted monodomain* model (Coudière & Rioux, 2012): a more accurate way to approximate the bidomain model than the monodomain model, with a similar computational cost as the monodomain model.
- *Bilayer monodomain model for atria* (Labarthe et al., 2014): a model that simulates both layers of the atria with a single surface mesh.
- *Volume fraction* (Davidović et al., 2021): a way to modulate the tissue conductivity from a single scalar field that describes the fraction of healthy tissue per unit volume.
- *Stimulation by a pacemaker* (Pannetier et al., 2025): cardiac tissue can be stimulated by a realistic current pattern, with full coupling to the bidomain model.
- *High-order exponential numerical schemes* (Coudière et al., 2020),(Coudière et al., 2018) suited for cardiac ionic models.
- *Automated convergence tests*: we provided an easy way to convert the resolution of a single problem which depends on time and/or space into a convergence study.

Usage

CEPS runs exclusively in a non-interactive way, because it is intended to be launched in batch mode on computing clusters, and easily integrated in scripts. This means that all the runs must be completely parametrized beforehand. Simulation parameters are passed through a single YAML file, which may refer to other input files such as meshes or data files for spatially varying coefficients. A [comprehensive list](#) of all possible inputs can be found in the online documentation. The documentation and downloaded files also include examples of YAML input files for each of the main problems that can be solved with CEPS.

Software quality

Among the 400+ unit and non-regression tests that are part of continuous integration, twelve of them are run to check that CEPS solves accurately the benchmark problems that were proposed in (Pathmanathan & Gray, 2014), and suggested by the FDA to validate cardiac electrophysiology software. We also [documented](#) CEPS results of the (Niederer et al., 2011) benchmark and other convergence results for cardiac solvers. Additionally, we use the [SonarQube linter](#) to maintain good software quality as we code.

Acknowledgements

We deeply thank all previous contributors that did not wish to be authors of the current paper, as well as the Inria SED and STIP services for their support.

CEPS uses the [fkYAML](#) library to parse YAML files.

Development of CEPS was partially carried out using the [PlaFRIM](#) experimental testbed, supported by Inria, CNRS (LaBRI and IMB), Université de Bordeaux, Bordeaux INP and Conseil Régional d'Aquitaine. It was also carried out on the computing facilities of the MCIA (Mésocentre de Calcul Intensif Aquitain).

This work was also supported by:

- the H2020 EU SimCardioTest project (Digital transformation in Health and Care SC1-DTH-06-2020; grant agreement number 101016496).
- the French government through the “Agence Nationale de la Recherche” (ANR), grant references ANR-10-IAHU-04 and 13-MONU-0004-04.

References

- Cooper, F. R., Baker, R. E., Bernabeu, M. O., Bordas, R., Bowler, L., Bueno-Orovio, A., Byrne, H. M., Carapella, V., Cardone-Noott, L., Cooper, J., Dutta, S., Evans, B. D., Fletcher, A. G., Grogan, J. A., Guo, W., Harvey, D. G., Hendrix, M., Kay, D., Kursawe, J., ... Gavaghan, D. J. (2020). Chaste: Cancer, heart and soft tissue environment. *Journal of Open Source Software*, 5(47), 1848. <https://doi.org/10.21105/joss.01848>
- Coudière, Y., Douanla Lontsi, C., & Pierre, C. (2020). Rush-Larsen time-stepping methods of high order for stiff problems in cardiac electrophysiology. *Electronic Transactions on Numerical Analysis*, 55, 342–357. https://doi.org/10.1553/etna_vol52s342
- Coudière, Y., Douanla-Lontsi, C., & Pierre, C. (2018). Exponential adams–bashforth integrators for stiff ODEs, application to cardiac electrophysiology. *Mathematics and Computers in Simulation*, 153, 15–34. <https://doi.org/10.1016/j.matcom.2018.04.006>
- Coudière, Y., & Rioux, M. (2012). Virtual electrodes mechanisms predictions with a current-lifted monodomain model. *2012 Computing in Cardiology*, 837–840.
- Davidović, A., Coudière, Y., & Bourgault, Y. (2021). Modelling the action potential propagation in a heart with structural heterogeneities: From high-resolution MRI to numerical simulations. *International Journal for Numerical Methods in Biomedical Engineering*, 37(11), e3322. <https://doi.org/10.1002/cnm.3322>
- Labarthe, S., Bayer, J., re, Y., Henry, J., Cochet, H., s, P., & Vigmond, E. (2014). A bilayer model of human atria: mathematical background, construction, and assessment. *Europace*, 16 Suppl 4, iv21–iv29. <https://doi.org/10.1093/europace/euu256>
- Niederer, S. A., Kerfoot, E., Benson, A. P., Bernabeu, M. O., Bernus, O., Bradley, C., Cherry, E. M., Clayton, R., Fenton, F. H., Garny, A., Heidenreich, E., Land, S., Maleckar, M., Pathmanathan, P., Plank, G., Rodríguez, J. F., Roy, I., Sachse, F. B., Seemann, G., ... Smith, N. P. (2011). Verification of cardiac tissue electrophysiology simulators using an N-version benchmark. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences*, 369(1954), 4331–4351. <https://doi.org/10.1098/rsta.2011.0139>
- Pannetier, V., Leguèbe, M., Coudière, Y., Walton, R., Fauré, G., & Setzu, R. (2025). Towards validation of two computational models of artificial pacemakers. In T. H. Radomír Chabiniok Qing Zou (Ed.), *Functional imaging and modeling of the heart* (Vol. 15673). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-94559-5_12
- Pathmanathan, P., & Gray, R. A. (2014). Verification of computational models of cardiac electro-physiology. *International Journal for Numerical Methods in Biomedical Engineering*, 30(5), 525–544. <https://doi.org/10.1002/cnm.2615>
- Plank, G., Loewe, A., Neic, A., Augustin, C., Huang, Y.-L. (Cary)., Gsell, M., Karabelas, E., Nothstein, M., Sánchez, J., Prassl, A., Seemann, G., & Vigmond, E. (2021). The openCARP simulation environment for cardiac electrophysiology. *Computer Methods and Programs in Biomedicine*, 208, 106223. <https://doi.org/10.1016/j.cmpb.2021.106223>
- Potse, M. (2018). Scalable and Accurate ECG Simulation for Reaction-Diffusion Models of the Human Heart. *Frontiers in Physiology*, 9, 370. <https://doi.org/10.3389/fphys.2018.00370>