TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

Heart Valve Replacements: Past, Presents, and Future Directions

Australian Government
Australian Research Council

Australian Government
Department of Health

THE UNIVERSITY OF SYDNEY

Digital Twins and Medicine 4.0

From **in silico** simulations to patient specific solutions

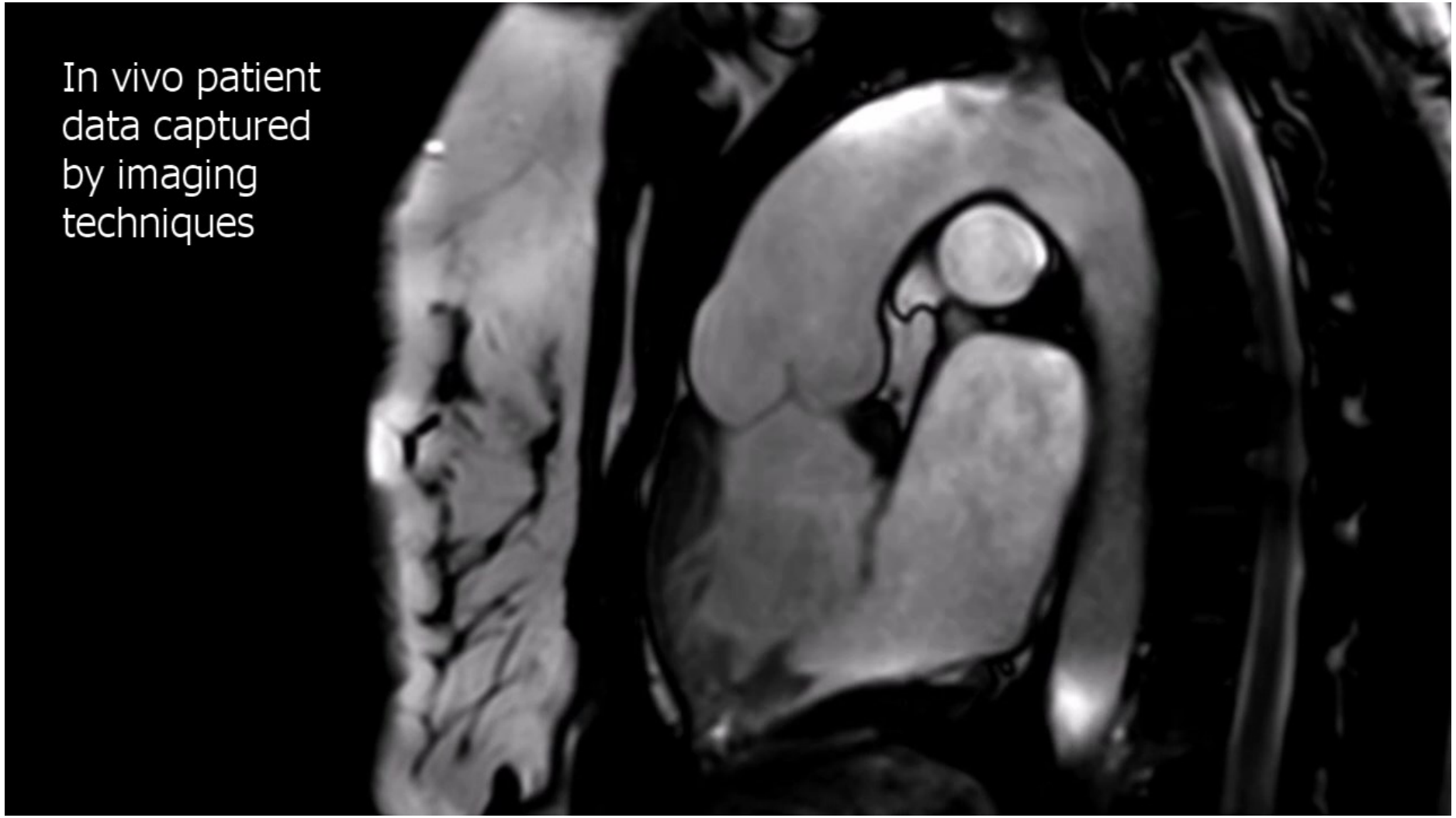
Prof. Marco E. Biancolini

Associate Professor at **UTV**

CTO and Owner at **RBF Morph srl**

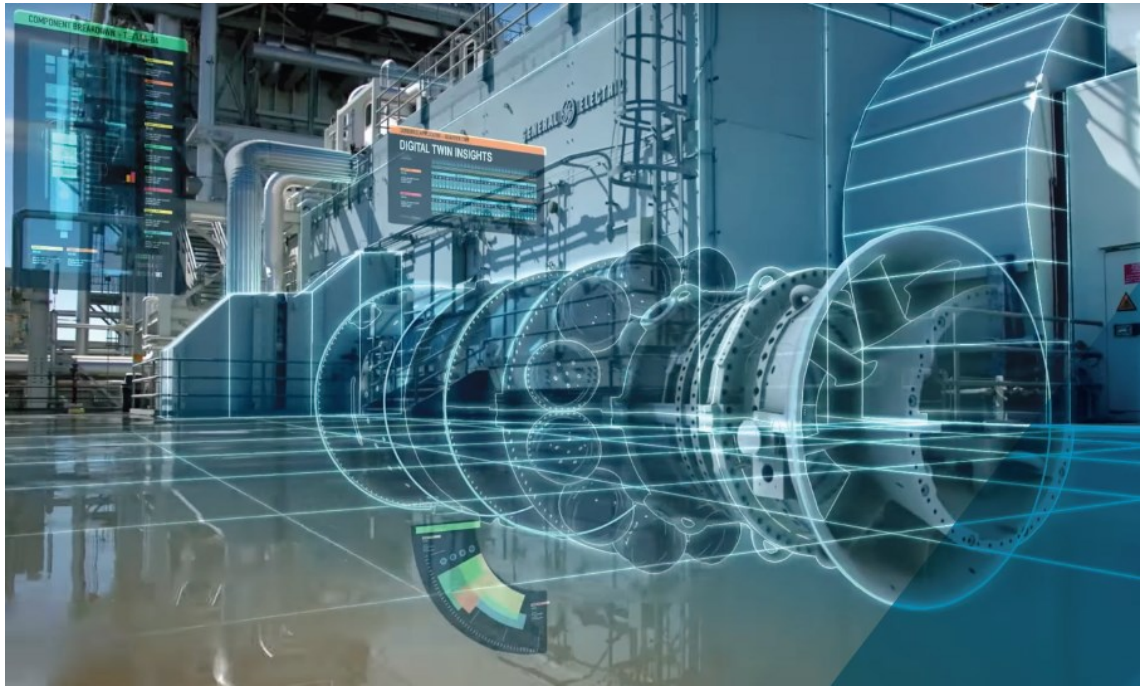
rbf™

In silico?



Agenda

- An overview on Digital Twin
- Medical Digital Twin in EC funded Research
  - MeDiTATe
  - Copernicus



Digital Twin **yesterday**-today-tomorrow

- Digital Twins are nothing new. Today we talk about DT a lot. But we have experience of DT daily use. ABS / ESP in our car. The Prius Hybrid (year 2004)!
- The governing equations of the physics of the twin were previously written by hand and then embedded in the electronics. Software components made up of great skills (for example vehicle dynamics). Telemetry and racing strategies in Formula 1. Advanced control systems on board the products.
- **Matlab Simulink**

Digital Twin yesterday-**today**-tomorrow

- System integration according to standards (an example are the FMU defined according to the FMI protocol *functional mockup interface*)
- Generic purpose IIoT platforms are available
- Twinning of industrial assets intended for the optimization of service, performance and maintenance
- **GE Predix**

"Digital twin eliminates the guesswork when determining the best way to service critical physical assets—from engines to power turbines. Easy access to this unique combination of deep knowledge and intelligence about your assets paves the road to optimization and business transformation."

Colin Parris, Vice President
GE Software Research

Digital Twin yesterday-today-**tomorrow**

- Integration of high fidelity CAE (FEA, CFD, FSI) and system simulation ones (Modelica)
- Combination of AI, Machine Learning and numerical simulation (ROM)
- Hybrid twins combining historic Big Data (when available) with synthetic Big Data by simulation – data fusion
- **ANSYS Twin Builder**

An overview on Digital Twin: a multi-sectoral multi-physics challenge

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- What is a digital twin?
- Predix Technology GE
- Ansys Twin Builder
- Functional Mock Up Interface
- Digital Twin Consortium

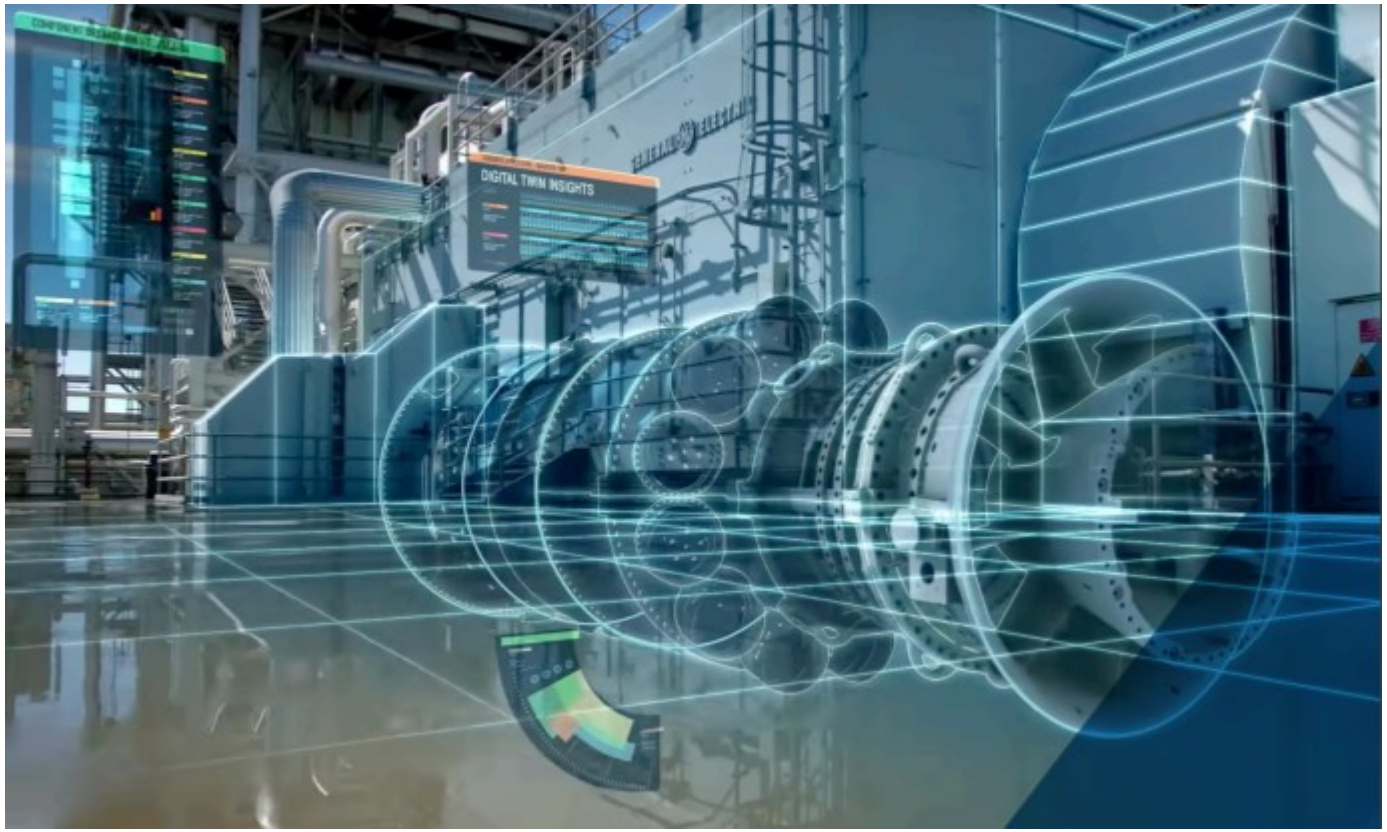
MathWorks®

Ansys

digital twin CONSORTIUM

fmi Functional Mock-up Interface

What is a digital twin?



- A digital twin is a digital copy of an existing and working physical asset.
- It's connected with the actual state of the asset, remembers its history
- It allows to evaluate more about the current status of the asset. Can be used to forecast its evolution

What is a digital twin?

- With a DT we can represent a **component**, a **system** of components or a system of systems: pumps, engines, power plants, production lines or fleet vehicles.
- Underlying modelling for the definition of a digital twin can be **statistical processing** of actual data (data driven) or created by **physical modelling** (Physics-informed Machine Learning).
- The twin represents the **actual working environment** of the asset, the age and the configuration; a bidirectional stream of data is a key for a proper **sync of the twin** and the asset (IIoT).

Power plant

Three pistons pump

Fleet Vehicles

PREDIX TECHNOLOGY BRIEF

PREDIX TECHNOLOGY BRIEF

Digital Twin

For Industrial Intelligence that analyzes the past, understands the present, and predicts the future

Asset-centric companies are seeking to move from a reactive to a proactive, digital approach to optimize and transform their business.

Industrial companies are realizing that to thrive they need to optimize their operations, improve lagging productivity, and develop innovative new business models.

Sensor capabilities, affordable data storage and computing, analytics, and ubiquitous network connectivity are creating opportunities for companies to connect their assets and collect their data. Progress in analytics, models, and machine learning is creating even more possibilities for better insights. And yet, many industrial companies underestimate the complexity of connecting the physical and digital worlds, operating without a platform, methodology, or approach.

What's needed is a new way to build apps optimized for understanding physical assets.

Digital twins build the bridge from the physical to the digital worlds, providing understanding of each unique asset over time. They combine the data from sensors and devices with analytics, models, and material science for a constantly improving digital model of industrial components and assets, and even entire processes and plants. As more digital twins run on the platform, the industrial learning system feeds back data to the individual digital twins, improving fidelity.

"Digital twin eliminates the guesswork when determining the best way to service critical physical assets—from engines to power turbines. Easy access to this unique combination of deep knowledge and intelligence about your assets paves the road to optimization and business transformation."

Colin Parris, Vice President
GE Software Research

Predix Digital Twin Fast Facts

- A radical new approach to industrial asset and systems intelligence
- Represent a wide variety of complexity: From spark plugs to engines, to a power generation unit, to an entire power plant
- Multi-level data and intelligence across the life cycle of parts, assets, and systems: Design, Build, Run, Operate, and Service
- Asset and system knowledge, early warnings, predictions, learnings, and optimization

PREDIX

Predix is the only platform and learning system optimized for digital twins

Predix is GE Digital's platform for the Industrial Internet. Predix empowers domain experts and developers to build and run digital twins using a set of sophisticated data and modeling techniques. These digital twins are used to create innovative outcome-based industrial applications.

Digital twins on the Predix platform provide a new approach to asset and system intelligence. Digital twins provide a rich, constantly evolving picture of machines and operations, capturing everything from components to functions to entire processes and plants. They capture the entire lifespan of an asset, as well as entire asset classes, and gain insights into past and present performance and future intelligence. Furthermore, digital twins are an ideal software object to perform simulations, allowing for scenario testing and further optimization.

Whether you are an asset manufacturer or asset operator, Predix-powered digital twins offer a unique, highly accurate digital representation of your assets and systems across their **design, build, run, operate and service** lifecycle, removing barriers to insight and innovation.

Think about the possibilities.

Roadmap to digital twin-enabled industrial apps

Build asset/system: Data scientists package asset data and intelligence, applying analytics, models, and machine learning. Predix provides standard toolkits to help accelerate the build process.

Run: The platform runs and persists digital twins for each asset/system.

Consume: Apps and developers access context data, APIs, and insights from the digital twin.

Get started by meeting our world-class team of asset and system experts and data science and machine learning professionals. Uncover relationships between your data and key business drivers, exploring new monetization opportunities:

ge.com/digital/services/advisory-services

Outcomes that matter

Aviation

- A bearing anomaly detection for jet engines gives a 15-30 day heads-up on potential failures
- Lifing prediction for stage 1 blades leads to $44M in savings in engine maintena
- Dynamic nance sch understar maintena $10M ann

Industrial

Digital twins provide the analytical and predictive power to expose new business opportunities and better operational methods.

ge.com/digital/predix

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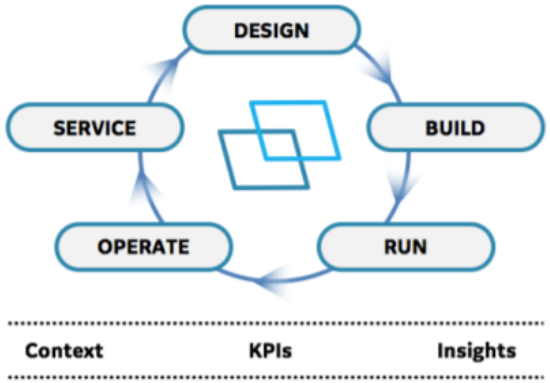
PREDIX

Industrial Lifecycle of an Asset



https://www.ge.com/digital/applications/digital-twin

ANSYS Twin Builder

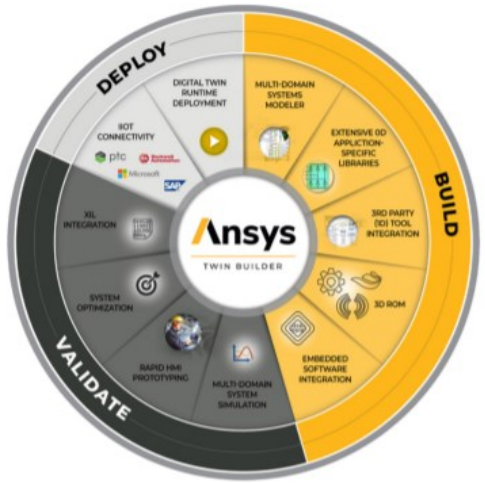
Ansys

DIGITAL TWIN

Ansys Twin Builder

Simulation-Based & Hybrid Analytics

Build, Validate and Deploy Simulation-Based Digital Twins

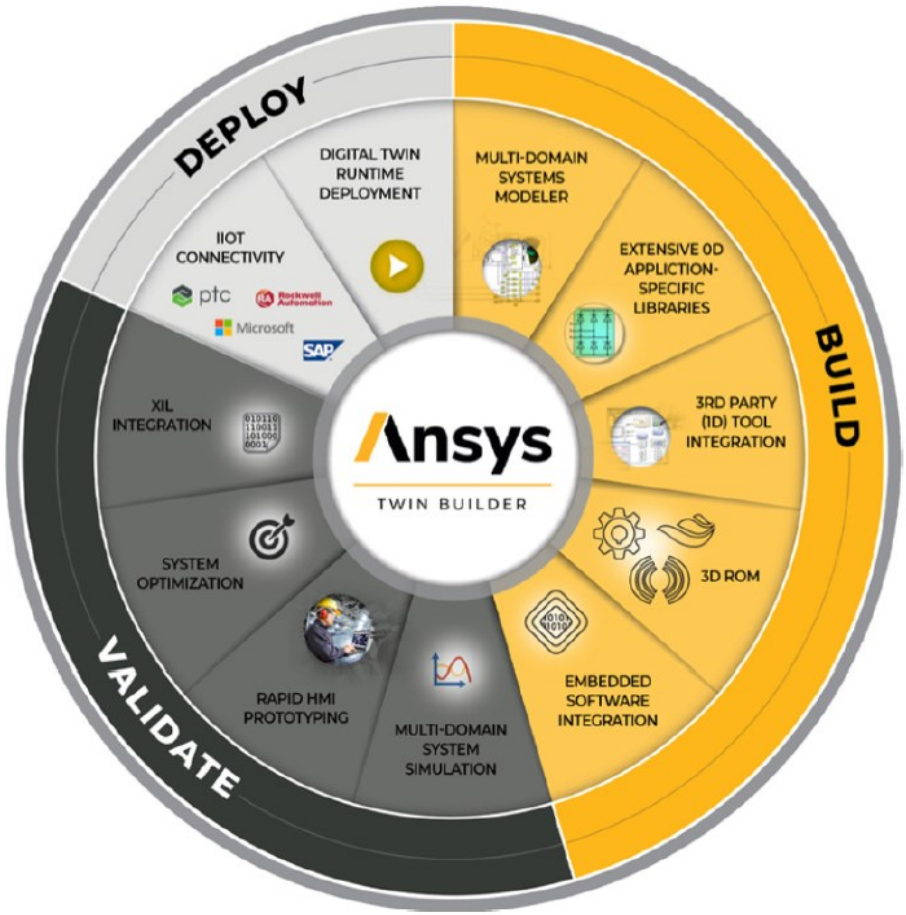


Ansys Twin Builder is a multi-technology platform that allows engineers to create simulation-based digital twins – digital representations of assets with real-world sensor inputs. Twin Builder improves predictive maintenance outcomes to save on warranty and insurance costs and optimize your product's operations.

To build your system quickly and easily, Twin Builder combines the power of a multidomain systems modeler with extensive 0D application-specific libraries, 3D physics solvers and reduced-order model (ROM) capabilities. When combined with embedded software development tools, Twin Builder allows you to reuse existing components and quickly create a systems model of your product.

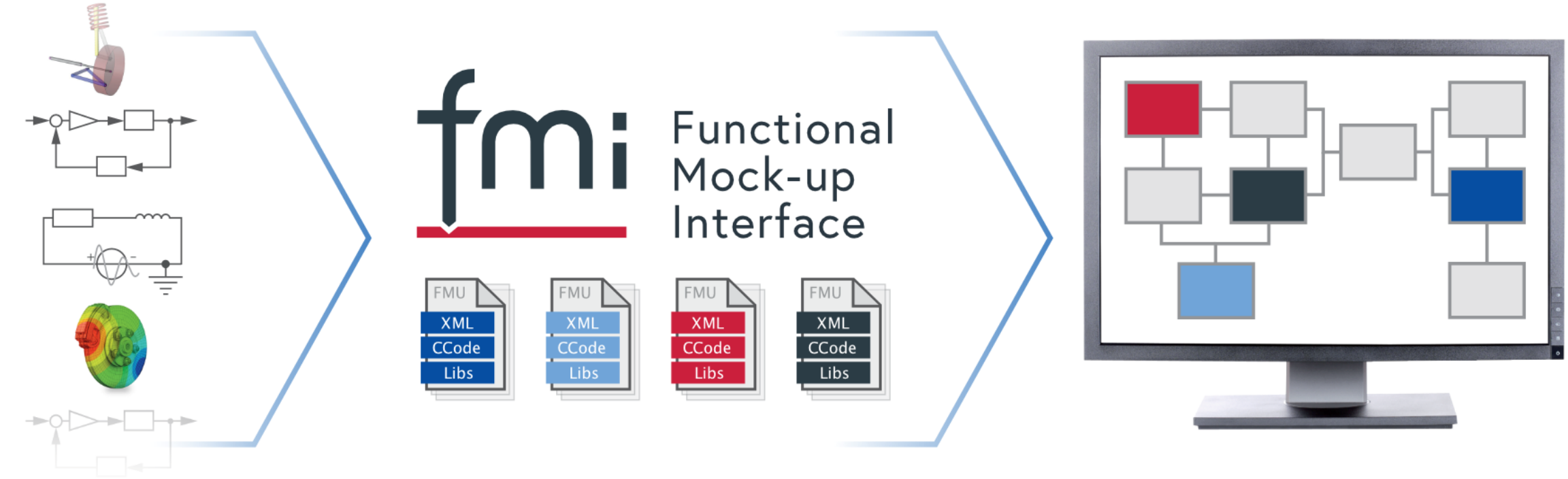
To validate your system and ensure expected performance, Twin Builder combines multidomain systems simulation capabilities with rapid human-machine interface (HMI) prototyping, systems optimization and XiL validation tools.

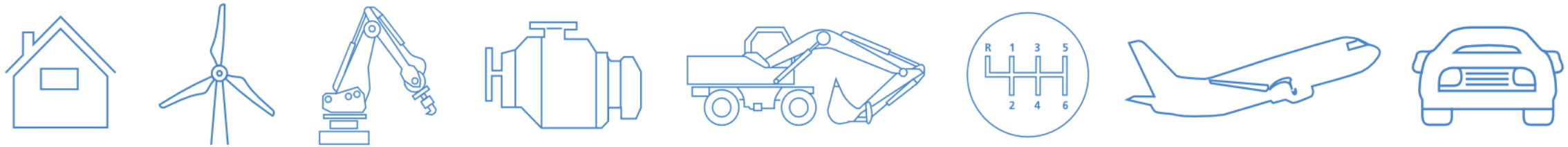
To connect your twin to test or real-time data, Twin Builder easily integrates with industrial internet of things (IIoT) platforms and contains runtime deployment options, allowing you to perform predictive maintenance on your physical product. It is the only product that offers a packaged approach for your digital twin strategy.



https://www.ansys.com/it-it/products/digital-twin/ansys-twin-builder

Functional Mock-Up Interface





https://fmi-standard.org/

Digital Twin Consortium

digital twin CONSORTIUM

Founding Members

Ansys AUTODESK. Bentley DELL Technologies

GE Digital lendlease Microsoft NORTHROP GRUMMAN

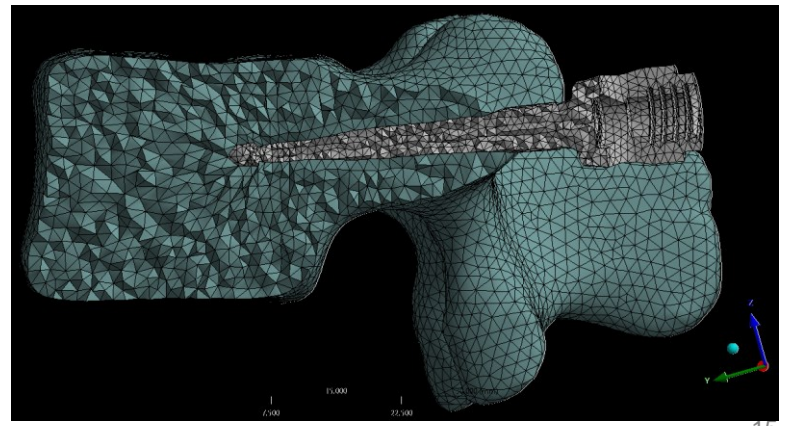
https://www.digitaltwinconsortium.org/glossary/glossary.html

Medical Digital Twin

- Human body is a very important physical asset!
- Medical engineering combines **in silico** approach with the in vivo and in vitro ones
- CFD simulation of cardiovascular systems, structural simulations of stress acting on prostheses and on tissues, aerodynamic simulation of airways.
- Patient digital twin (Medical Digital Twin) aims at an easy adoption of in silico results in the medical environment (translation).
- Numerical simulation requires high performance computing (HPC) to have real time usage compression methods (ROM, PCA) are key enablers to adopt digital twin in real time
- Medical digital twin requires the fusion of image data and digital images (interactive visualization), the definition of biomarkers and the presentation of the results with tools and language that can be easily understood by the medical staff.
- https://www.vph-institute.org/history.html

Examples of Medical Digital Twin

- Aneurysms prevention and treatment (MeDiTATe project -The Medical Digital twin for aneurysm prevention and treatment)
- Shunting according to the mBTS (FF4EuroHPC project experiment - Cloud-Based HPC Platform to Support Systemic-Pulmonary Shunting Procedures)
- Patient specific airways treatment (FF4EuroHPC project experiment - Digital-Twin for Airflow and Drug Delivery in Human Airways)
- Patient specific spine surgery (Spinner Project - SPINe: Numerical and Experimental Repair strategies)



PROJECT OVERVIEW

MARCO EVANGELOS BIANCOLINI
UNIVERSITY OF ROME "TOR VERGATA"

MeDiTaTe Project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 859836

General information

Project title	**The Medical Digital Twin for Aneurysm Prevention and Treatment**
Starting date	**01/01/2020**
Duration in months	**48**
Programme	**Marie Skłodowska-Curie Actions**
Topic	**Innovative Training Networks**
Call Identifier	**H2020-MSCA-ITN-2019**
Form	**European Industrial Doctorates (EID)**
Grant agreement no.	**859836**
Fund	**3 750 403.86 Euros**

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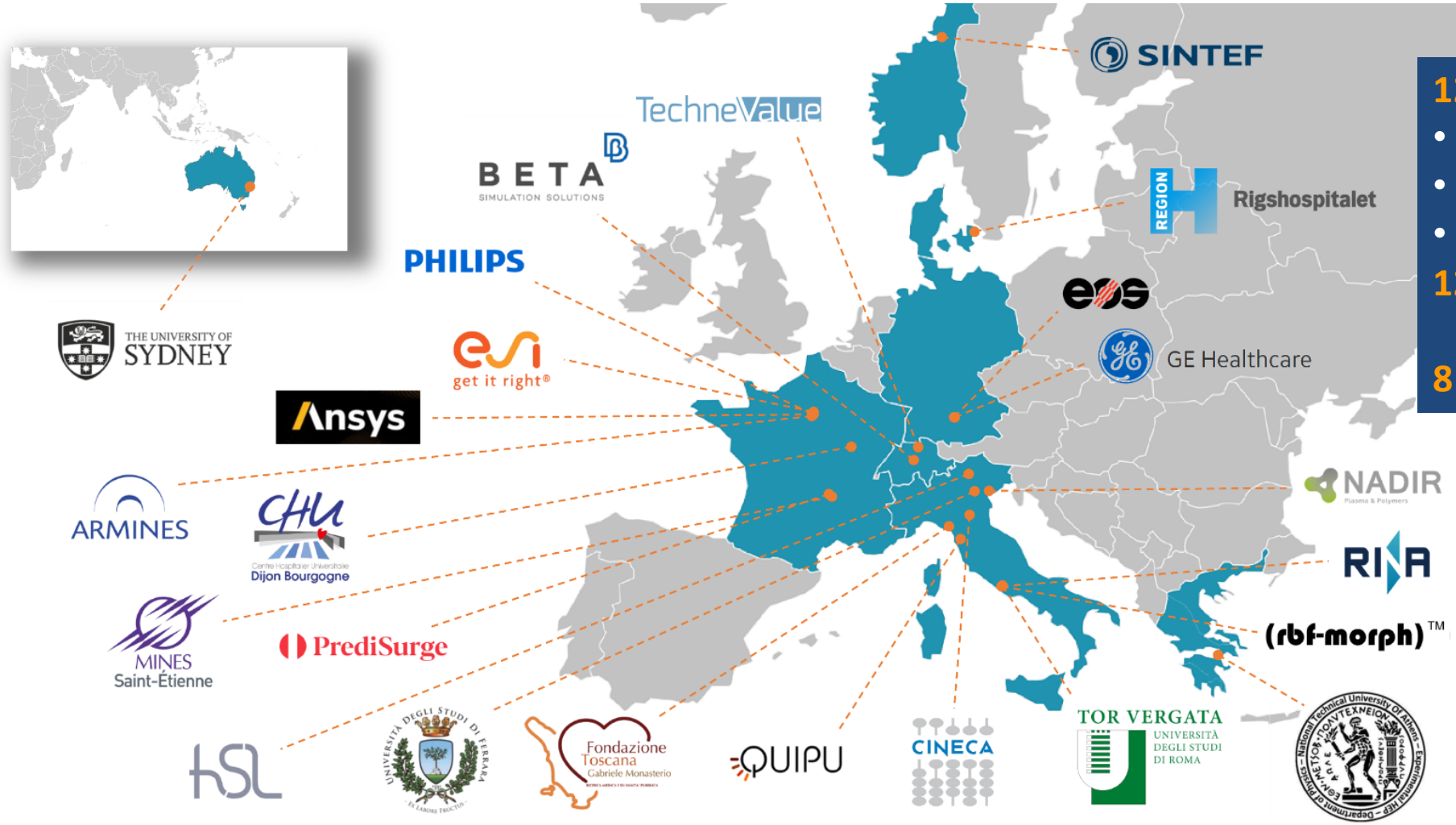
Consortium



12 beneficiaries
- 3 academic
- 7 industrial
- 2 clinical centres

12 partners

8 countries

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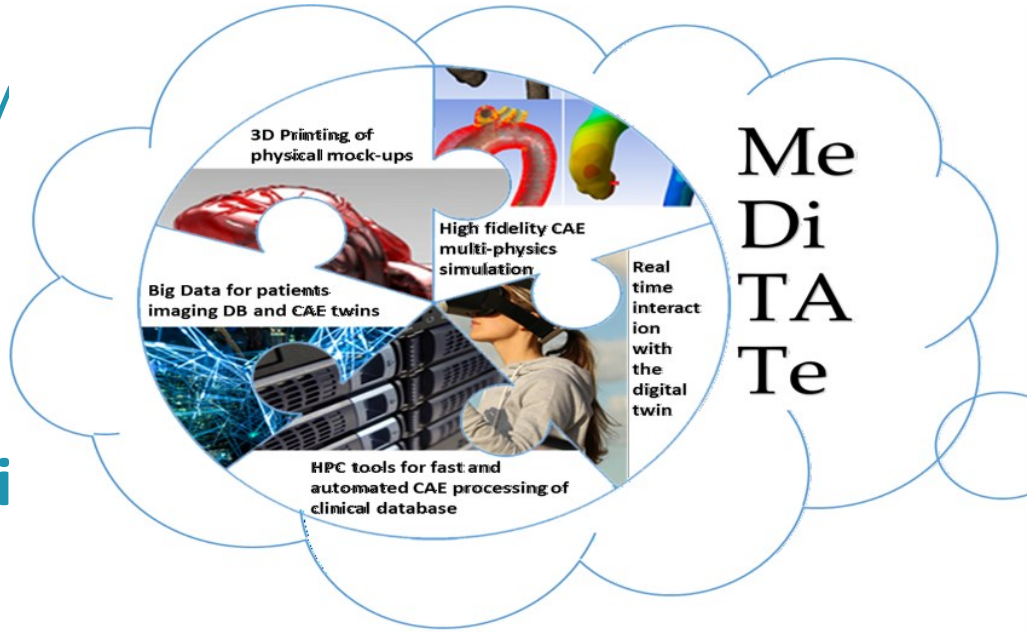
Research Tracks

1. High fidelity **CAE multi-physics** simulation with RBF mesh morphing (FEM, CFD, FSI, inverse FEM
2. Real time interaction with the Digital Twin by **Augmented Reality**, Haptic Devices and **ROM**.
3. HPC tools, including GPUs, and cloud-based paradigms for **fast and automated CAE processi** of clinical databases.



4. Big Data management for population of patients imaging data and **high fidelity CAE twins**.
5. Additive Manufacturing of **physical mock-up** for surgical planning and training.

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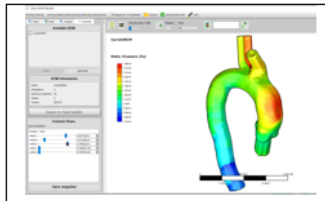
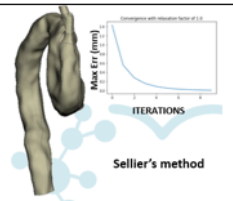
Individual Research Projects

https://meditate-project.eu/phd-projects/

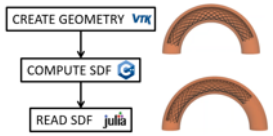


ESR1 Interactive ROM to reshape the aneurysm

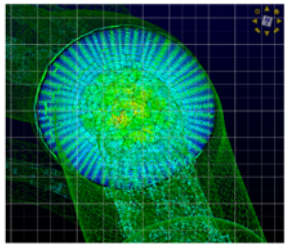


ESR2 Zero pressure shape definition for high fidelity FSI

MEDITATE



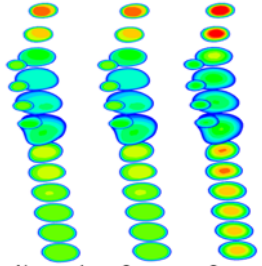
ESR3 Custom FEM beam solver for stent deploy



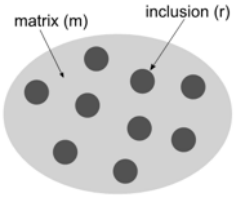
ESR4 Advanced meshing for accurate HiFi GPU simulations

PUMA (NTUA)

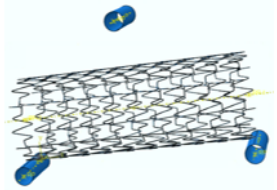
ESR5 FSI coupling simulation accelerated with GPU



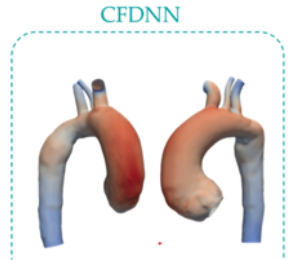
ESR6 Non-Newtonian fluids modelling



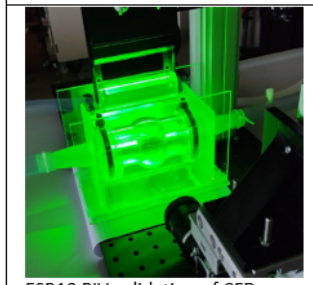
ESR7 Material models matched by FEA identification of image data



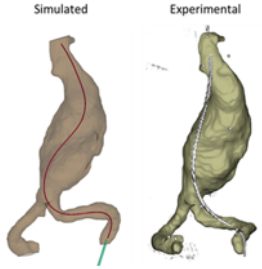
ESR8 Auxetic structures are modelled by nonlinear FEA



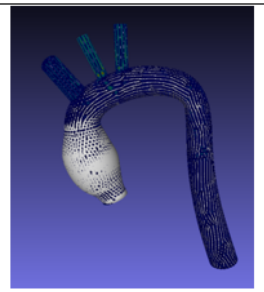
ESR9 CFD computed by Physics informed Machine Learning



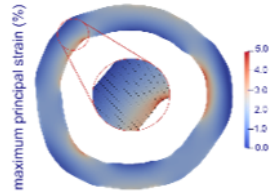
ESR10 PIV validation of CFD simulations of phantoms



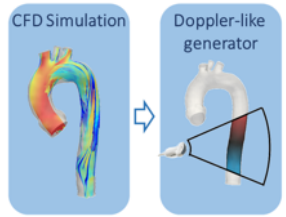
ESR11 FEM simulation of guided navigation



ESR12 RBF Mesh Morphing of patient specific vessels



ESR13 RBF predicted strain map on US images



ESR14 CFD digital twin to simulate US

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Early Stage Researchers

https://meditate-project.eu/early-stage-reserachers/














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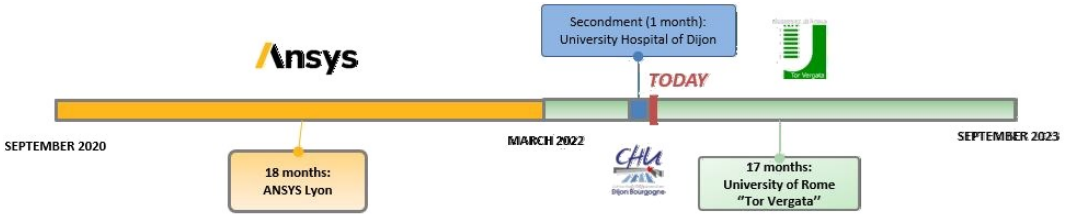
ESR 02 - The combined use of mesh morphing, force-feedback device and static reduced-order models for achieving real-time hemodynamic solution over geometric changes

Dec. 2019, Master's degree in Biomedical Engineering, *University of Pisa*
Title of the thesis: "Development of a fast high-fidelity FSI workflow to simulate polymeric aortic valves: an RBF mesh morphing study"

Jun. - Dec. 2019, Thesis Internship, *BioCardioLab, Fondazione Monasterio, Massa*
Approach to numerical simulation in the cardiovascular field

Jan. – Jul. 2020, Junior Developer, RBF Morph, *Rome*
Implementation of Biomedical/Mechanical morphing applications
Development of ACT extension in Ansys Mechanical

Sept. 2020 – Sept 2023, PhD student, MeDiTATe project



ESR 02 – LEONARDO GERONZI

Leonardo Geronzi / Research Engineer – PhD Student
MeDiTATe - EU H2020 Marie Sklodowska-Curie project https://meditate-project.eu

E-mail:
Leonardo.Geronzi@uniroma2.it

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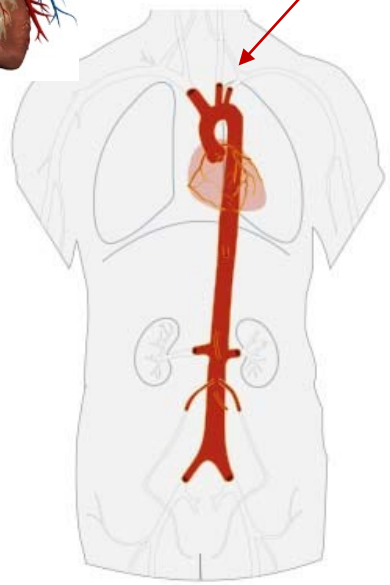
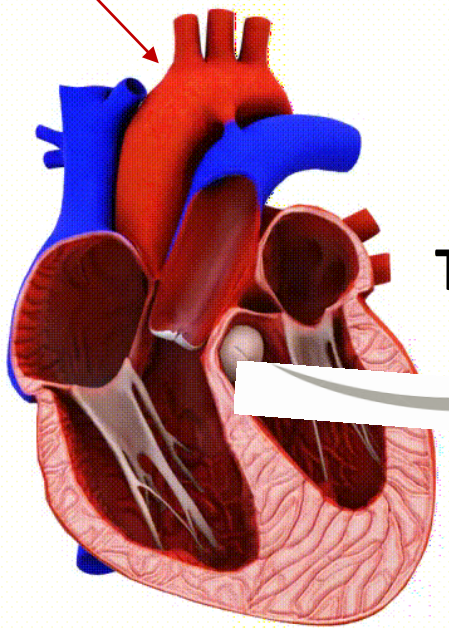
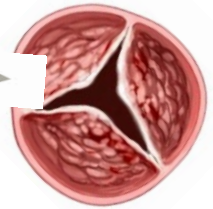
The Anatomy and the Clinical Problem



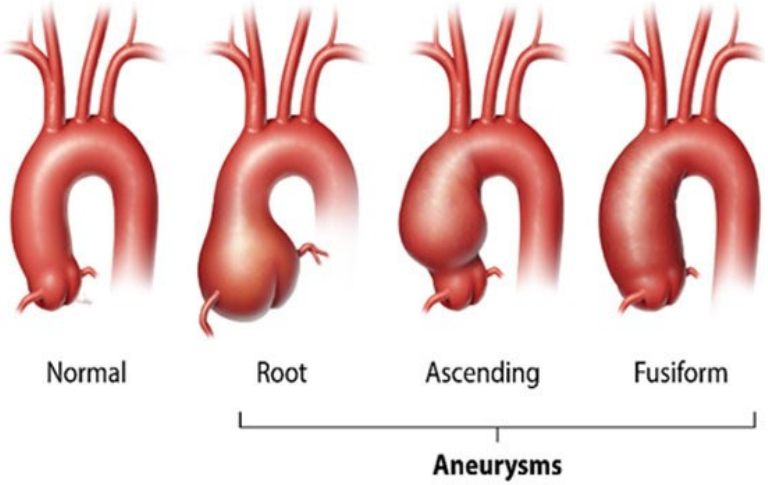
The aorta



The aortic valve



The ascending aortic aneurysm



The **criterion** to perform **ascending aortic aneurysm surgery** is currently based only on the evaluation of the ascending aorta **diameter**.

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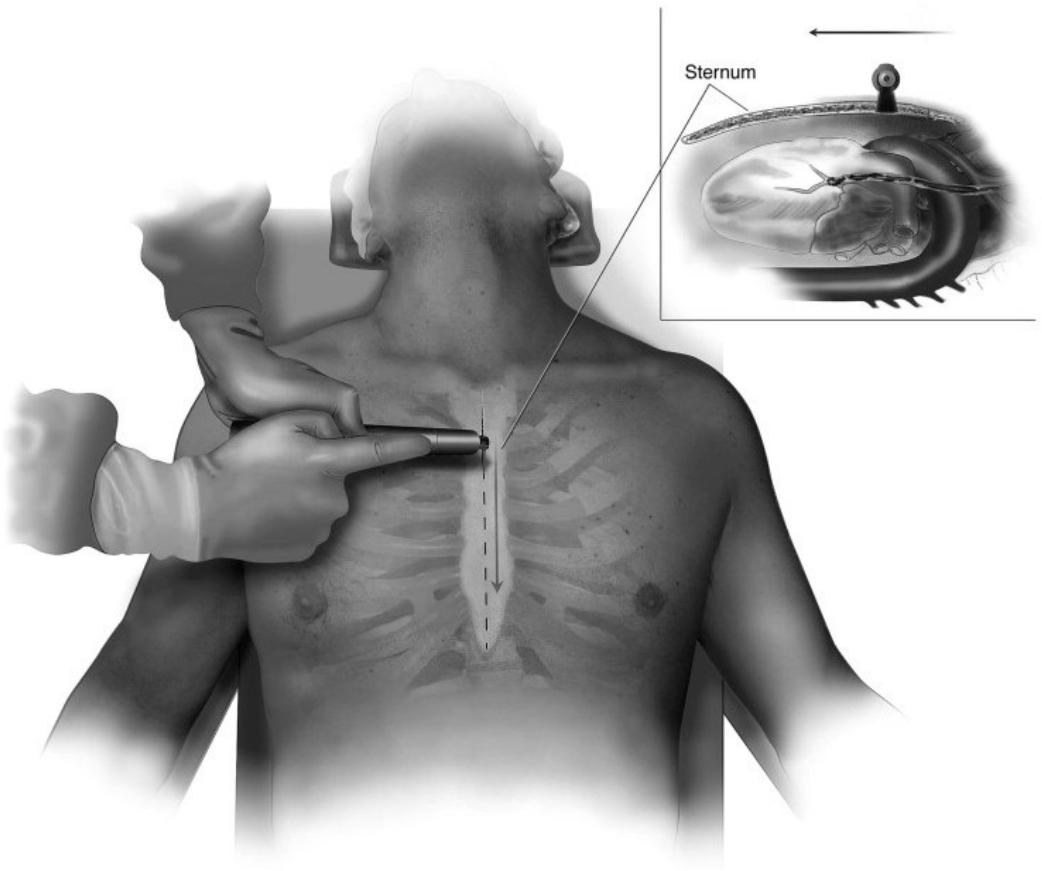
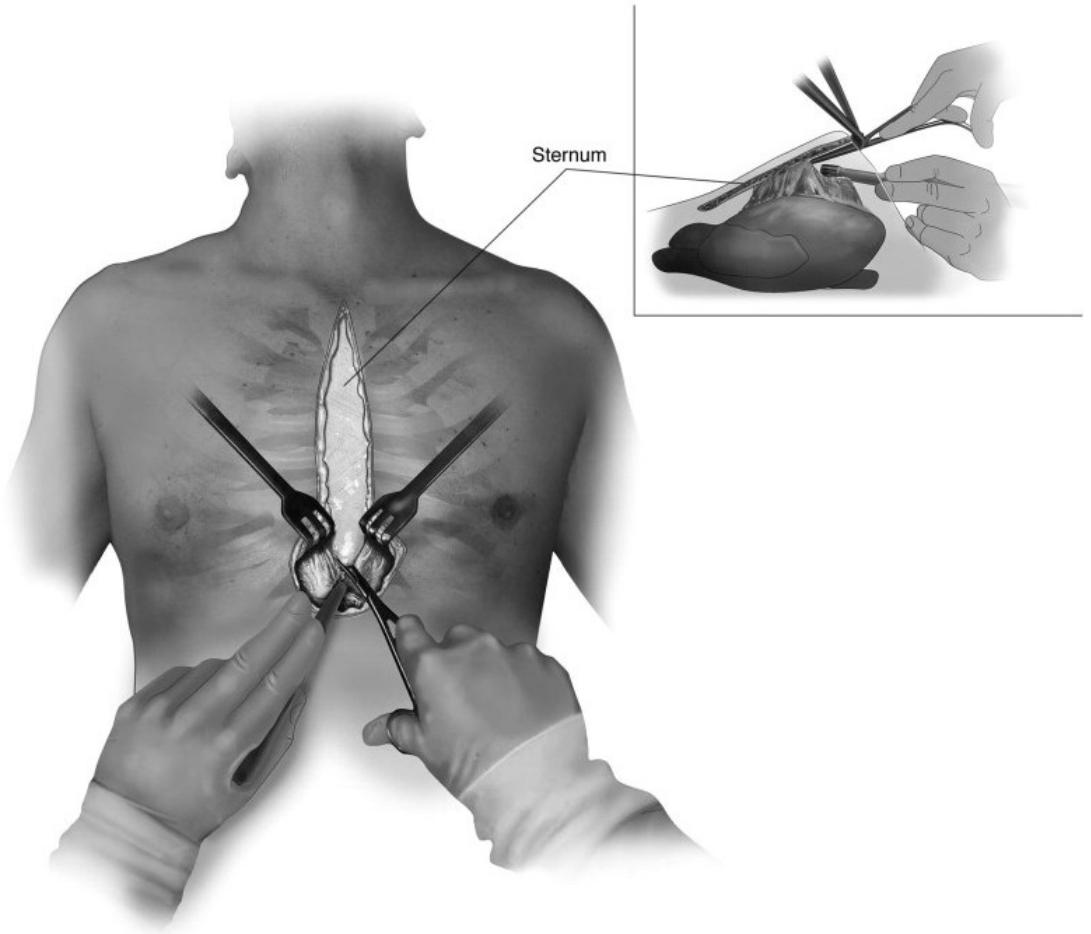
The surgery





[1] Leonard N.Girardi, MD, Operative Techniques in Thoracic and Cardiovascular Surgery

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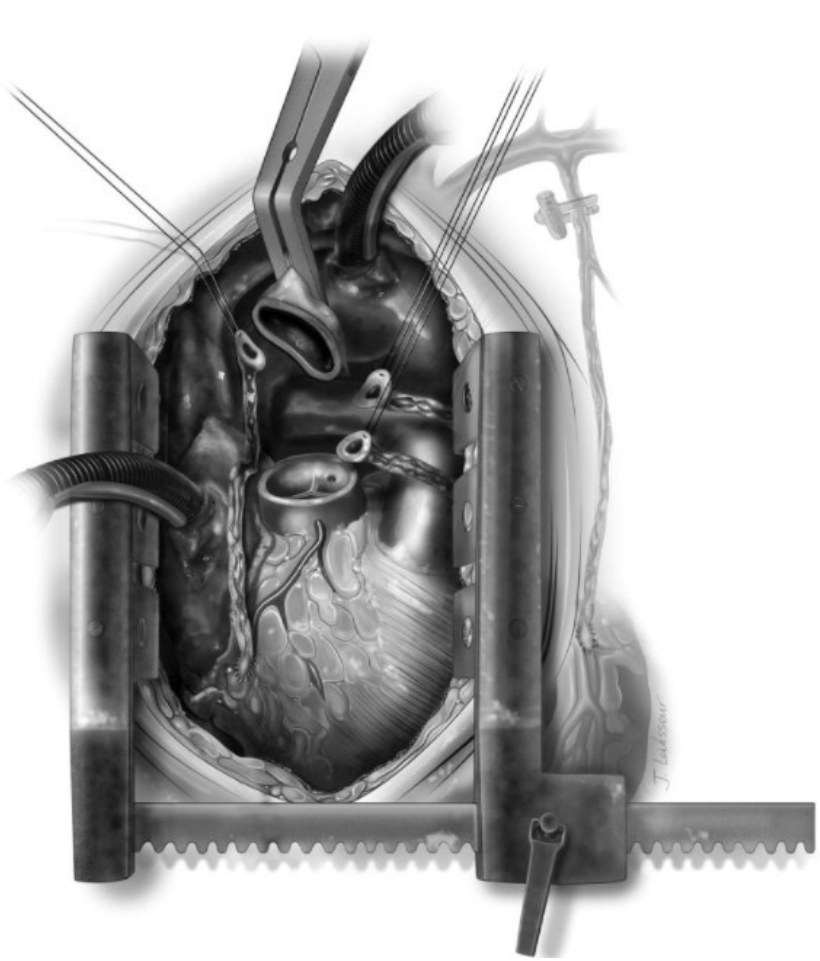
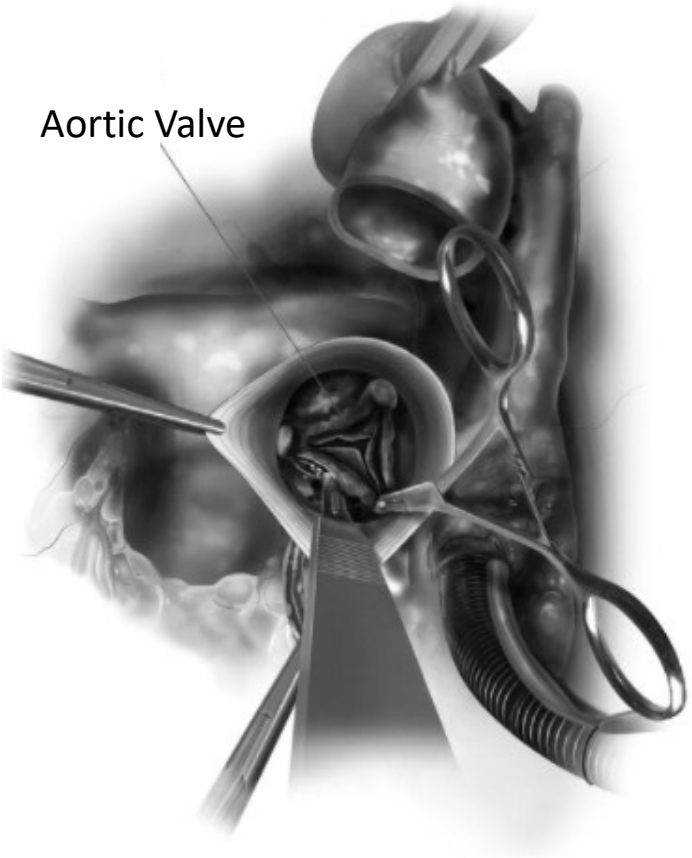
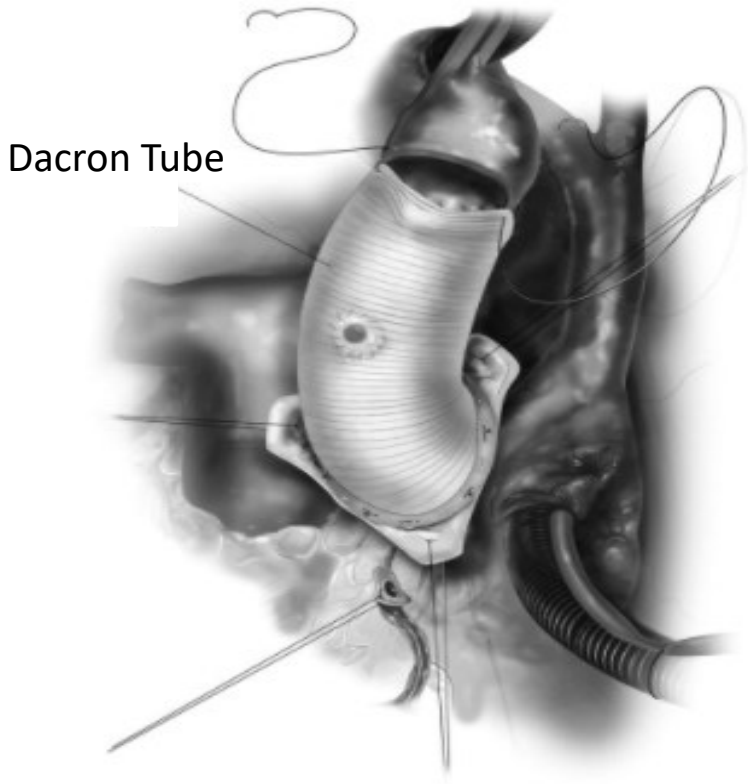
The surgery







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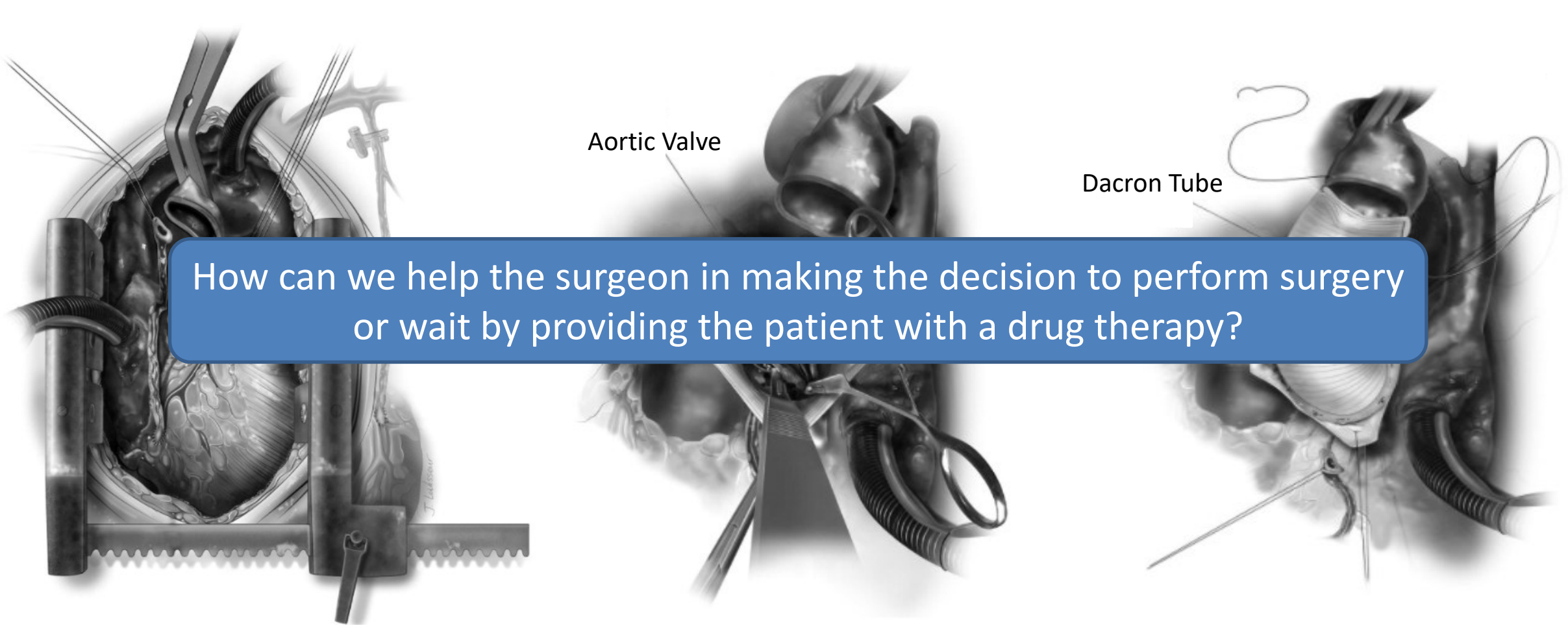
MeDiTaTe Project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 859836

The surgery



How can we help the surgeon in making the decision to perform surgery or wait by providing the patient with a drug therapy?

[1] Leonard N.Girardi, MD, Operative Techniques in Thoracic and Cardiovascular Surgery

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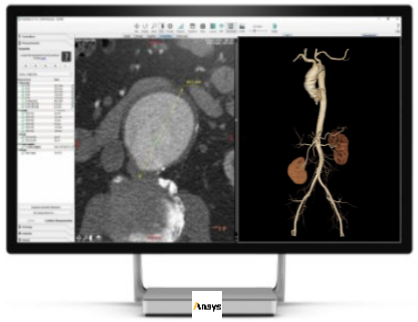
Digital Twin and Real Time Simulation

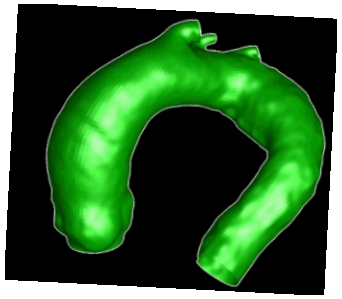
Creating a workflow to go from images to simulation results in a few seconds...



Rapid growth

ANEURYSM GROWTH RATE

No growth

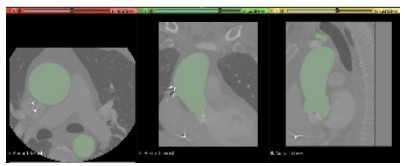


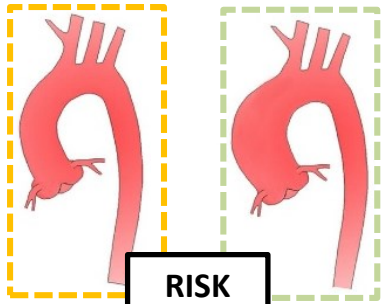
SEMI-AUTOMATIC SEGMENTATION

METRICS ON THE GEOMETRY

STATISTICAL SHAPE MODELING

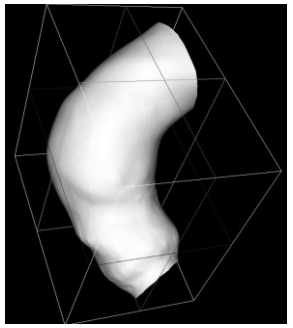
3DSlicer



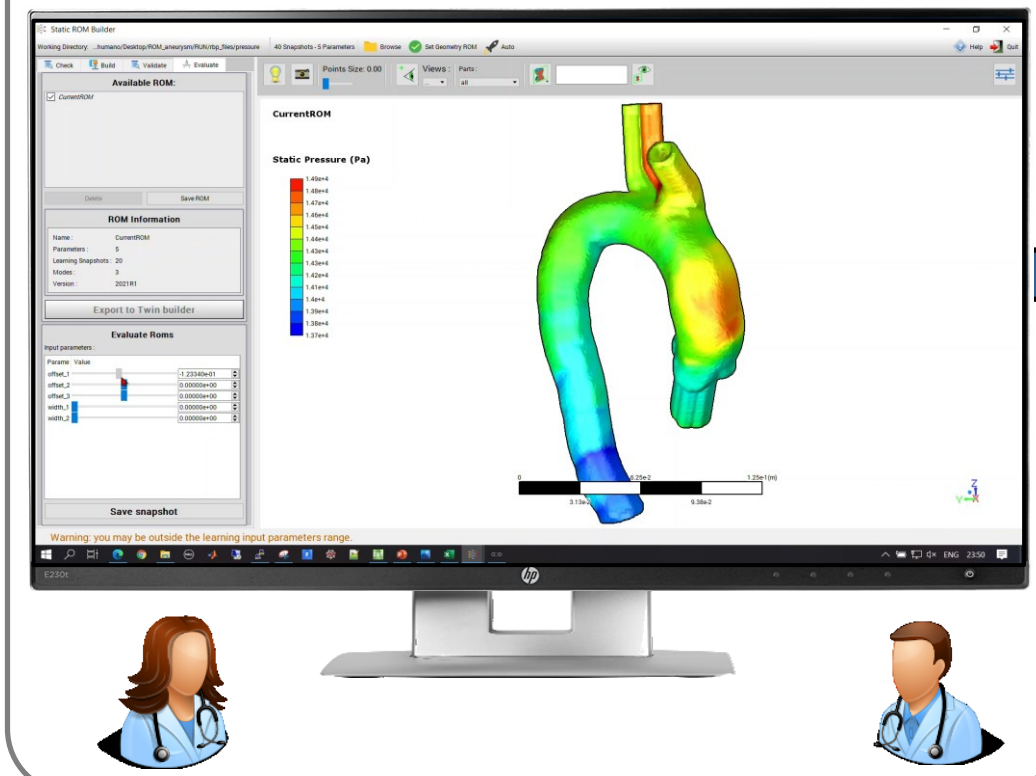


RISK

LOW HIGH



REDUCED ORDER MODELS AND REAL-TIME SIMULATION



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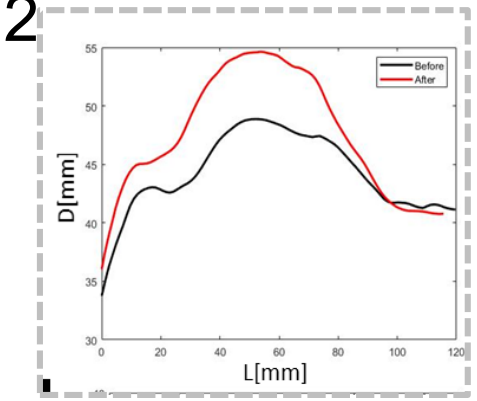
Relationship between shape and growth rate?

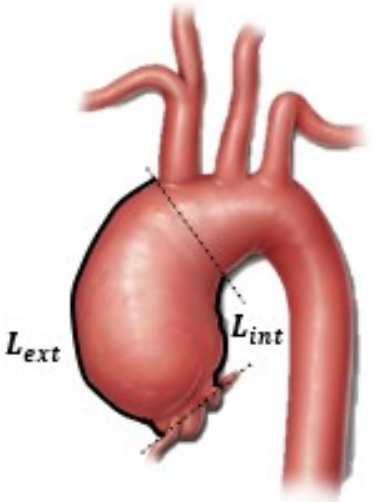
Exploiting longitudinal data: CTScan/MRI time 1 and CTScan/MRI time 2

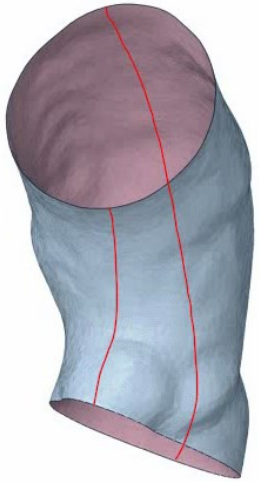
Maximum diameter along the centerline



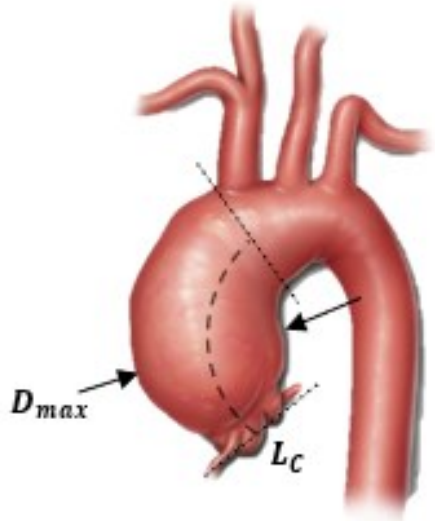
Ascending Aorta model

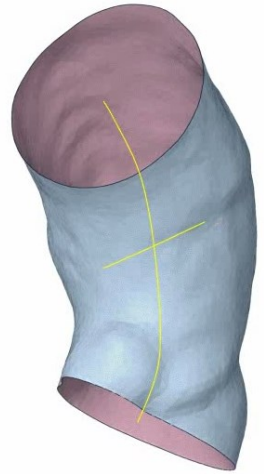
… n months…





$$EIR = \frac{L_{ext}}{L_{int}}$$





$$DCR = \frac{D_{\max}}{L_c}$$

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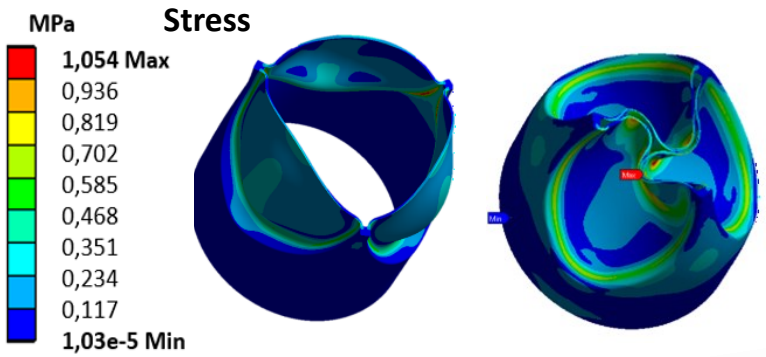
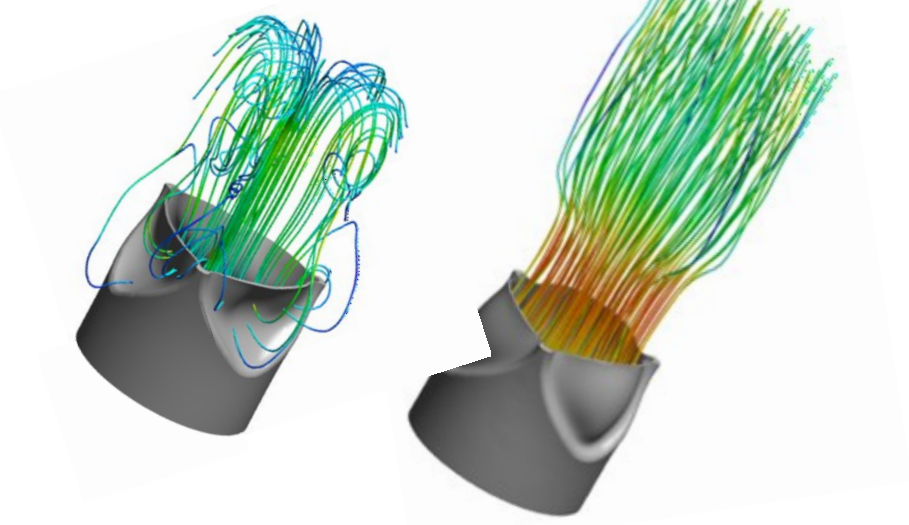
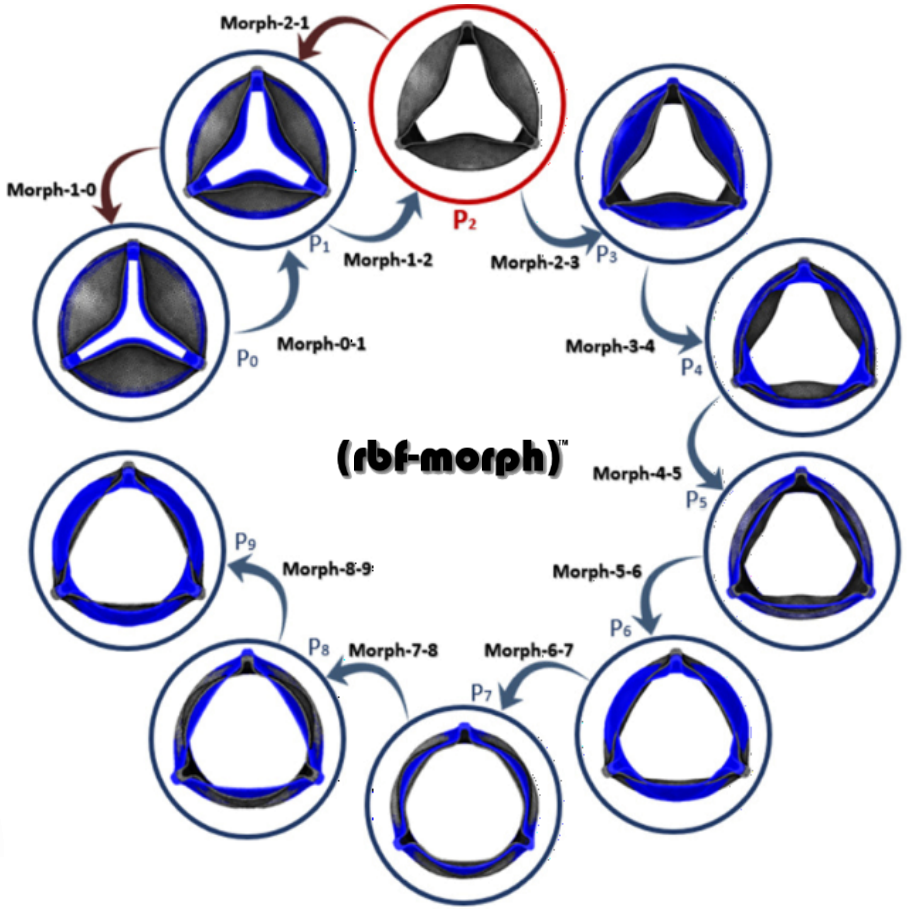
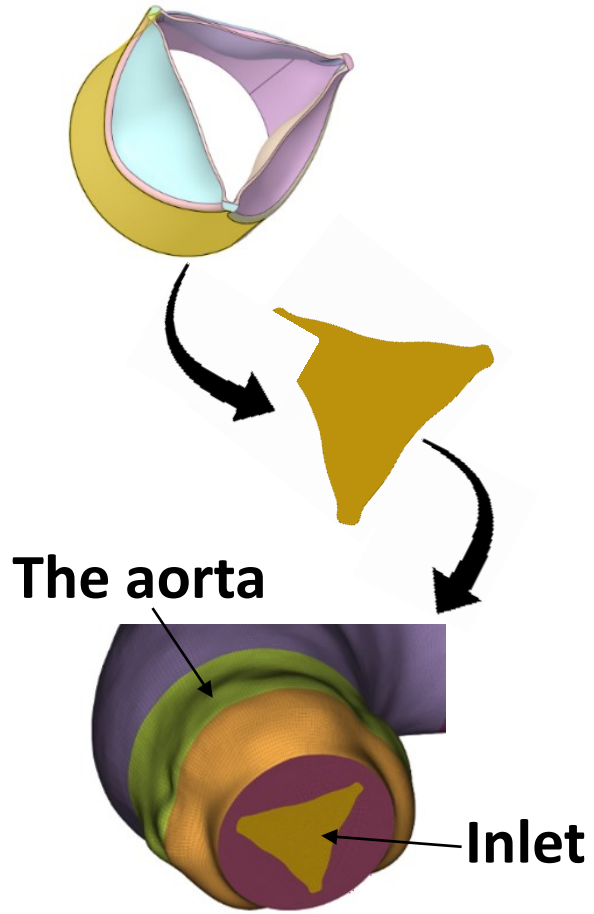
Study of the aortic valve using RBF mesh morphing









[2] Geronzi, Leonardo, et al. "High fidelity fluid-structure interaction by radial basis functions mesh adaption of moving walls: a workflow applied to an aortic valve." *Journal of Computational Science* 51 (2021): 101327. https://doi.org/10.1016/j.jocs.2021.101327

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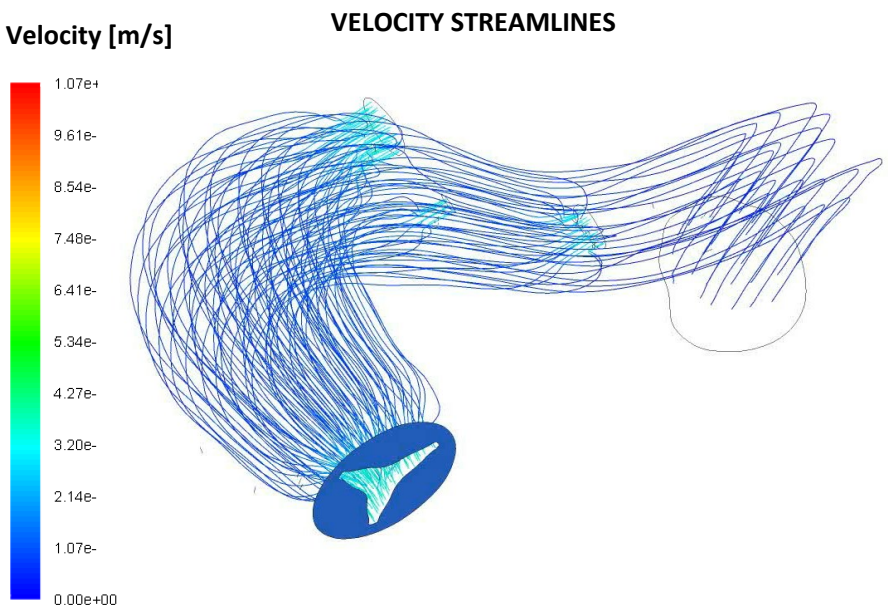
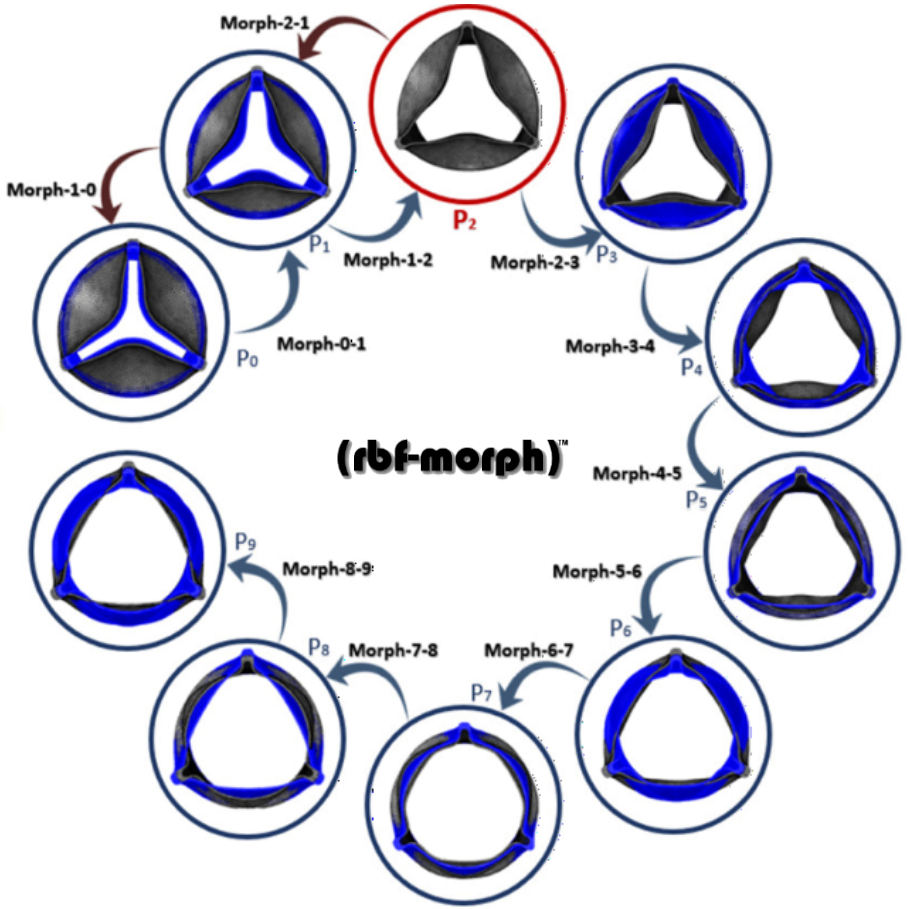
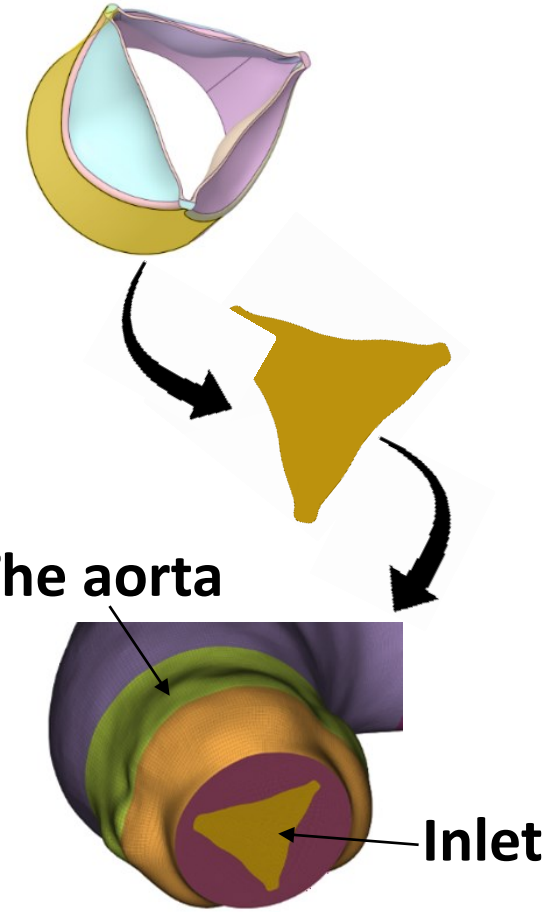
Study of the aortic valve using RBF mesh morphing

CFD simulation of the aorta
with valve opening and closing





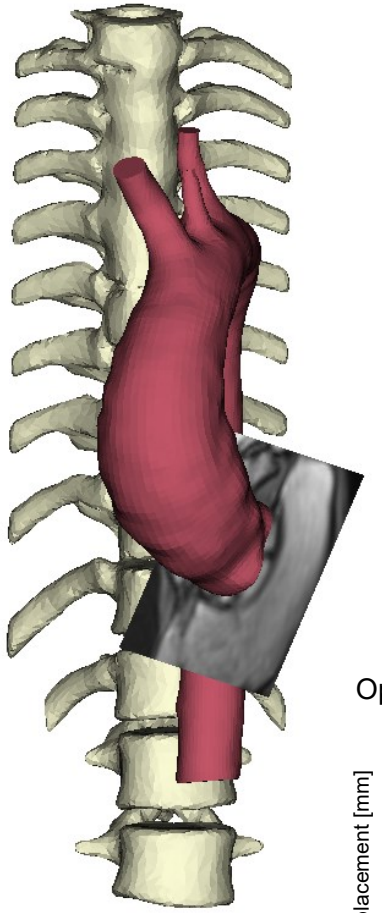


[3] Bonomi, Diana, et al. "Influence of the aortic valve leaflets on the fluid-dynamics in aorta in presence of a normally functioning bicuspid valve." *Biomechanics and modeling in mechanobiology* 14.6 (2015): 1349-1361.

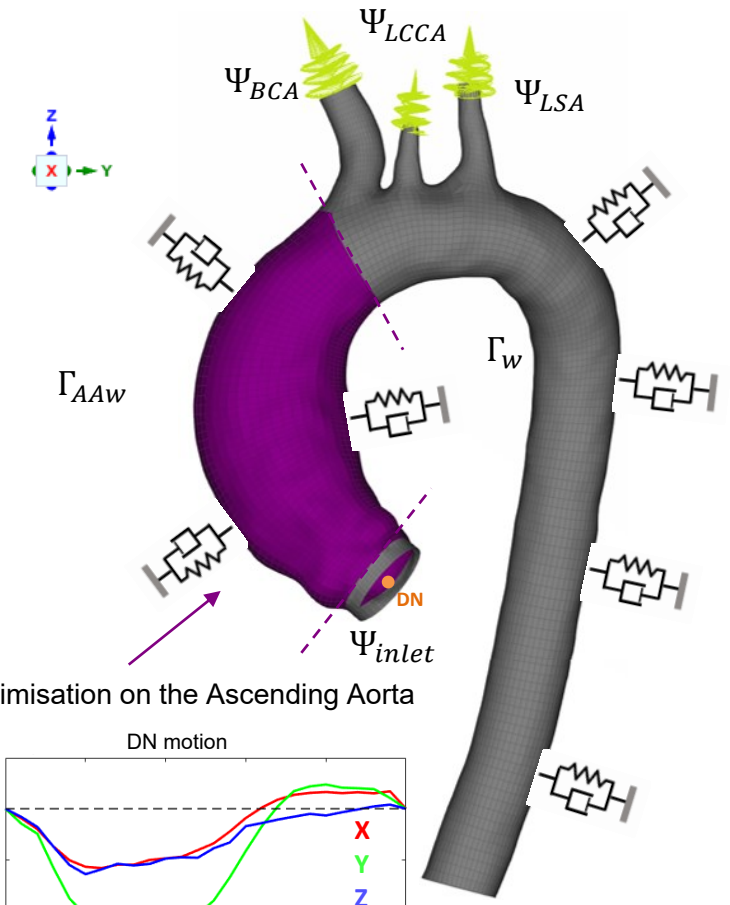
MeDiTaTe Project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 859836

Effect of the heart motion on a thoracic aorta model and calibration of the boundary conditions

Segmented anatomies

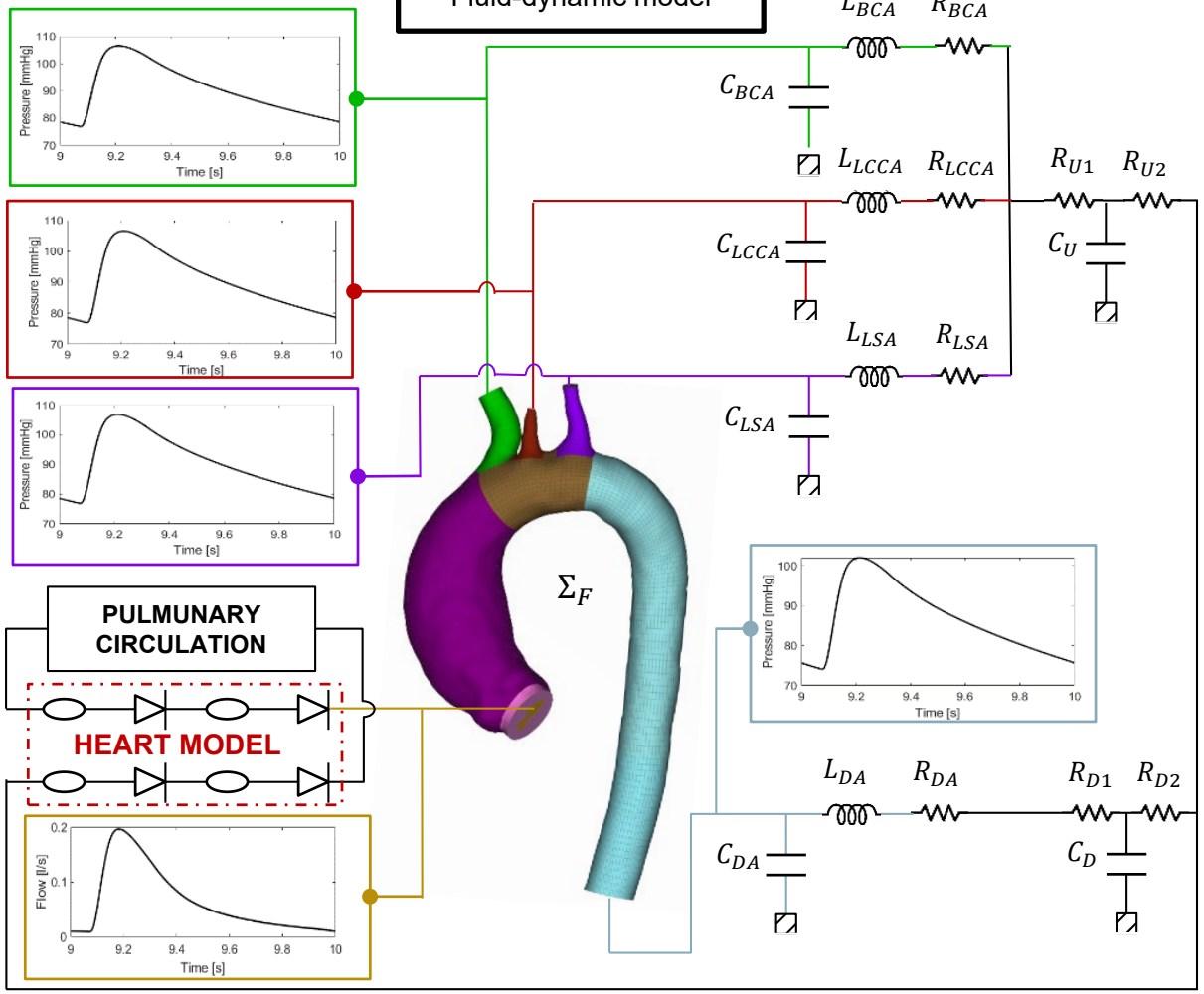


Structural model



Optimisation on the Ascending Aorta

Fluid-dynamic model



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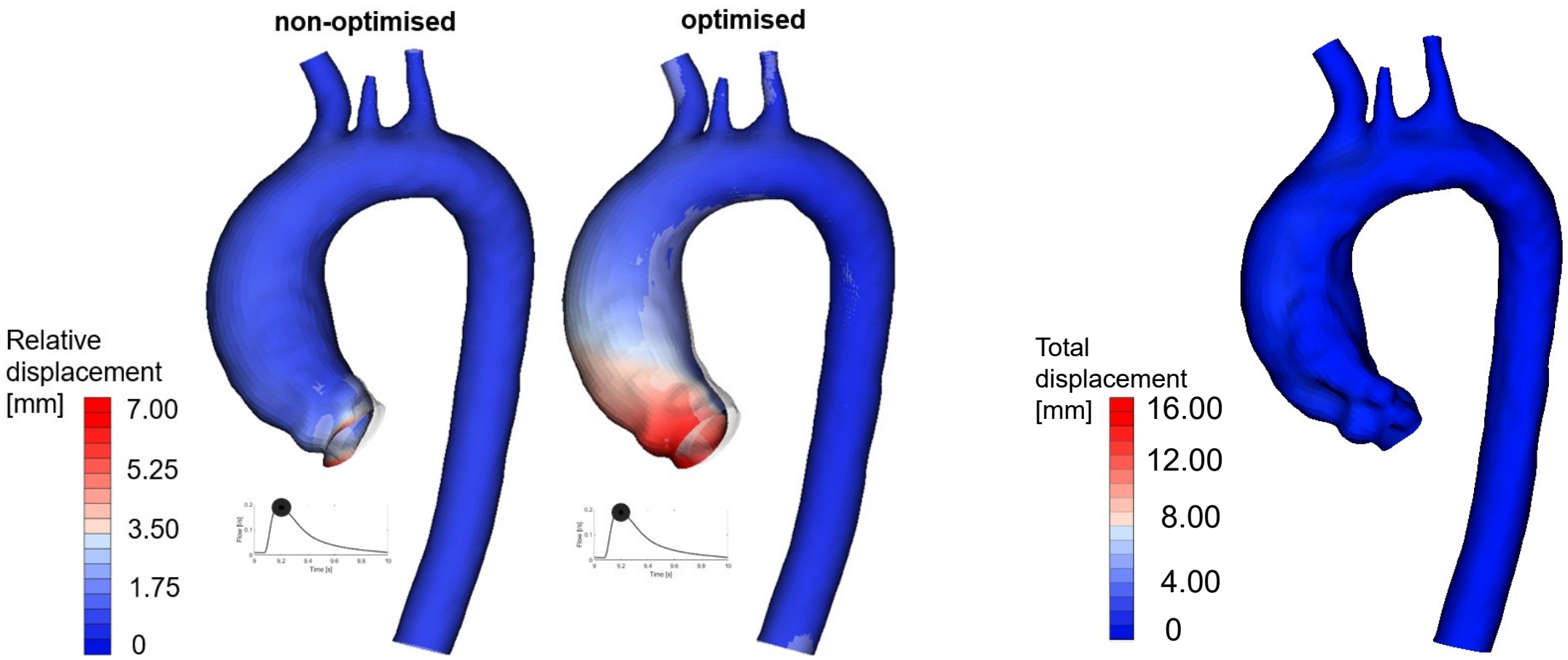
Effect of the heart motion on a thoracic aorta model and calibration of the boundary conditions

RESULTS



MeDiTaTe Project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 859836

Copernicus

Cloud-based HPC platform to support systemic-pulmonary shunting procedures

Emiliano Costa, RINA

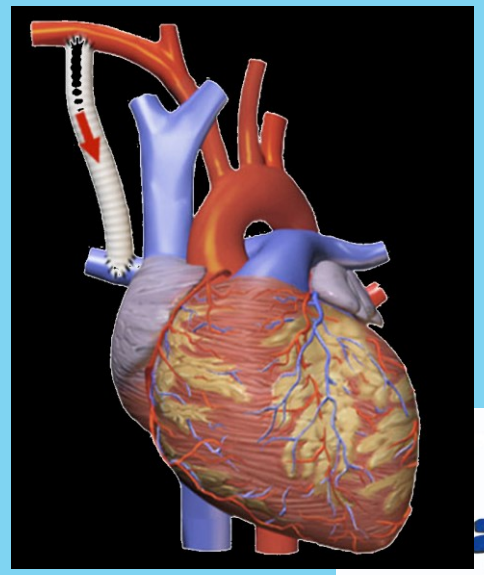
This project has received funding from the European High-Performance Computing Joint Undertaking Joint Undertaking (JU) under grant agreement No 951745. The JU receives support from the European Union's Horizon 2020 research and innovation programme and Germany, Italy, Slovenia, France, Spain.

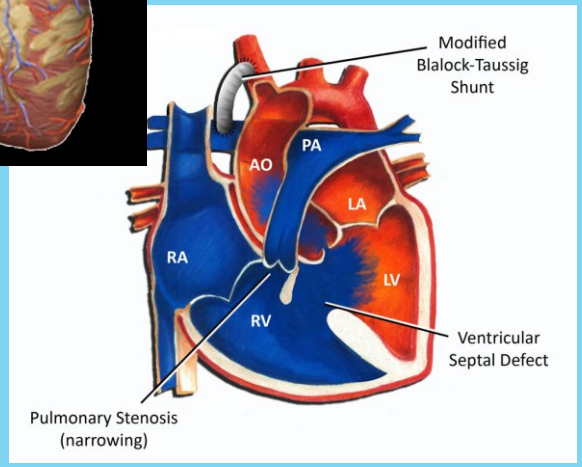
Experiment Consortium & Roles

Partner	Acronym	Role	Logo
InSilicoTrials Technologies SpA	IST	Industrial end-user	
RBF Morph Srl	RBF	Technology expert, ISV	
Fondazione Toscana Gabriele Monasterio	FTGM	Application expert, Clinical end-user	
RINA Consulting	RINA-C	Technology expert	
CINECA	CINECA	HPC expert, Host Centre	

The Problem

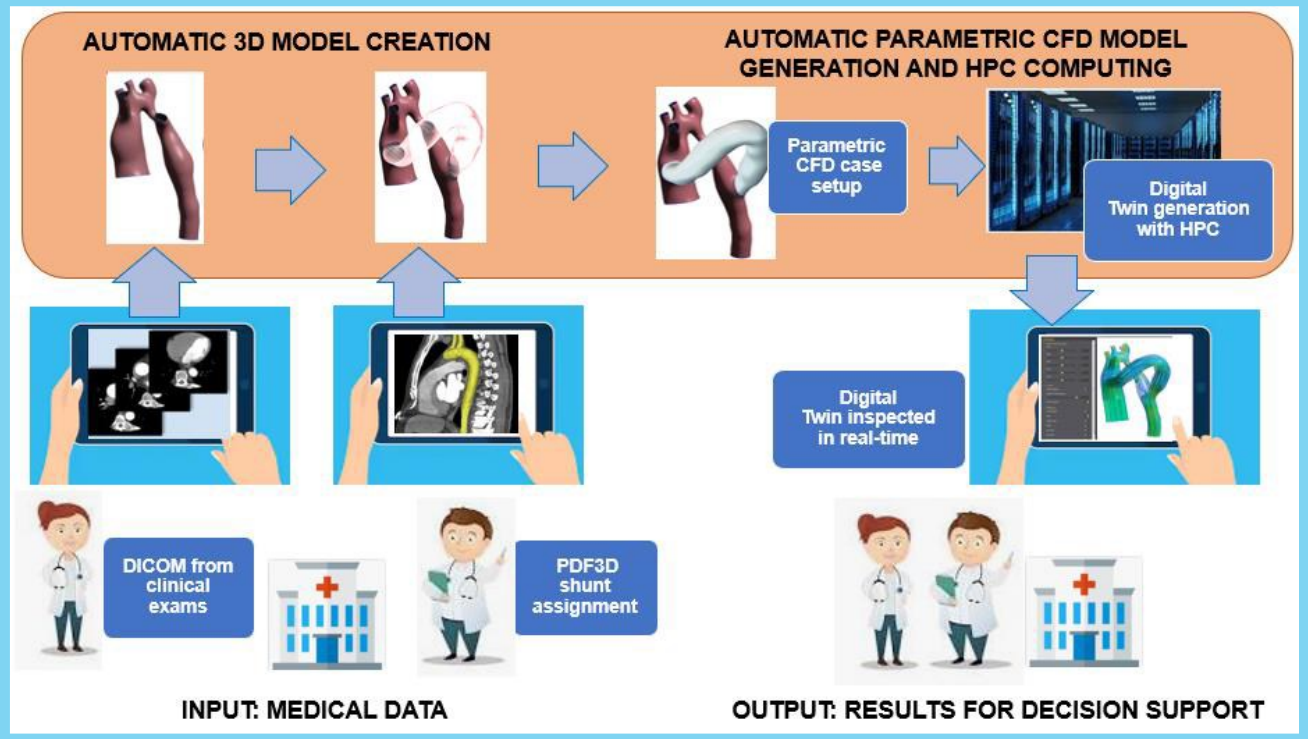
- **Congenital heart diseases** (CHDs) account for nearly **one-third** of all congenital birth defects and **7th cause of death** in children younger than 1 year in 2017.
- Without the ability to alter the prevalence of CHD, interventions and resources must be focused to **improve survival** and **quality of life**.
- The **Modified Blalock Taussig Shunt** (mBTS) is a common **palliative operation** on cyanotic heart diseases, but it is associated with **significant mortality** (~7,2%).



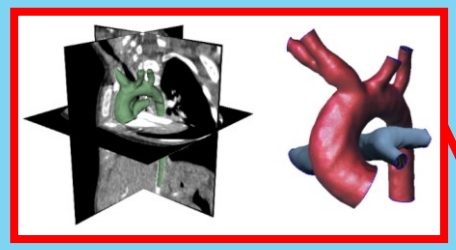


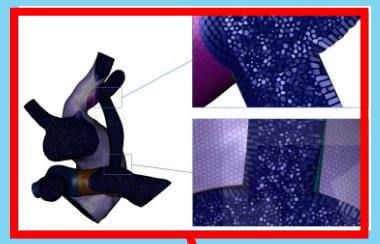
Experiment Approach & Expected Outcome

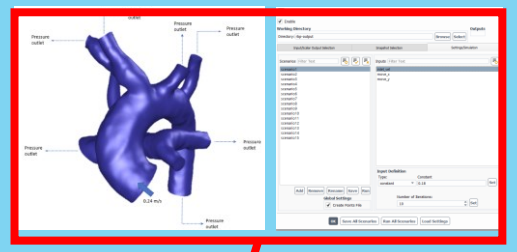
- The Copernicus application aims to provide an interactive **Medical Digital Twin** (MDT) of the patient-specific district to **support the surgery planning of mBTS under critical conditions**.
- The procedure was designed considering **advanced numerical means** with the objective to deploy MDT within **~48hh**.

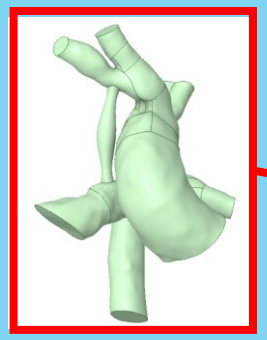


Copernicus workflow and numerical means









CT Image Segmentation (Python Code)

CAD Reconstruction + Shunt creation (SpaceClaim)

Surface and volume Mesh generation (Fluent – Watertight)

Ansys FLUENT

CFD and Snapshot set-up (Fluent – RBP)

RBF Shape modifiers set-up (Fluent – RBF Morph)

Ansys FLUENT rbf™

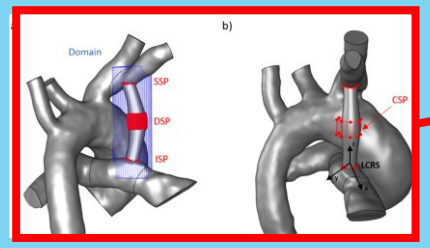
HPC for Snapshot generation (Fluent – RBF Morph)

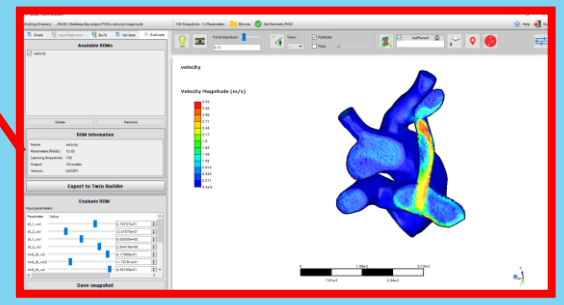
ROM Generation (Twin Builder)

ROM Evaluation (Twin Builder)

Ansys TWIN BUILDER

Ansys TWIN BUILDER





Copernicus Pre-Processing

Copernicus Computing

Copernicus Post-Processing

Copernicus numerical scenario for MBTS

Copernicus numerical case scenario for MBTS consists of the set-up of the framework to create an **accurate ROM(*) valuable from medical point of view**.

Such scenario foresaw:

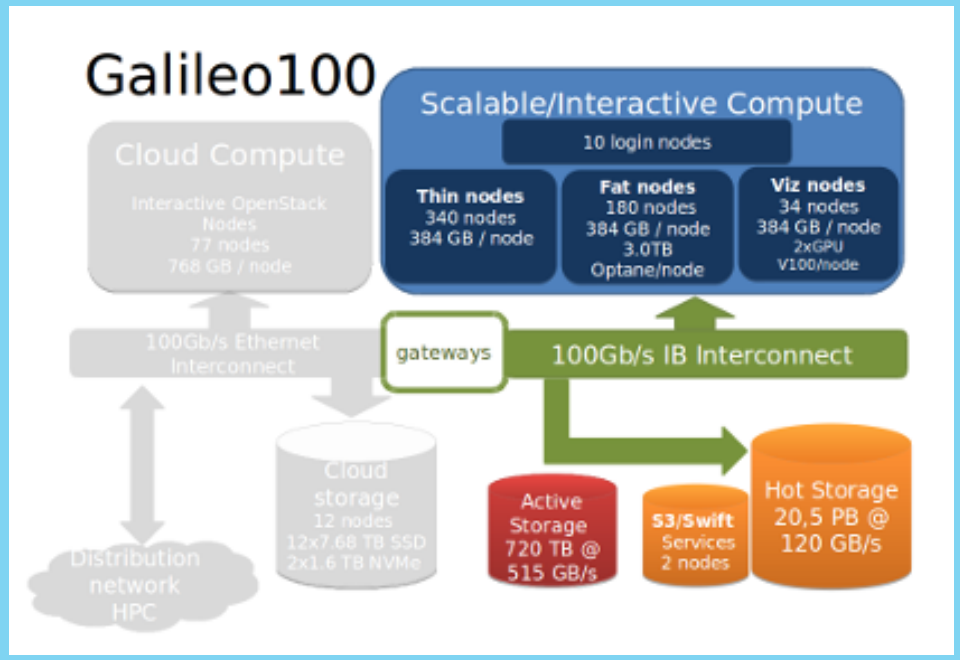
- Creation of a **high-fidelity CFD case** of the medical district (~2 million cellls)
- Creation of a suitable number of **RBF shape modifiers** with medical significance (#12)
- Set-up of **DoE** with a suitable number of design points (#150)
- Identification of the proper number of **computing processes** to use for CFD computing (#36)

(*) Kardampiki, Eirini et al., 2022. "The Hemodynamic Effect of Modified Blalock–Taussig Shunt Morphologies: A Computational Analysis Based on Reduced Order Modeling" Electronics 11, no. 13: 1930. https://doi.org/10.3390/electronics11131930

HPC environment and computing set-up

Main IT developments on HPC:

- **Set-up of the HPC environment** on the **Galileo 100** infrastructure of CINECA to carry out the **Copernicus's computing** stage.
- Implementation of the **multi-node strategy** to **automatically** enable calculations of **sets of snapshots in parallel** on **HPC** using the **Slurm** Workload Manager.

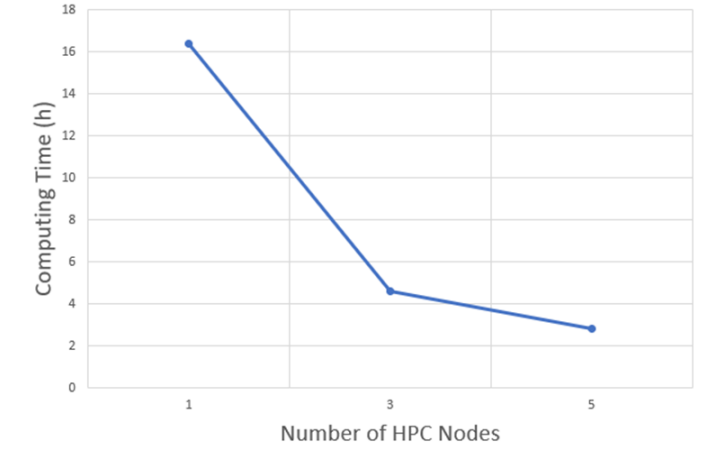


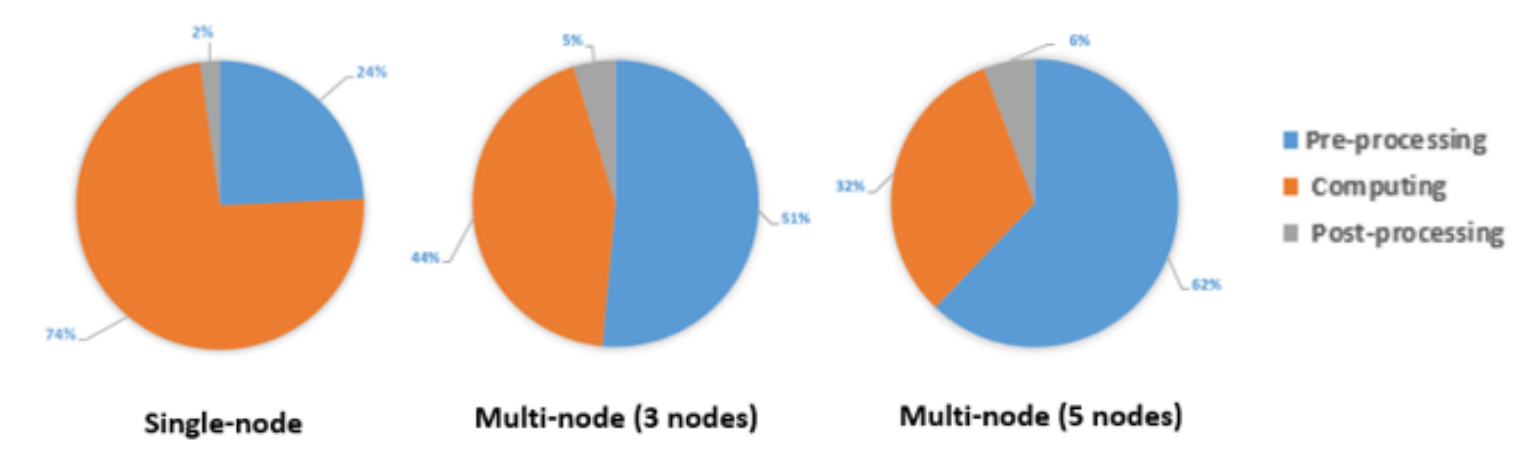
Results gained with HPC computing

Comparison between the results gained adopting the single-node and multi-node strategy is shown below.

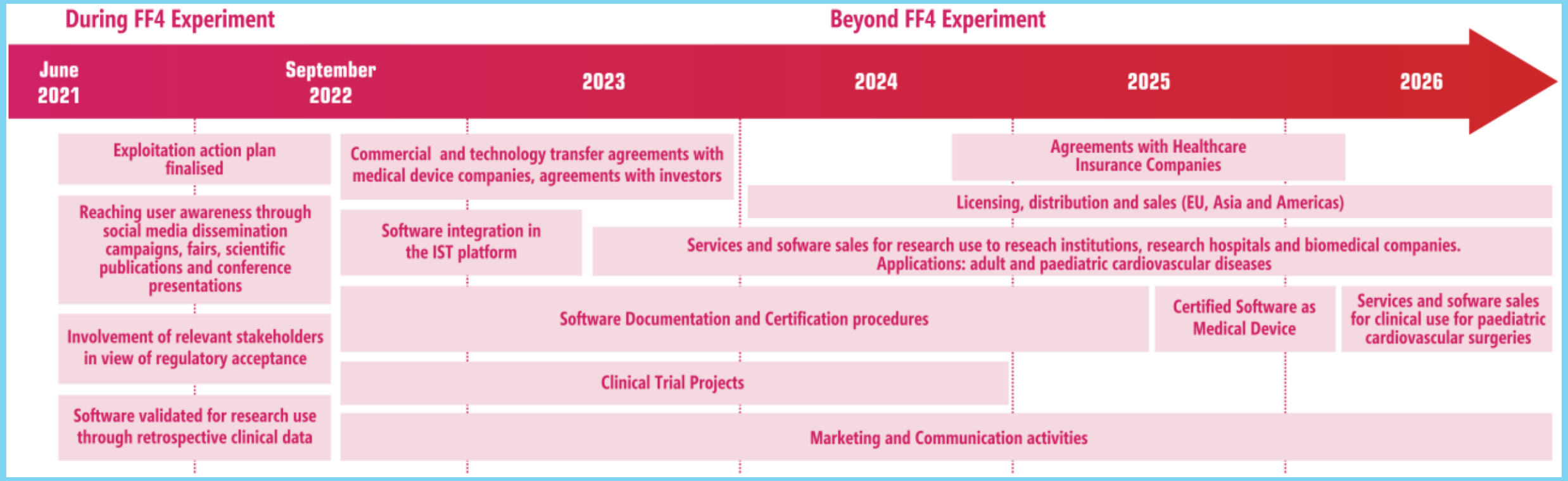
Exploiting all (5) licences available, the computing time was covered just in **3hh** approximatively.

Whole workflow duration: **9hh** (<< **48 hh**).



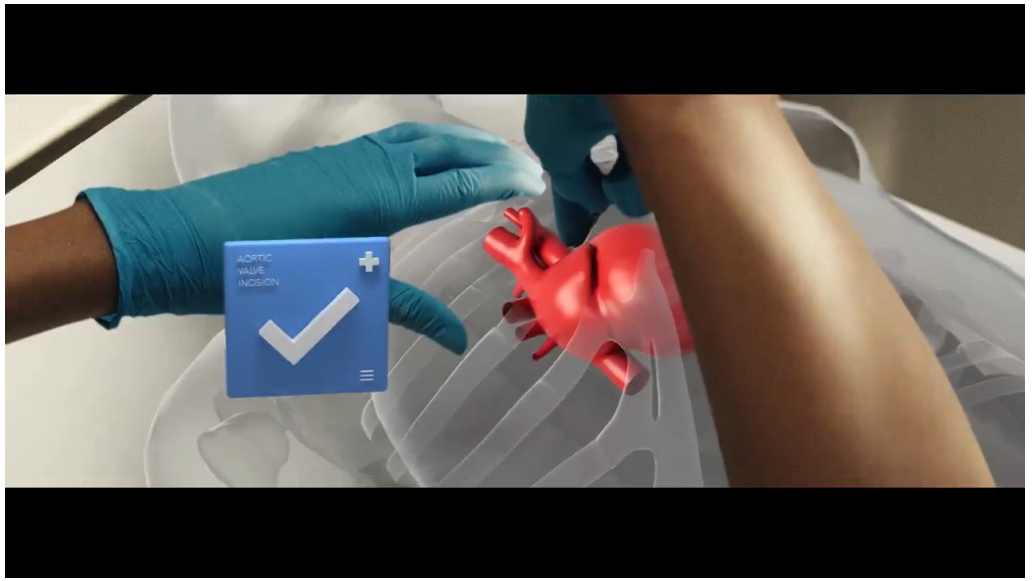


Exploitation roadmap



Conclusions

- Medical Digital Twins are feasible today!
- The **In Silico** path, i.e. MDT driven by high fidelity simulations, is ready and requires
  - Patient specific data (from images)
  - State of the art multi-physics simulation
  - Reduced order models and advanced mesh morphing
- A clear **business model** is required
  - Public funds are today the major resource
  - Certification is complex
- We are moving in the right direction and there is **mainstream focus** on Medical Digital Twins



Contacts

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University of Rome "Tor Vergata"

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https://www.rbf-morph.com/

https://www.linkedin.com/in/marcobiancolini/

https://www.youtube.com/user/RbfMorph

TOR VERGATA

UNIVERSITÀ DEGLI STUDI DI ROMA