Real-time simulations through data-driven reduced order models

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Reduced Order Models (ROMs) in a nutshell

Towards **Real-Time Computing** and Visualization, through an Offline–Online computational paradigm [1]-[2].

OFFLINE (full order): High Performance Computing

- **Very expensive** and time demanding;
- basis calculation done once after suitable parameters sampling (ex: **Proper Orthogonal Decomposition, RB, PGD**, ...);
- *HPC facilities*.

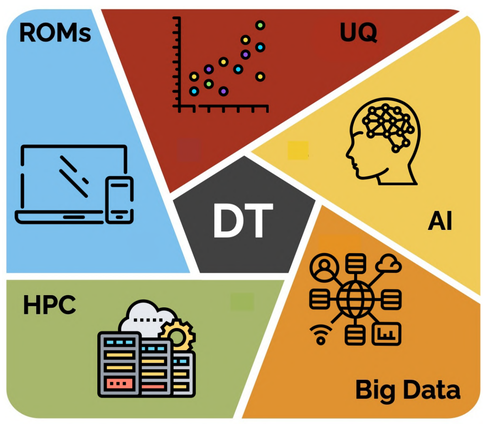
ONLINE (reduced order): Advanced ROM techniques

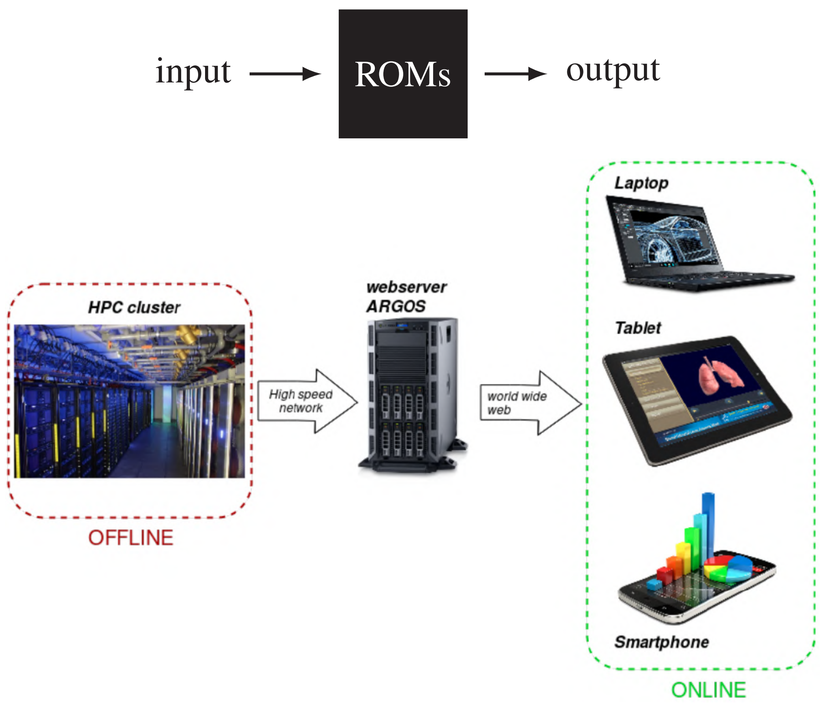
- **Extremely fast**;
- **real-time** input-output evaluation;
- computational **webserver** via browser;
- enhancing sustainability;
- *in situ, tablets or smartphones*.

The computational webserver: Advanced Reduced Groupware Online Simulation ARGOS (ERC PoC)

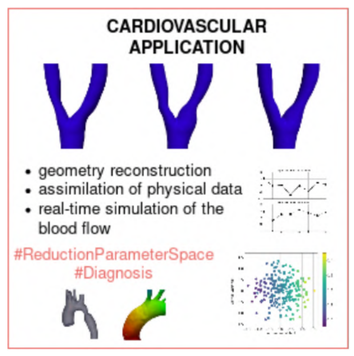
Model order reduction for computational web server: to real world applications (`https://argos.sissa.it/`)

ROMs are able to deal with **multiphysics** problems, as well as systems characterized by **multiple spatial and temporal scales**, under complex parametrization.
The input-output black box is suited for the enhancement by Artificial Intelligence (AI) algorithms.
An integrated framework and approach:



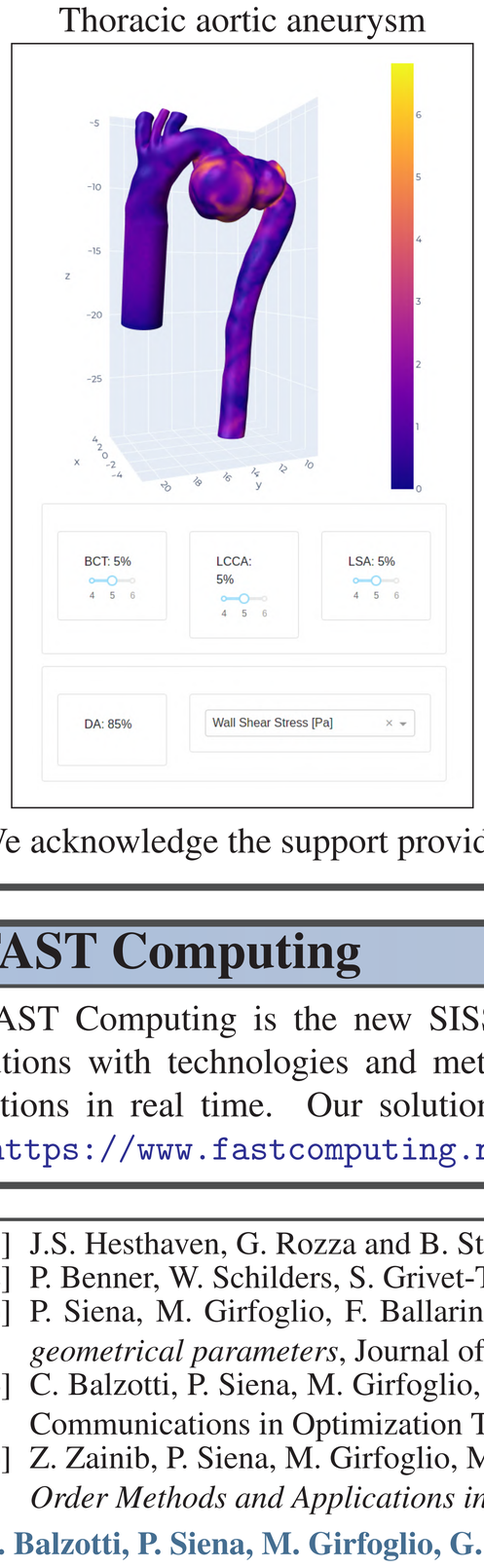


The methodology and associated computational technology is characterized by a significant portability in several fields and applications. ROMs provide important embedded tools for digital twins, especially if enhanced by AI, incorporating data analysis and Uncertainty Quantification (UQ).

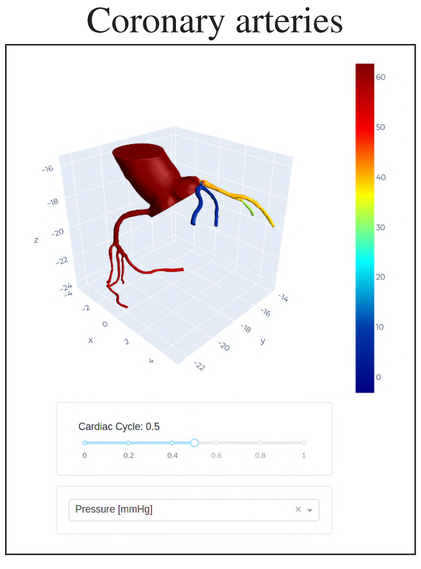


ATLAS: real-time computational webserver for data-driven cardiovascular flows

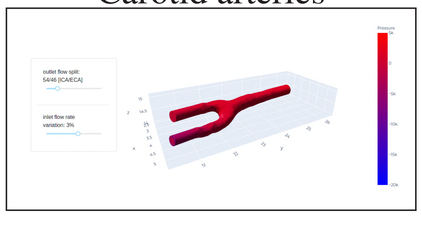
Thoracic aortic aneurysm



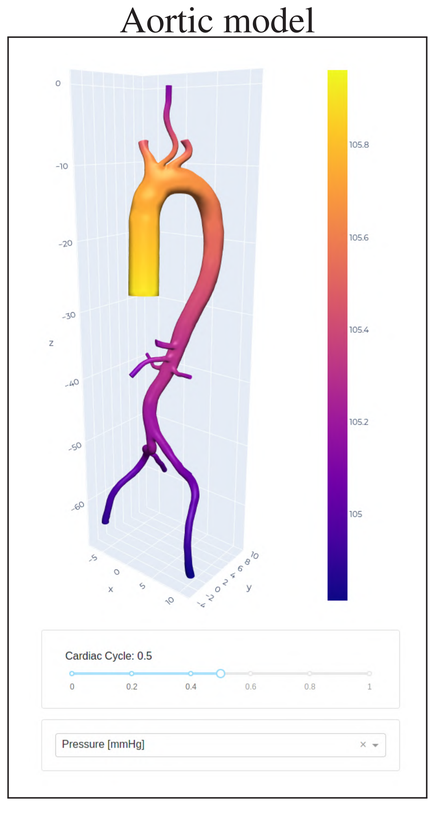
Coronary arteries



Carotid arteries



Aortic model



ROMs for patient-specific data

The aim is to develop an efficient ROM framework to reduce computational time and to achieve a **real time evaluation** in order to choose the best **surgical plan** [3][5].

ROMs for optimal control problem

The aim is to develop a framework by flow control on the **outlet boundary conditions** [4].

(`https://argos.sissa.it/atlas`)

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FAST Computing

FAST Computing is the new SISSA startup granted throught ARGOS ERC PoC. The aim is to supply enterprises and institutions with technologies and methodologies, both developed within the SISSA mathLab group, able to get scientific computations in real time. Our solutions are suitable for every field, from manufacturing, to medicine and environmental sciences (`https://www.fastcomputing.net`).

[1] J.S. Hesthaven, G. Rozza and B. Stamm. *Certified reduced basis methods for parametrized partial differential equations*, SpringerBriefs in Mathematics (2016).
[2] P. Benner, W. Schilders, S. Grivet-Talocia, A. Quarteroni, G. Rozza, and L. Miguel Silveira. *Model Order Reduction*, De Gruyter (2020).
[3] P. Siena, M. Girfoglio, F. Ballarin, and G. Rozza. *Data-driven reduced order modelling for patient-specific hemodynamics of coronary artery bypass grafts with physical and geometrical parameters*, Journal of Scientific Computing (2023).
[4] C. Balzotti, P. Siena, M. Girfoglio, A. Quaini, and G. Rozza. *A data-driven reduced order method for parametric optimal blood flow control: application to coronary bypass graft*, Communications in Optimization Theory (2022).
[5] Z. Zainib, P. Siena, M. Girfoglio, M.W. Hess, F. Ballarin, and G. Rozza, *Chapter 18: Reduced Order Methods for Hemodynamics Applications. In Advanced Reduced Order Methods and Applications in Computational Fluid Dynamics*, SIAM Press, CS 27 (2022).
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