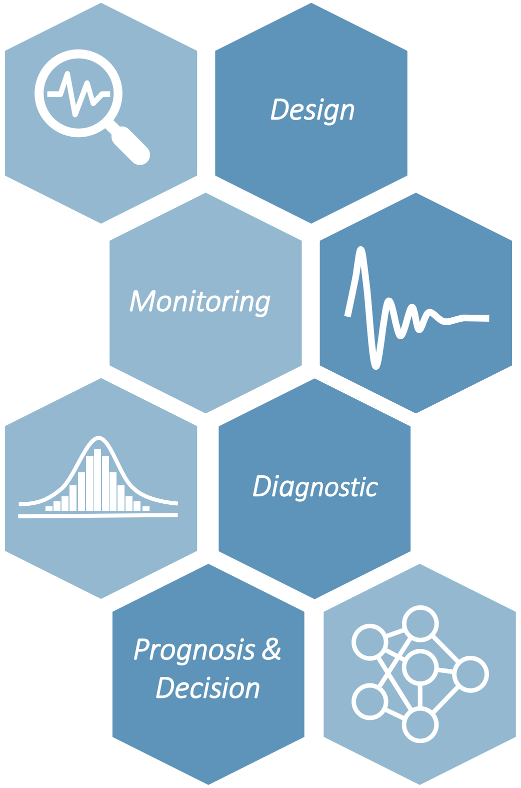
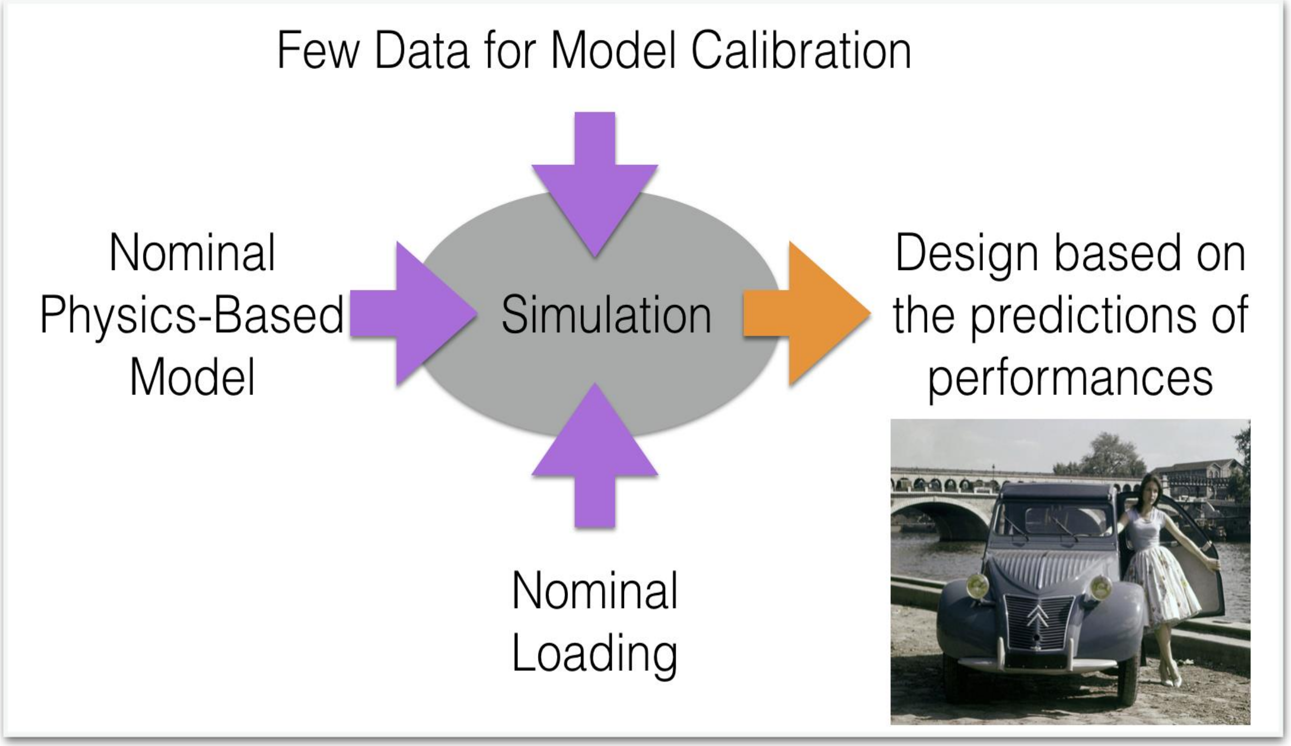
Jumeaux numériques :
généalogie, anatomie, physiologie et éthique

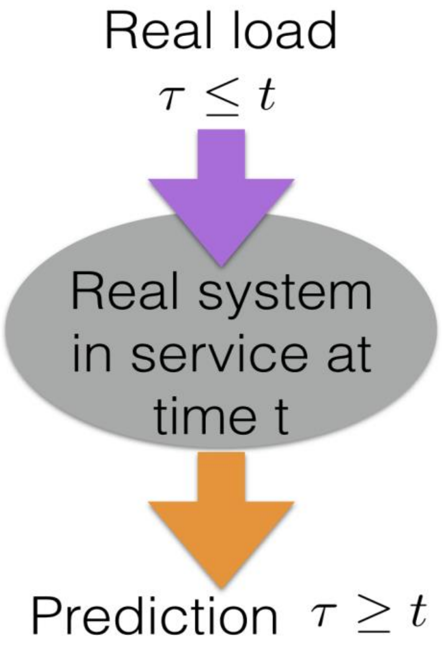


Francisco (Paco) CHINESTA
Francisco.Chinesta@ensam.eu

Performances in designs



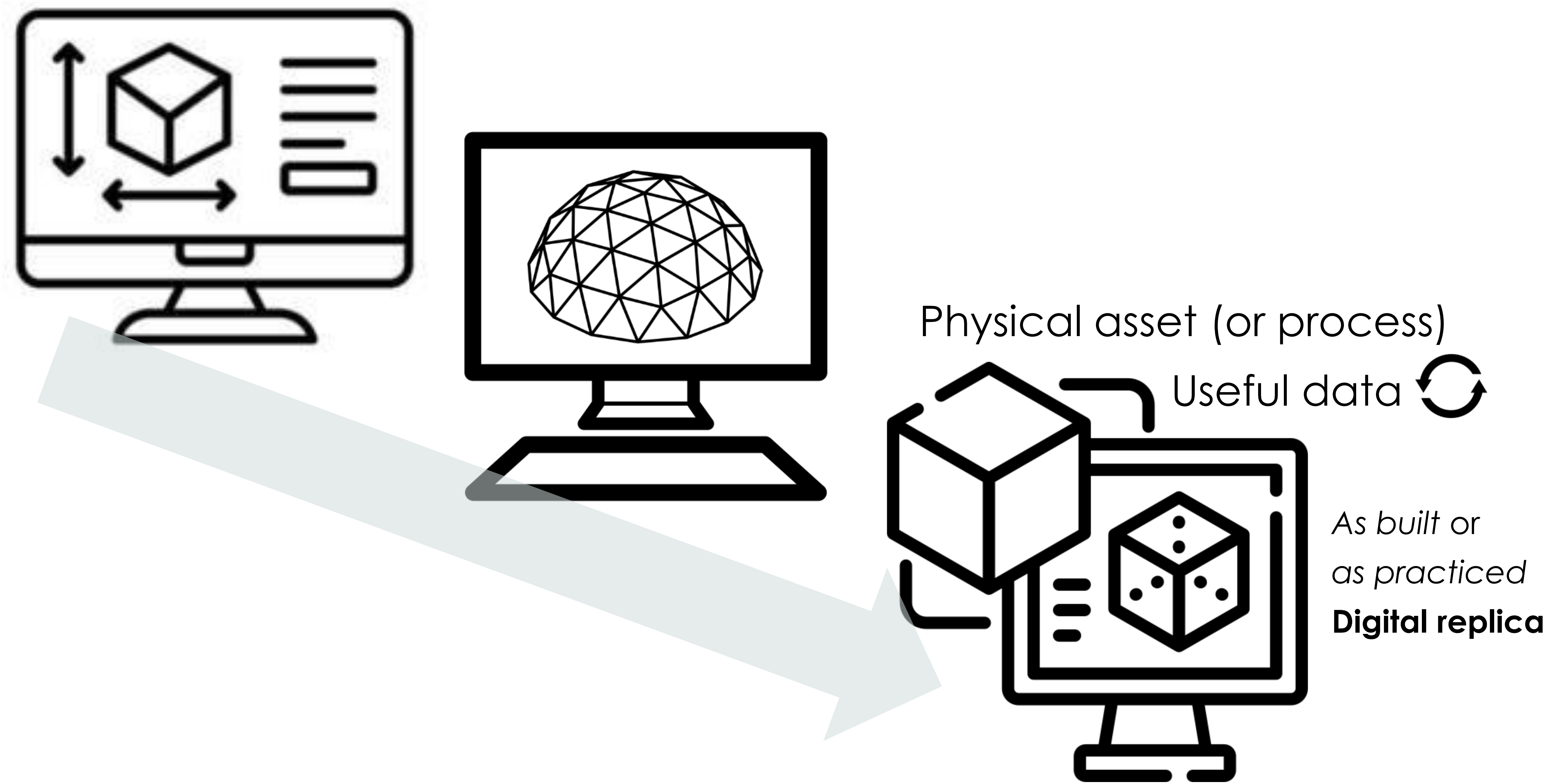
Performances in operation



World is changing. Today we do not sell aircraft engines, but hours of flight, we do not sell electric drills but good quality holes, … We are nowadays more concerned by the performance management than by the products themselves …

PREDICTING FAST & WELL

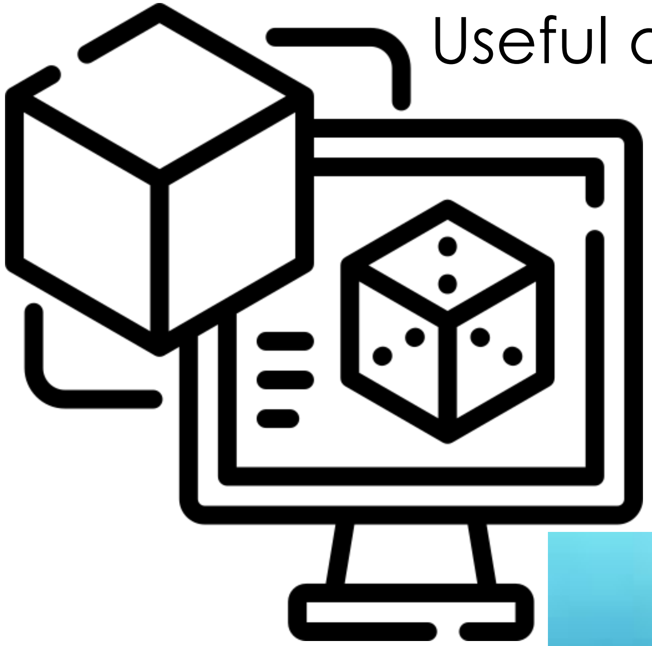
INTRODUCTION: three levels of digitalization as proposed by Charbel FARHAT



INTRODUCTION: Digital Twin instance – anatomy and function

Physical asset (or process)

Useful data



As built or

as practiced

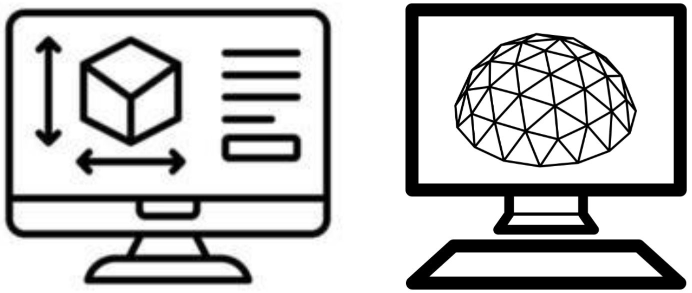
Digital replica

Based on:

- the best available multi-physics, multiscale & probabilistic computational models
- sensor information

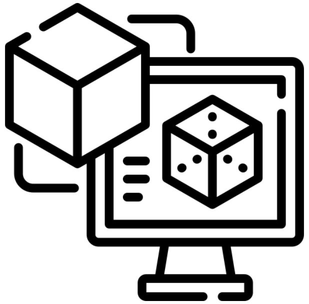
To mirror & predict the functioning and performances over the life cycle of the associated physical asset.

- **the digital twin prototype**



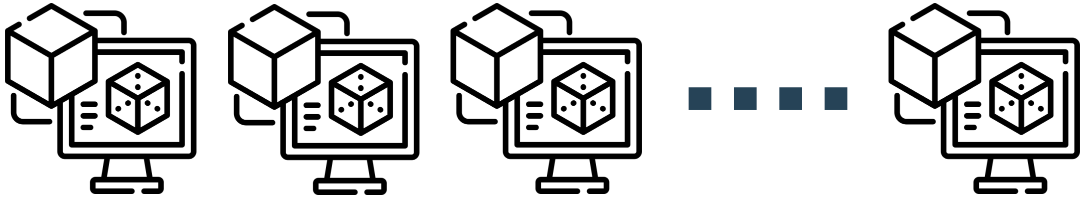
designs, analyses and processes used to realize the physical product

- **the digital twin instance**



digital twin of each individual instance of the product once it is manufactured

- **the digital twin aggregate**



allows for a larger set of data to be collected and processed for interrogation about the physical product.

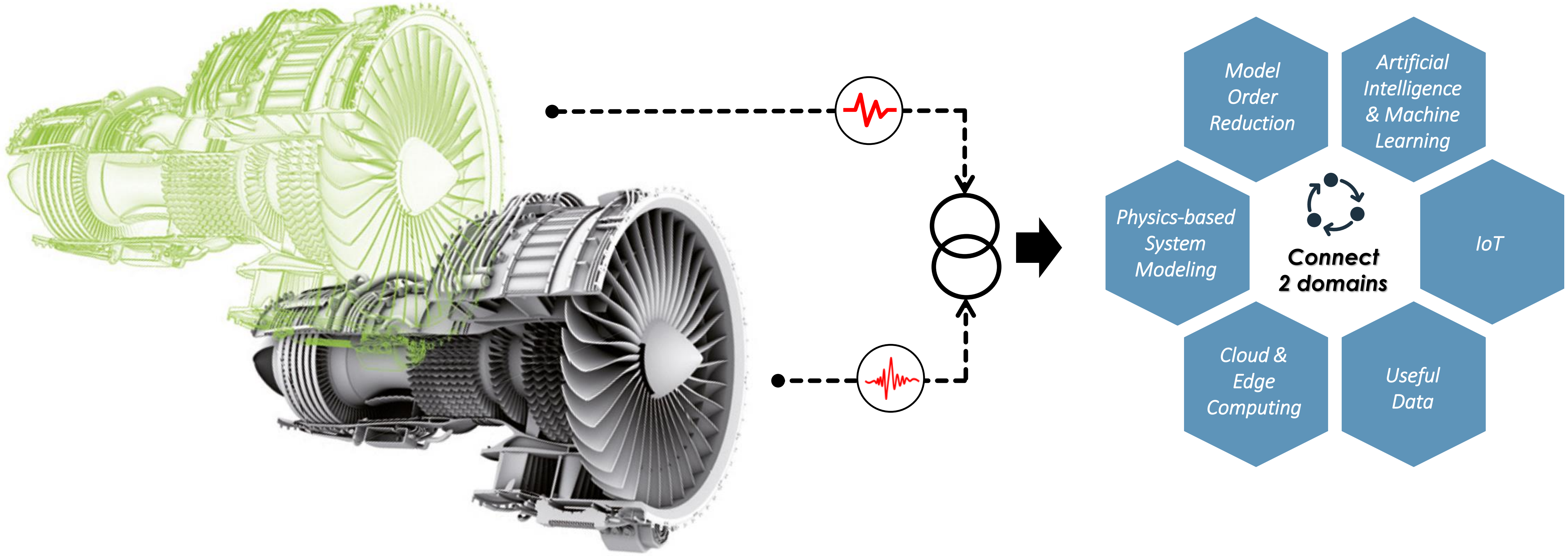
THE LIMITS OF THE EXISTING PARADIGMS

The usual simulation-based paradigm fails to perform diagnosis, prognosis and decision making when addressing complex systems of systems because of

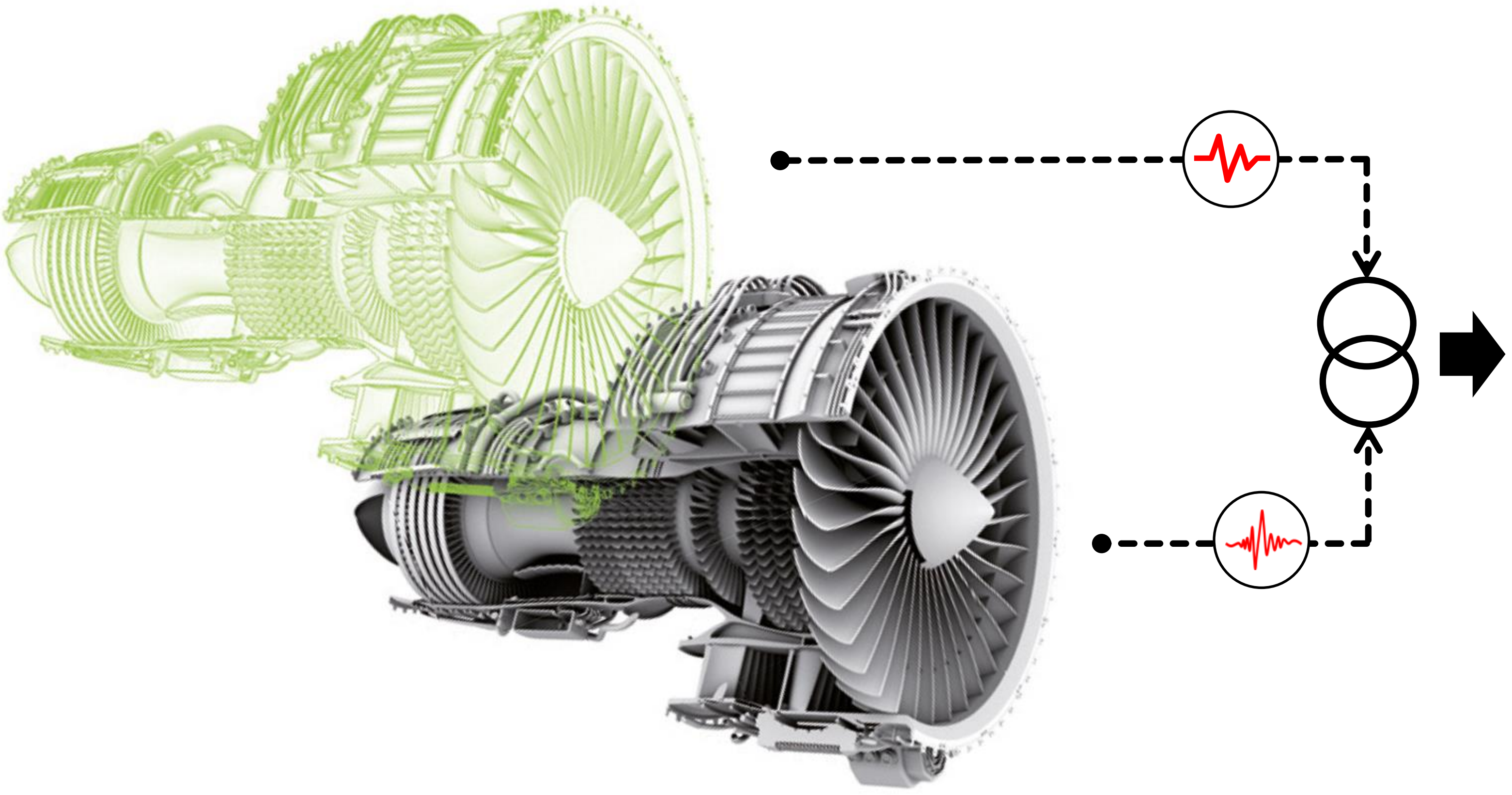
- **Physics-based:** the lack of fidelity of state-of-the-art models, and the lack of efficiency related to their solution procedures.
- **Data-driven:** the availability of data, its quality, as well as the limitations related to the extrapolation or the ability to explain the predictions offered by the trained models.

The **hybrid paradigm** conciliates both paradigms, knowledge and data enrich mutually, reducing the amount of data, driving their collection, enabling explaining and certifying predictions and decisions, accounting for human and societal interests and constraints.

Virtual representation of real-world entities and processes, synchronized at a specific frequency and fidelity throughout its lifecycle, and informs decisions that realize value



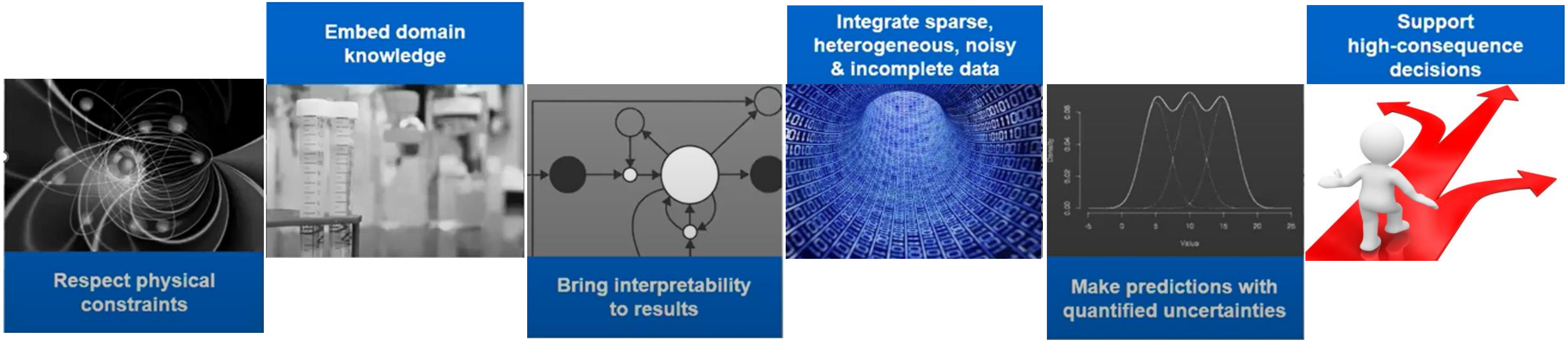
Virtual representation of real-world entities and processes, synchronized at a specific frequency and fidelity throughout its lifecycle, and informs decisions that realize value



Actionable Insights :

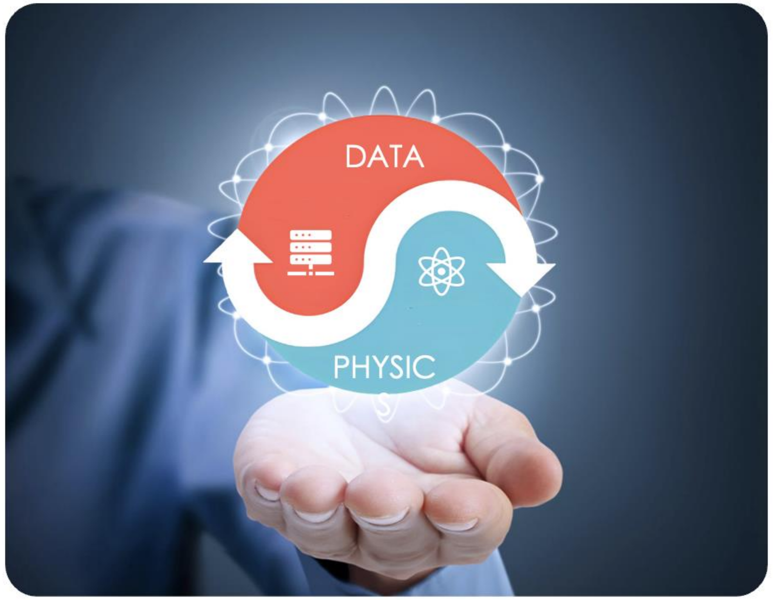
- Virtual Prototyping
- Testing & Validation
- Design Optimization
- Virtual Sensing (Monitoring)
- Predictive Model-Based Control
- Predictive Maintenance
- …..

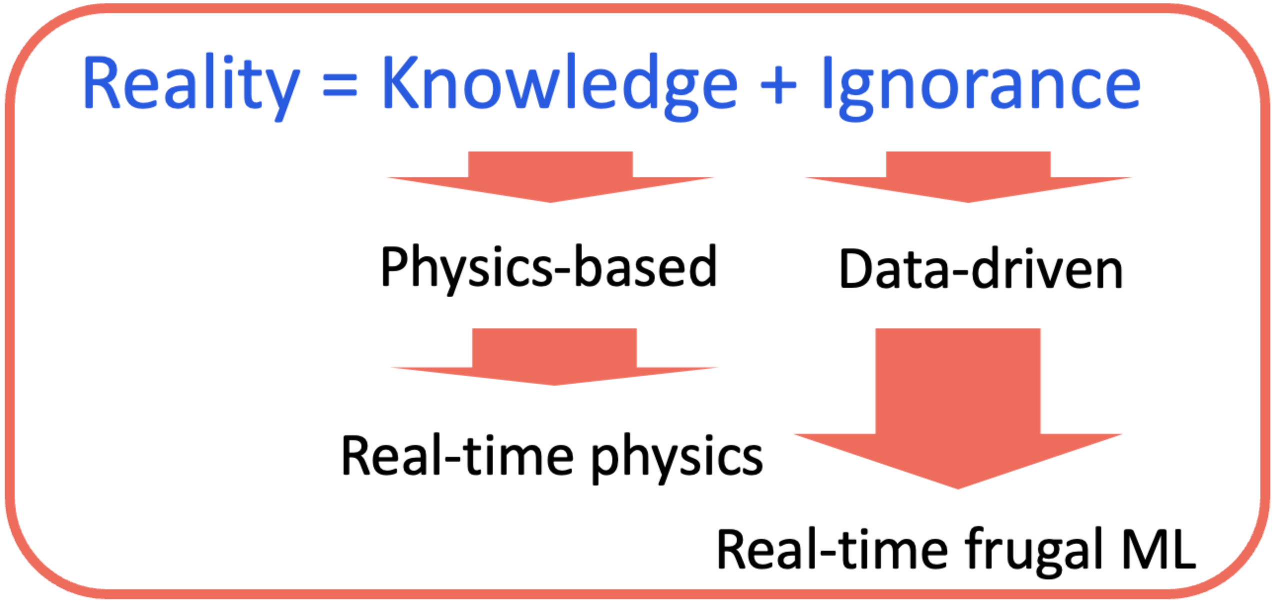
CONSTRAINTS



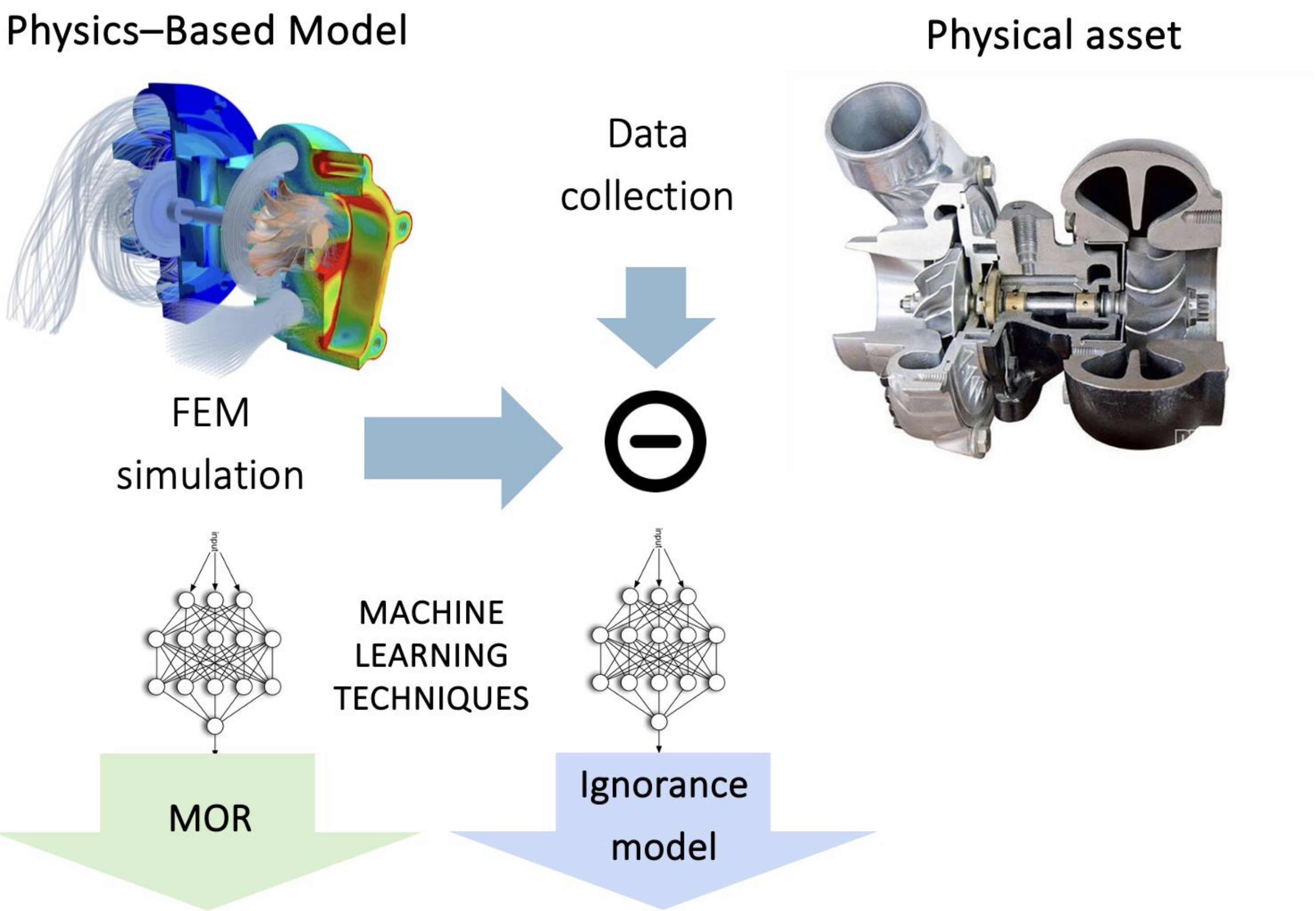
THE HYBRID PARADIGM

The **hybrid paradigm** conciliates both paradigms, knowledge and data enrich mutually, reducing the amount of data, driving their collection, enabling explaining and certifying predictions and decisions, accounting for human and societal interests and constraints.



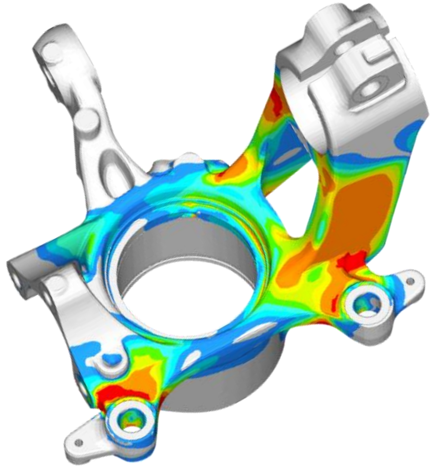
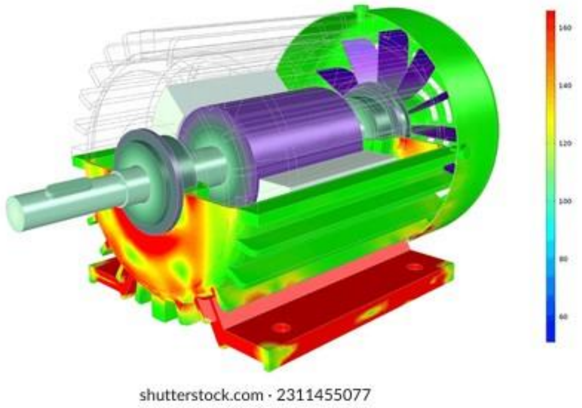
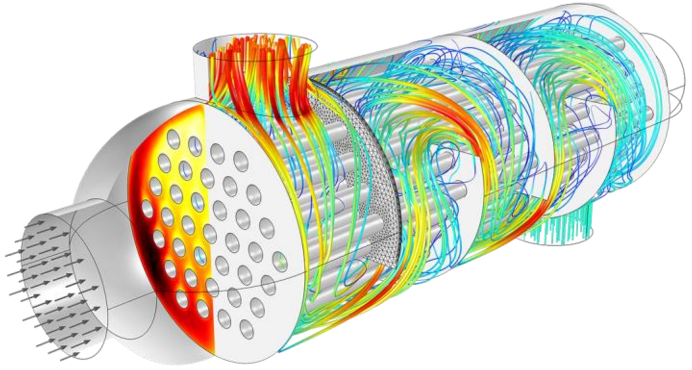


A SUCCESFULLY APPLIED HAI TECHNOLOGY FOR PREDICTING FAST & WELL



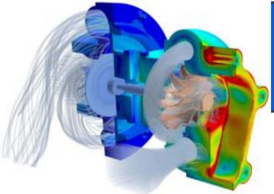
$$\frac{dx}{dt} = f^{\texttt{physics-based}}(x, \mathbf{z}) + f^{\texttt{data-driven}}(x, \mathbf{z})$$

A representation of the universal governing laws of nature complemented with phenomenological behavior relationships

Linear & Nonlinear Elasticity	Electromagnetism & Acoustics	Fluid Dynamics
		
minutes, hours, …	hours, days, …	days, weeks, …

- **Expensive but accurate**
- **Cheaper by using Model Order Reduction**

MODEL ORDER REDUCTION AND THE "ART OF SURROGATING"



MOR / Surrogate

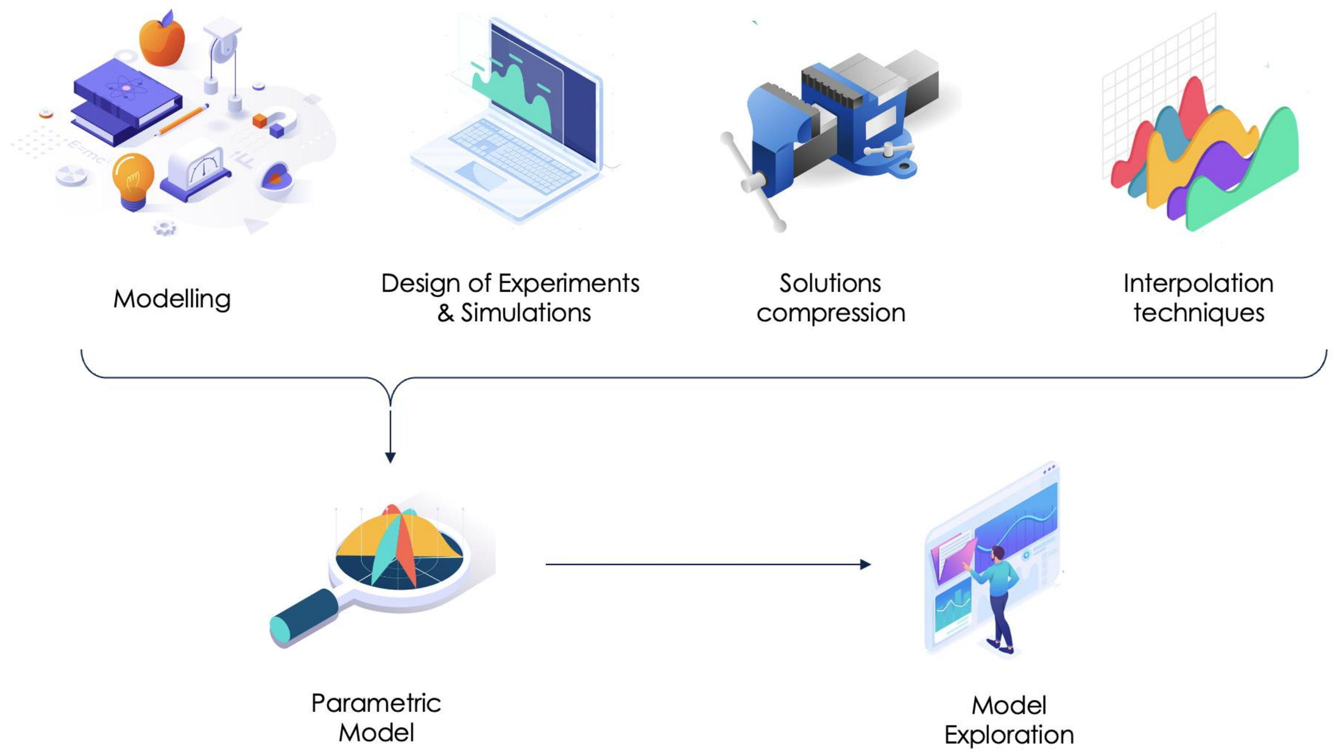
$$\frac{dx}{dt} = f^{\texttt{physics-based}}(x, \mathbf{z}) + f^{\texttt{data-driven}}(x, \mathbf{z})$$

Active Learning

- Goal-oriented GP
- Extended Fisher Information
  - Tensor decompositions
  - Information surrogates

Data Reduction

- Linear (PCA)
- Nonlinear:
  - Manifold learning
  - Autoencoders

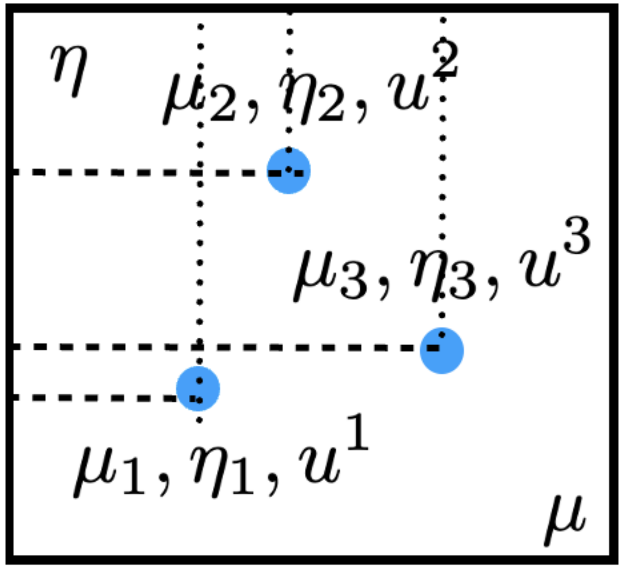


Regression (informed)

- Regularized Lineal Polynomial
  - Elastic Net, Ridge, Lasso, …
- Nonlinear:
  - NN-based
  - Optimal transport

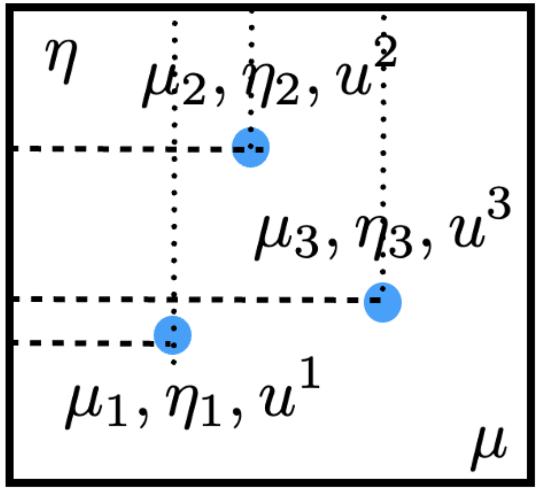
Postprocessing

- Data analytics
- Optimizers
- Uncertainty propagation
- Inversion / Data assimilation
- Control



Linear regression
Linear approximation

$$u(\mu, \eta) = a + b\mu + c\eta$$



SPARSE

$$[1, \mu, \eta, \mu^2, \mu\eta, \eta^2, \mu^2\eta, \mu^2\eta^2, \mu\eta^2]$$

$$u(\mu, \eta) = \sum_{i=1}^{N} c_i \mathcal{F}_i(\mu, \eta)$$

$$N \gg 3$$

Regularization

$$\sum_{j=1}^{3} \| u(\mu_j, \eta_j) - u^j \|_2^2 + \lambda \sum_{i=1}^{N} |c_i|$$

PHYSICS IN REAL TIME

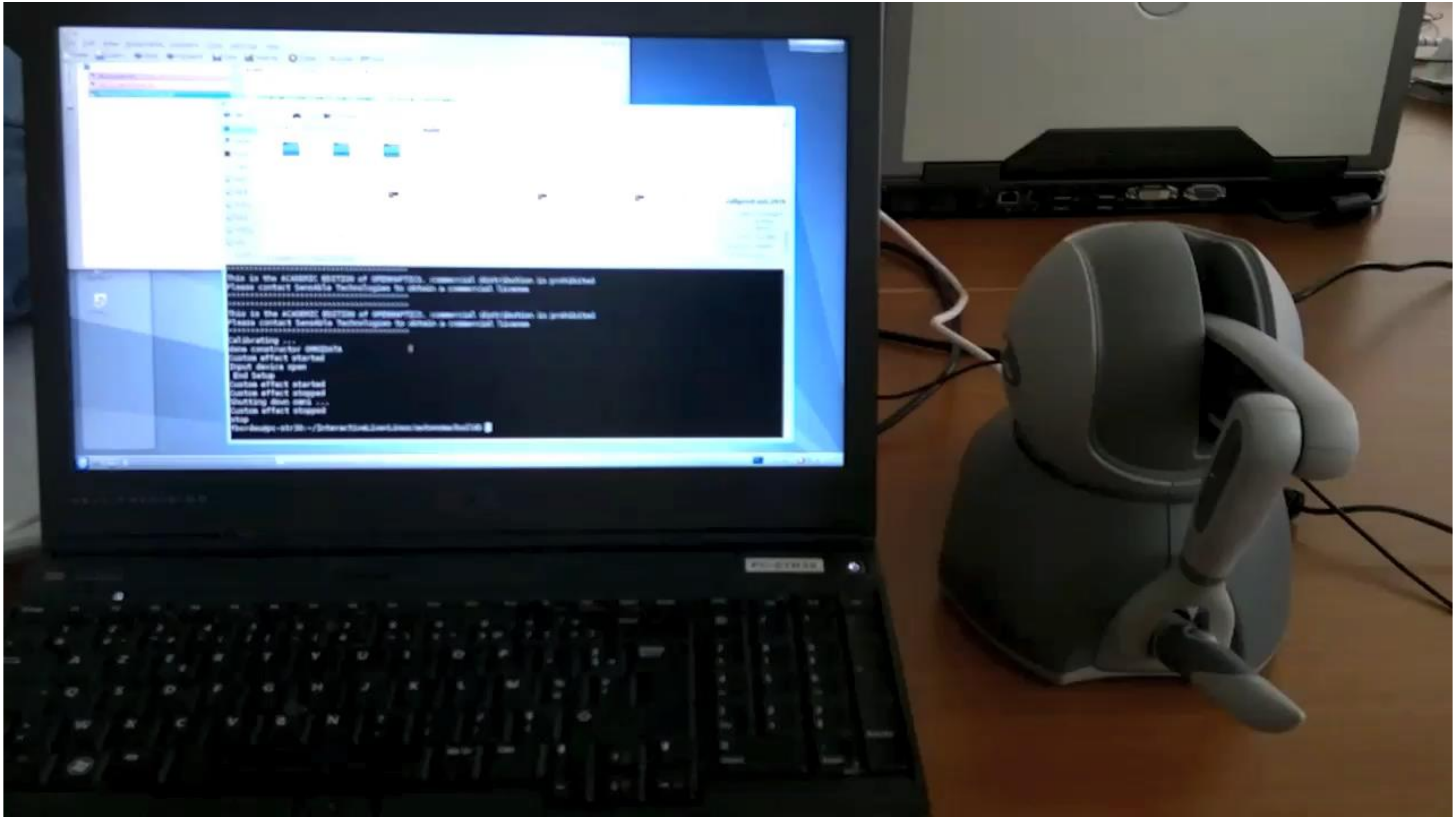
Physics-aware interaction between virtual and physical objects in Mixed Reality

A. Badías, D. González, I. Alfaro, F. Chinesta, E. Cueto

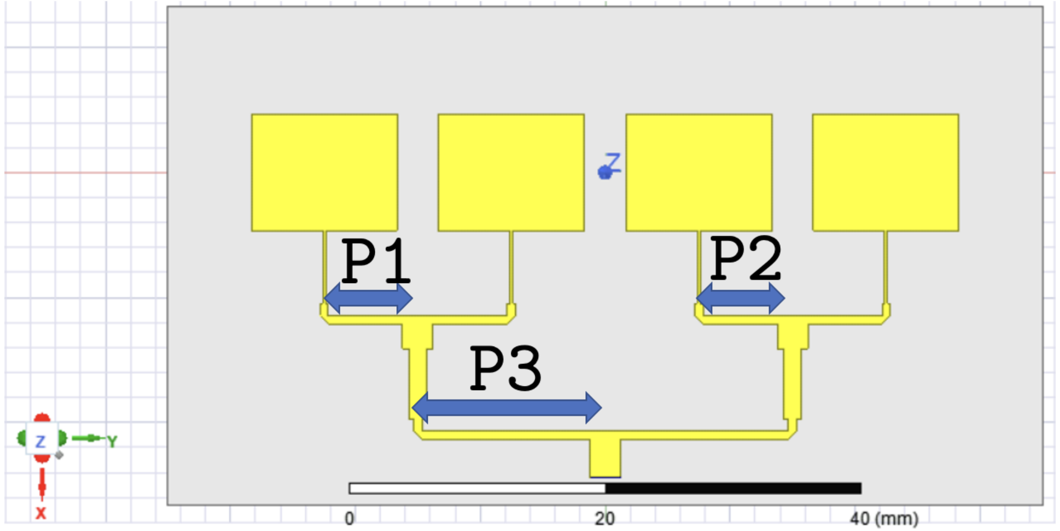
Universidad Zaragoza 1542

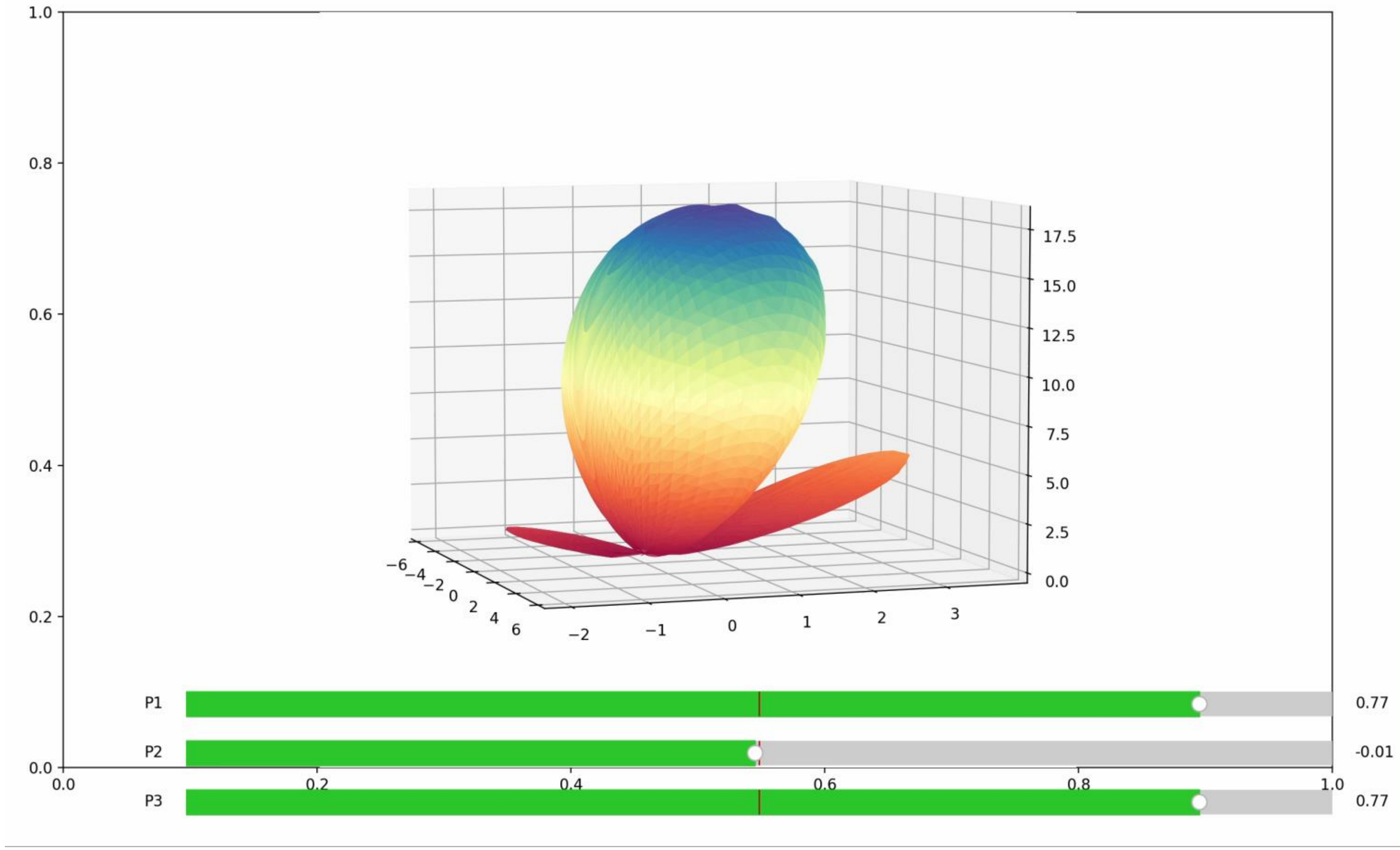
unizar.es

PHYSICS IN REAL TIME



PHYSICS IN REAL TIME





ML/AI TECHNICAL POINTS

Ignorance model

$$\frac{dx}{dt} = f^{\texttt{physics-based}}(x, \mathbf{z}) + f^{\texttt{data-driven}}(x, \mathbf{z})$$

- Regularized polynomial regressions, GP, DT, RF, SVR, …
- CNN
- GNN
- rNN, LSTM, ResNET, NeuralODE, DeepONet, Reservoir computing, Koopman…
- GAN
- Transformers
- Autoencoders
- PINN, SPNN, PANN, …

ML/AI TECHNICAL POINTS

Ignorance model

$$\frac{dx}{dt} = f^{\texttt{physics-based}}(x, \mathbf{z}) + f^{\texttt{data-driven}}(x, \mathbf{z})$$

Physically sound, self-learning digital twins for sloshing fluids

B. Moya, I. Alfaro, D. González, F. Chinesta, E. Cueto

Universidad Zaragoza

1542

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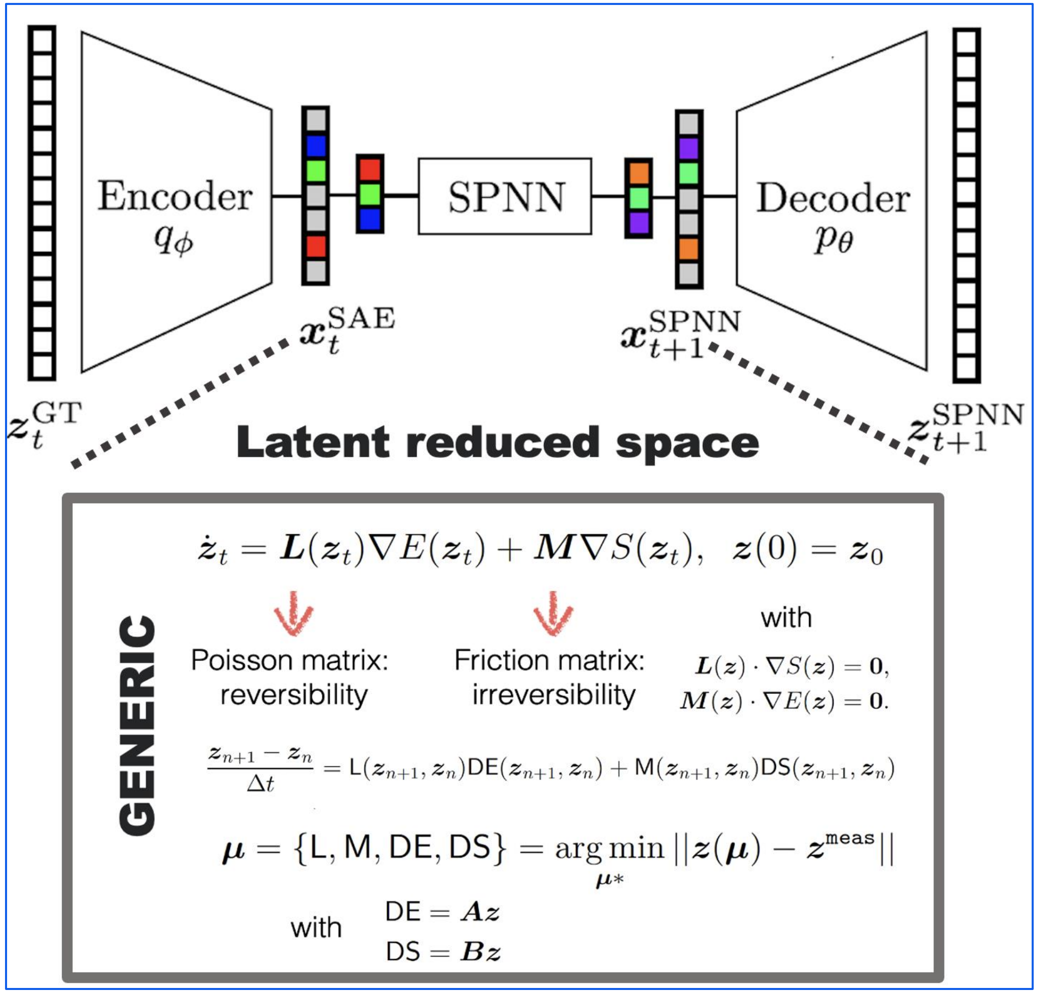
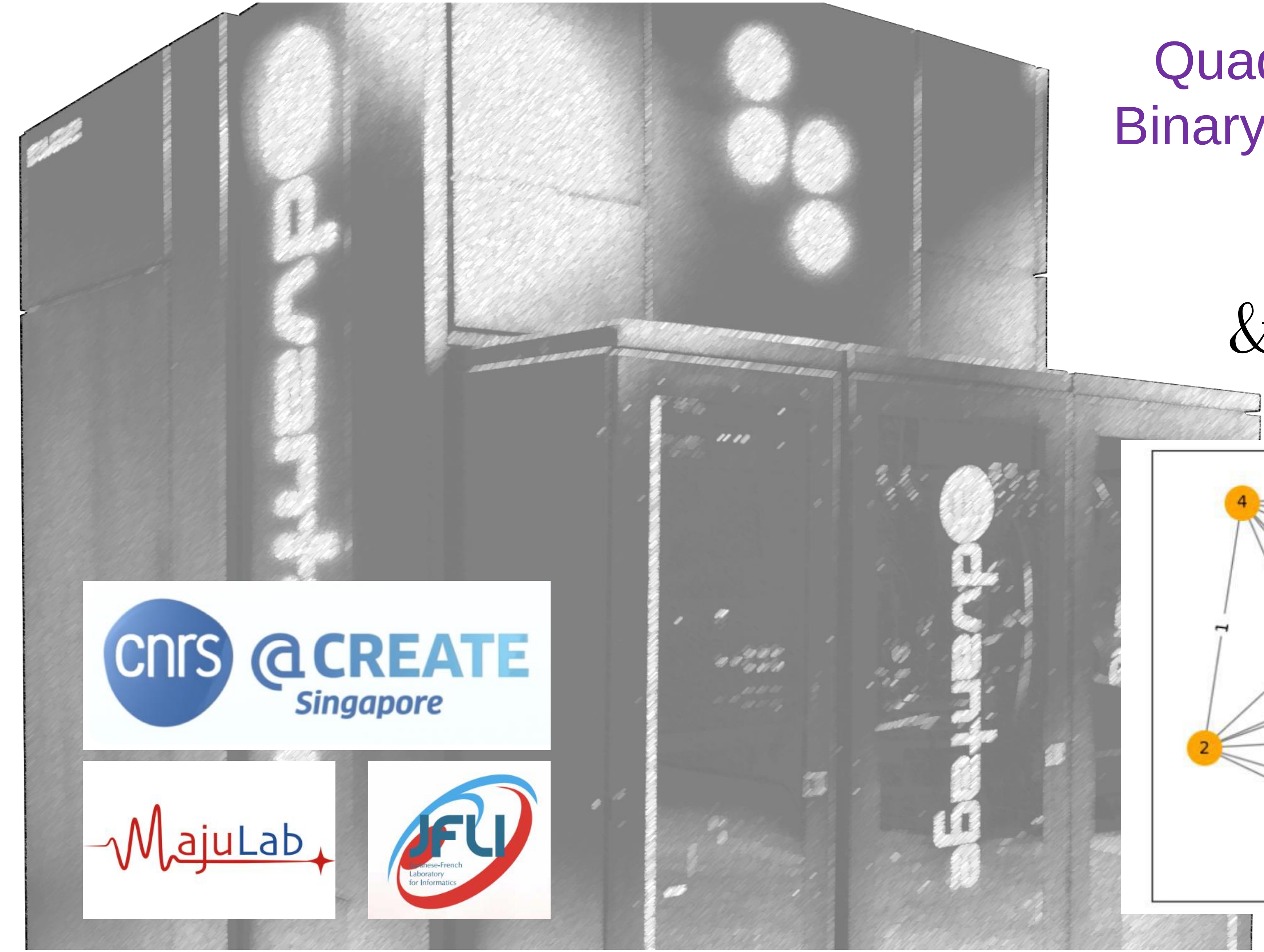


RESEARCH TOPICS

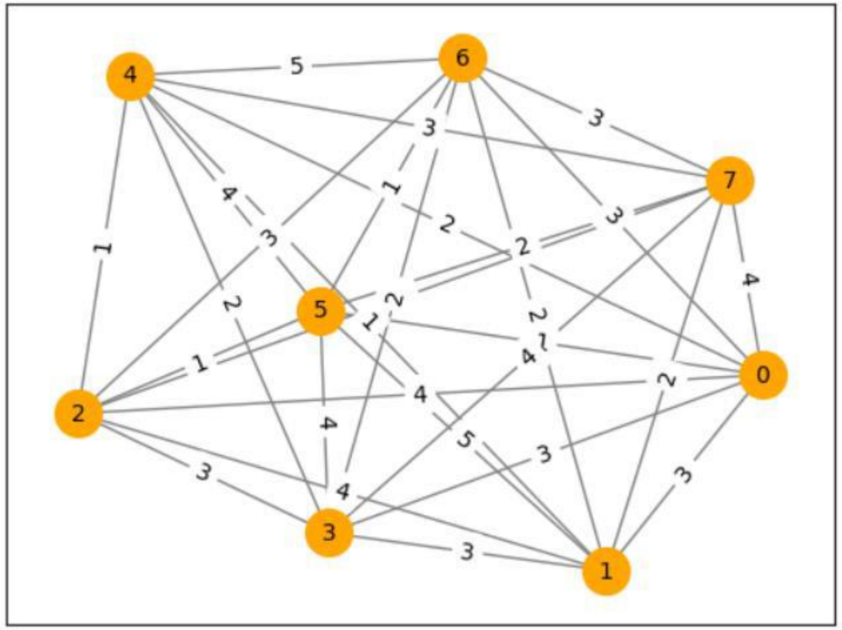
- I - MODEL ORDER REDUCTION: LEGO-LIKE & MULTI-TIME
- II - RANK REDUCTION AUTOENCODERS / CONSTRAINTS IN THE LATENT SPACE
- III - LEARNING PARSIMONIOUS PARAMETRIC (DYNAMICAL) MODELS
- IV - LEARNING HIERARCHICAL MULTI-TIME MODELS
- V - GENERATIVE AI for GENERATIVE DESIGN
- VI - GRAPHS NN: SHM, MULTI-PHYSICS, T-GCN & EVOLVING GCN, …
- VII - INDUCTIVE BIASES
- VIII - QUANTUM COMPUTING



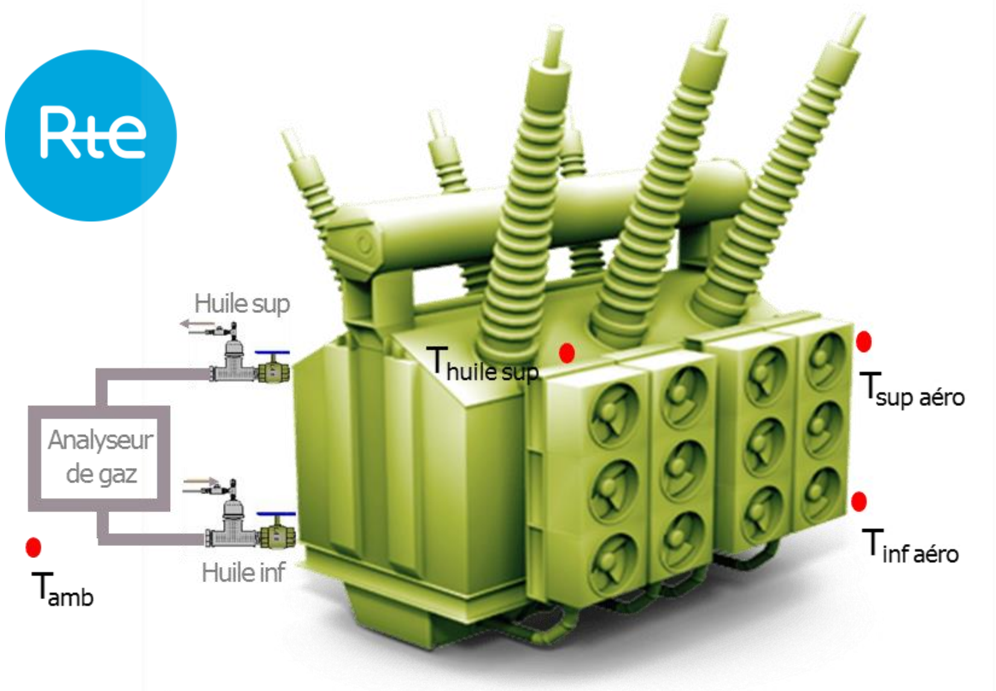
Quadratic Unconstrained Binary Optimization (QUBO)

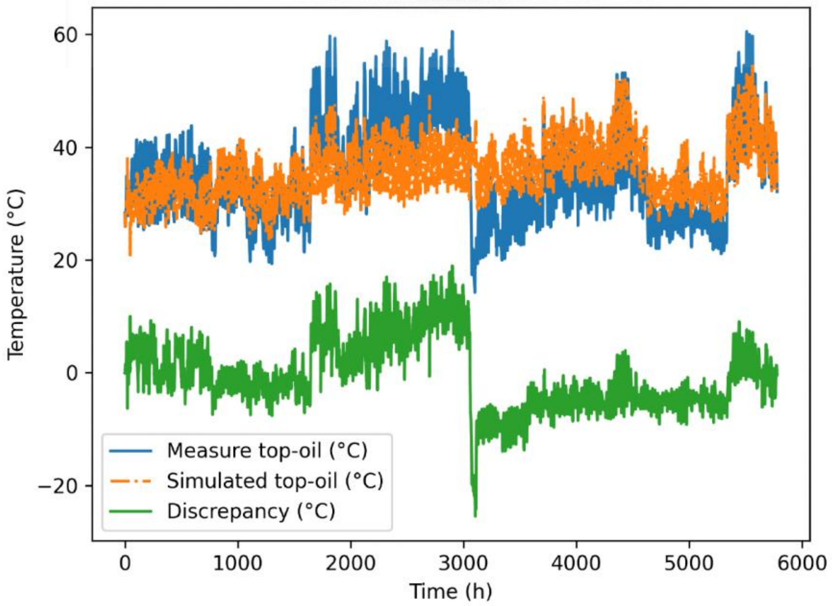
$$\mathcal{H} = X^T Q X$$

$$\& \texttt{constraints}$$

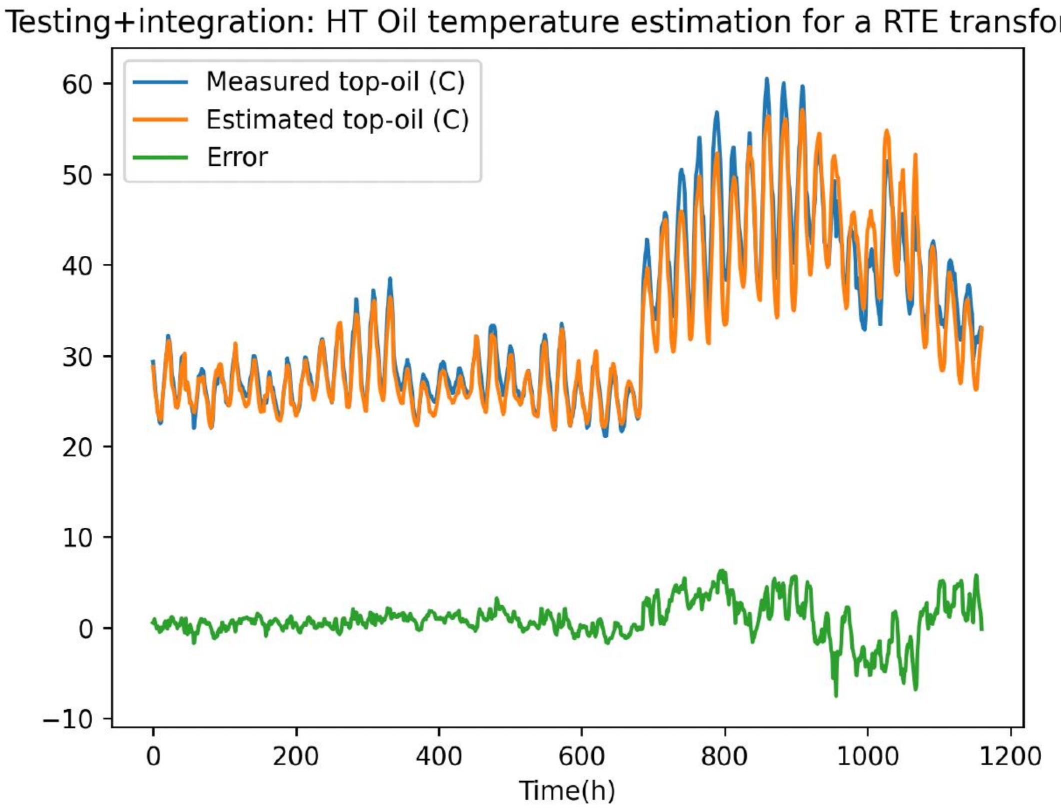


TRANFORMER HYBRID TWIN INSTANCE



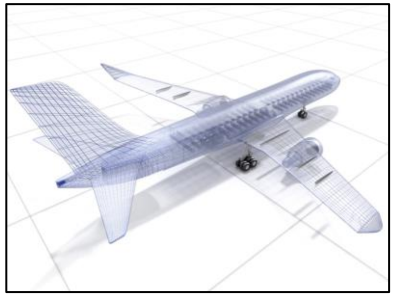


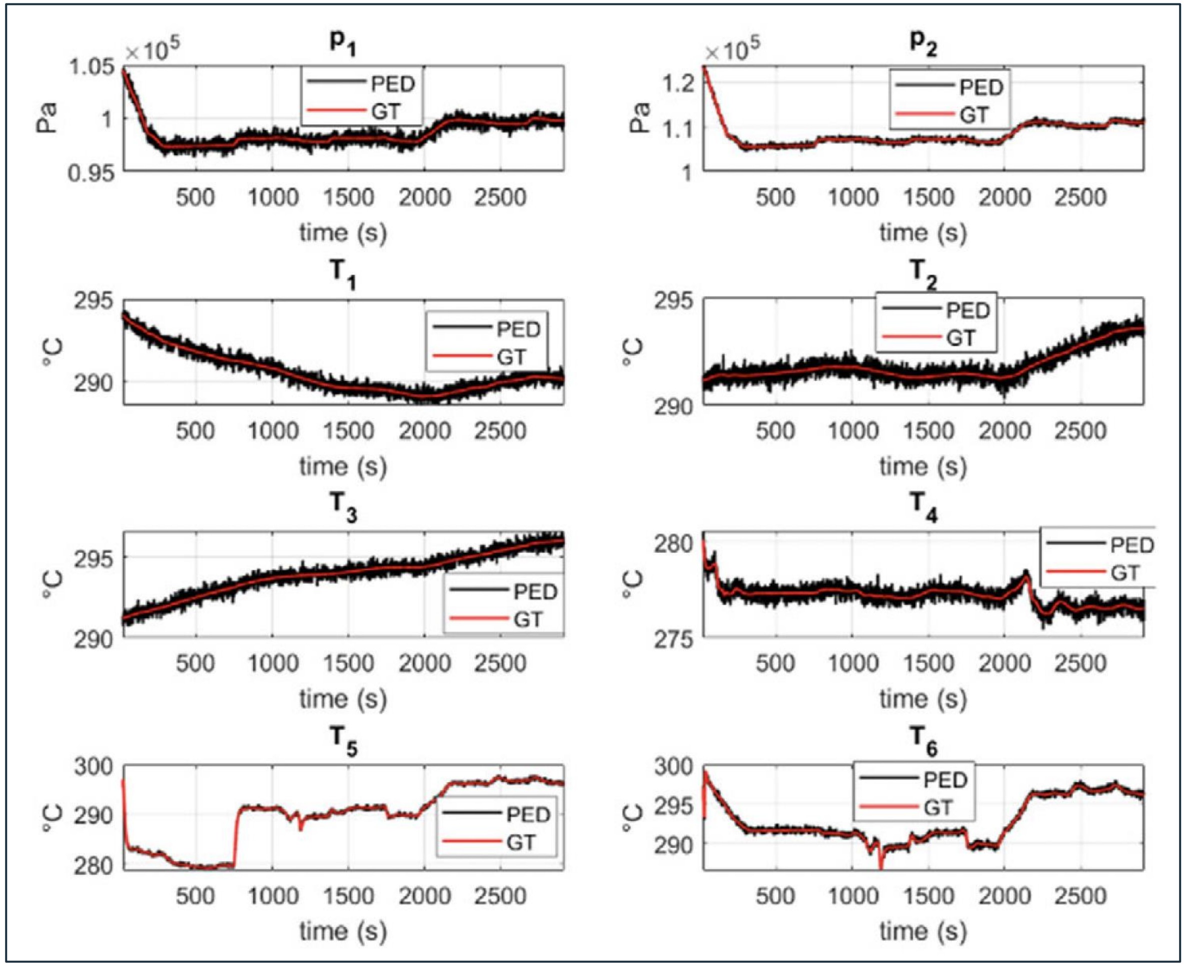
$$\frac{dx}{dt} = f^{\texttt{physics-based}}(x,\mathbf{z}) + f^{\texttt{data-driven}}(x,\mathbf{z})$$

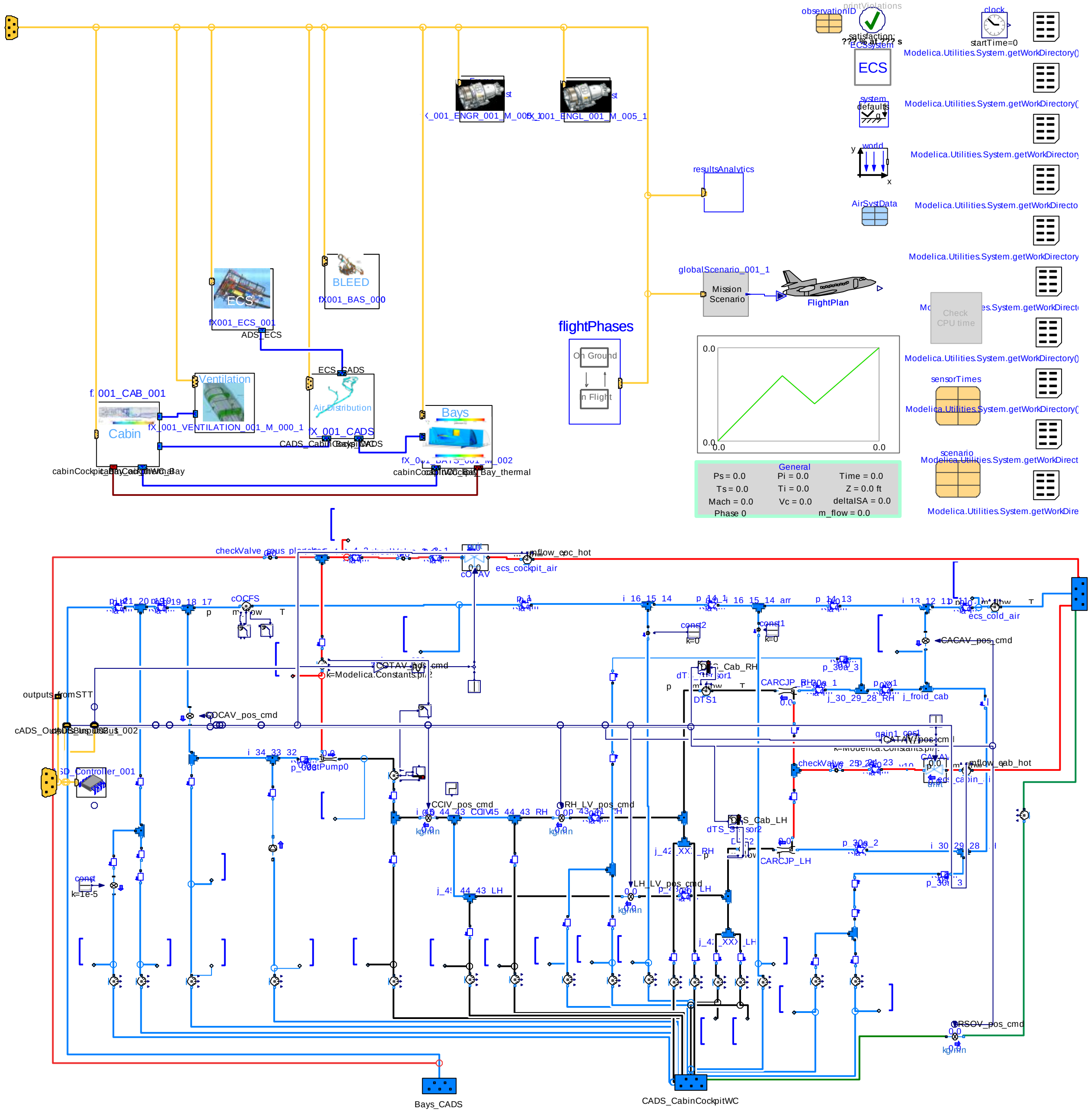


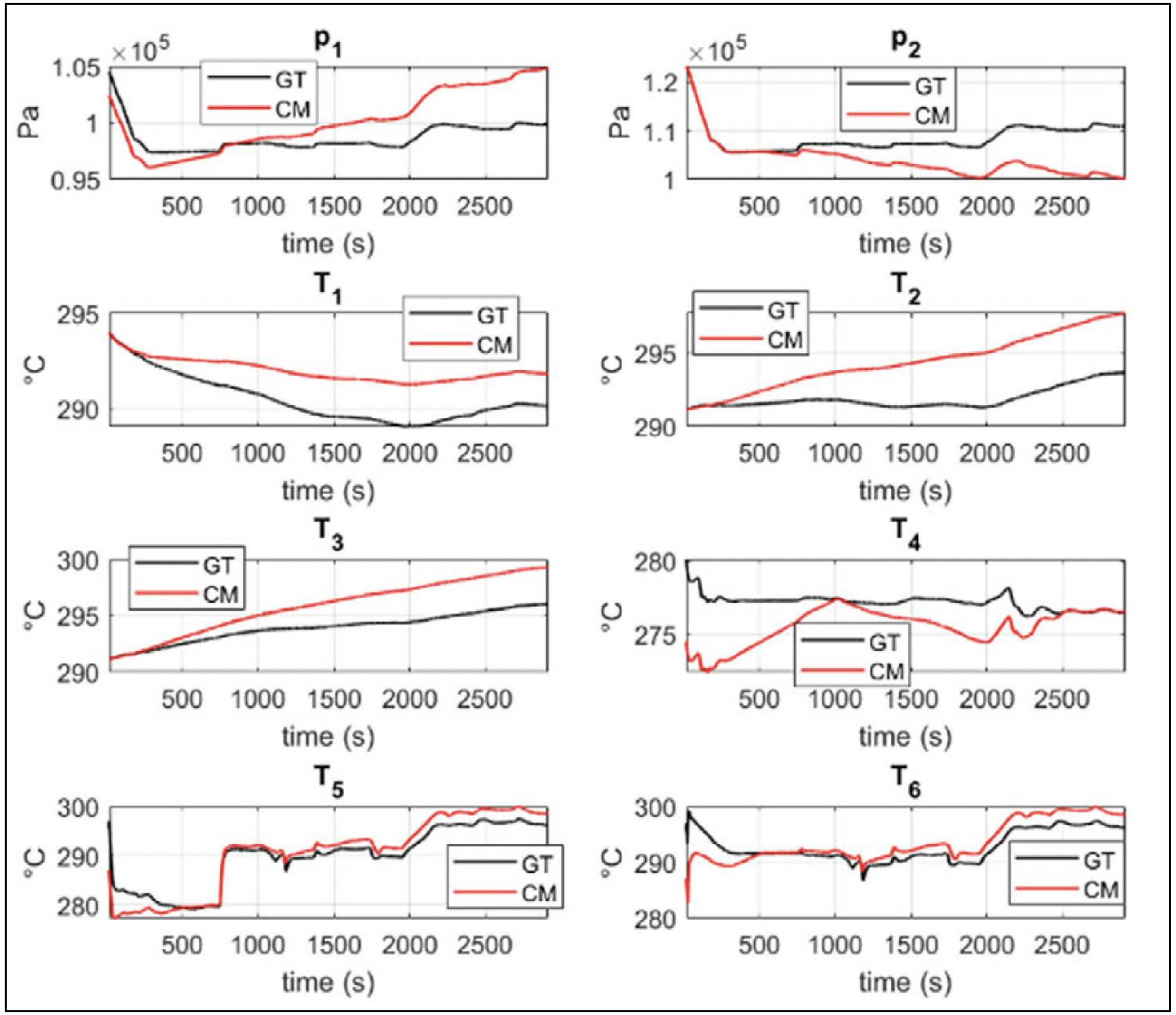
SYSTEM MODEL ENRICHMENT – HYBRID MODELLING

DASSAULT AVIATION

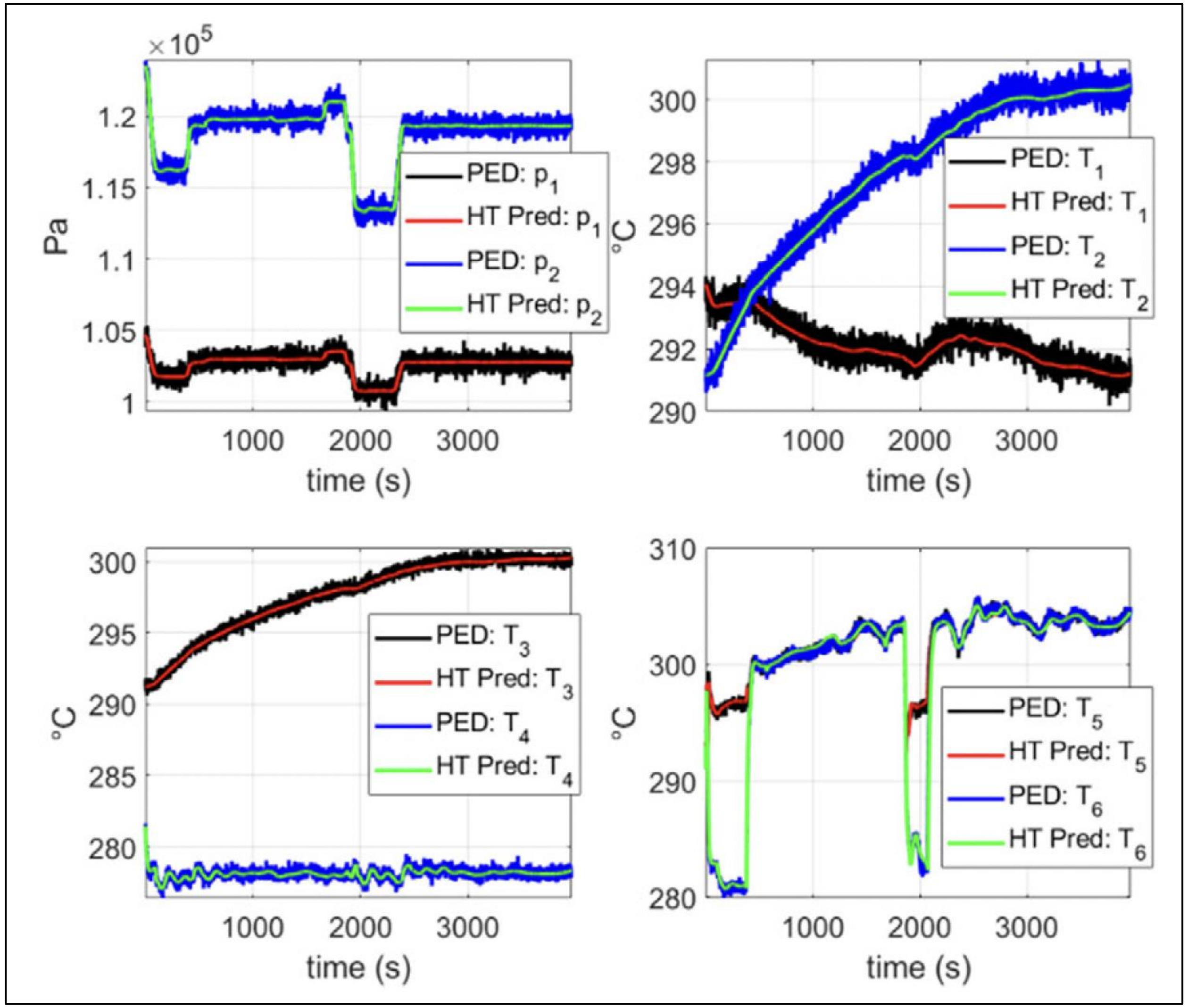








$$\frac{dx}{dt} = f^{\texttt{physics-based}}(x, \mathbf{z}) + f^{\texttt{data-driven}}(x, \mathbf{z})$$

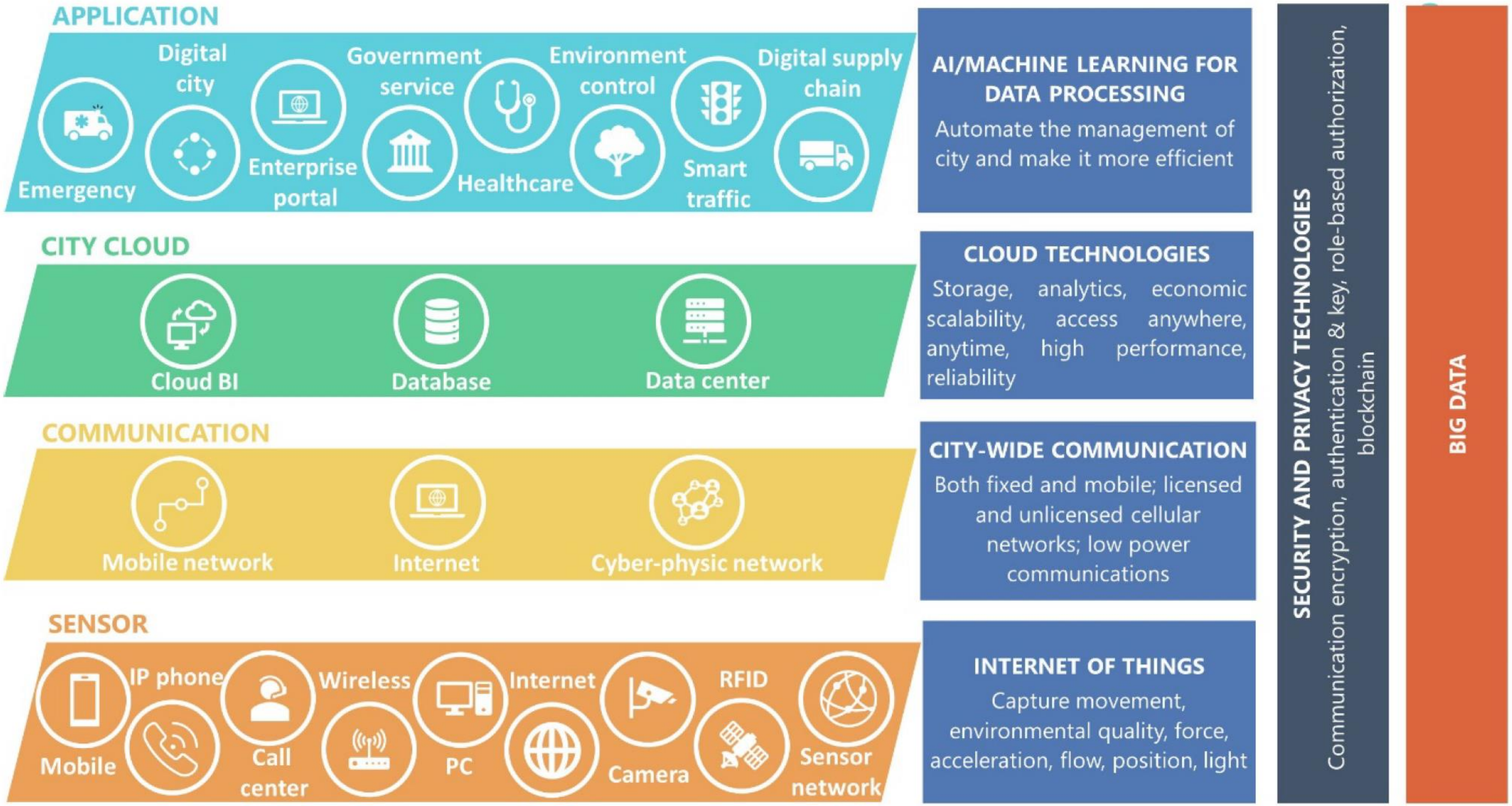


DesCartes

Intelligent modelling for decision making in critical urban systems

cnrs @ CREATE Singapore

NATIONAL RESEARCH FOUNDATION


APPLICATION
Emergency
Digital city
Enterprise portal
Government service
Healthcare
Environment control
Smart traffic
Digital supply chain
CITY CLOUD
Cloud BI
Database
Data center
COMMUNICATION
Mobile network
Internet
Cyber-physic network
SENSOR
Mobile
IP phone
Call center
Wireless
PC
Internet
Camera
RFID
Sensor network
AI/MACHINE LEARNING FOR DATA PROCESSING
Automate the management of city and make it more efficient
CLOUD TECHNOLOGIES
Storage, analytics, economic scalability, access anywhere, anytime, high performance, reliability
CITY-WIDE COMMUNICATION
Both fixed and mobile; licensed and unlicensed cellular networks; low power communications
INTERNET OF THINGS
Capture movement, environmental quality, force, acceleration, flow, position, light
SECURITY AND PRIVACY TECHNOLOGIES
Communication encryption, authentication & key, role-based authorization, blockchain
BIG DATA

SECURITY

RESPONSABILITY

ETHICS

Smart cities and territories constitute a complex system of systems, intimately entangled, contributing to the security, pleasure and comfort of citizens, and operating in a secure, responsible, ethical and transparent way.

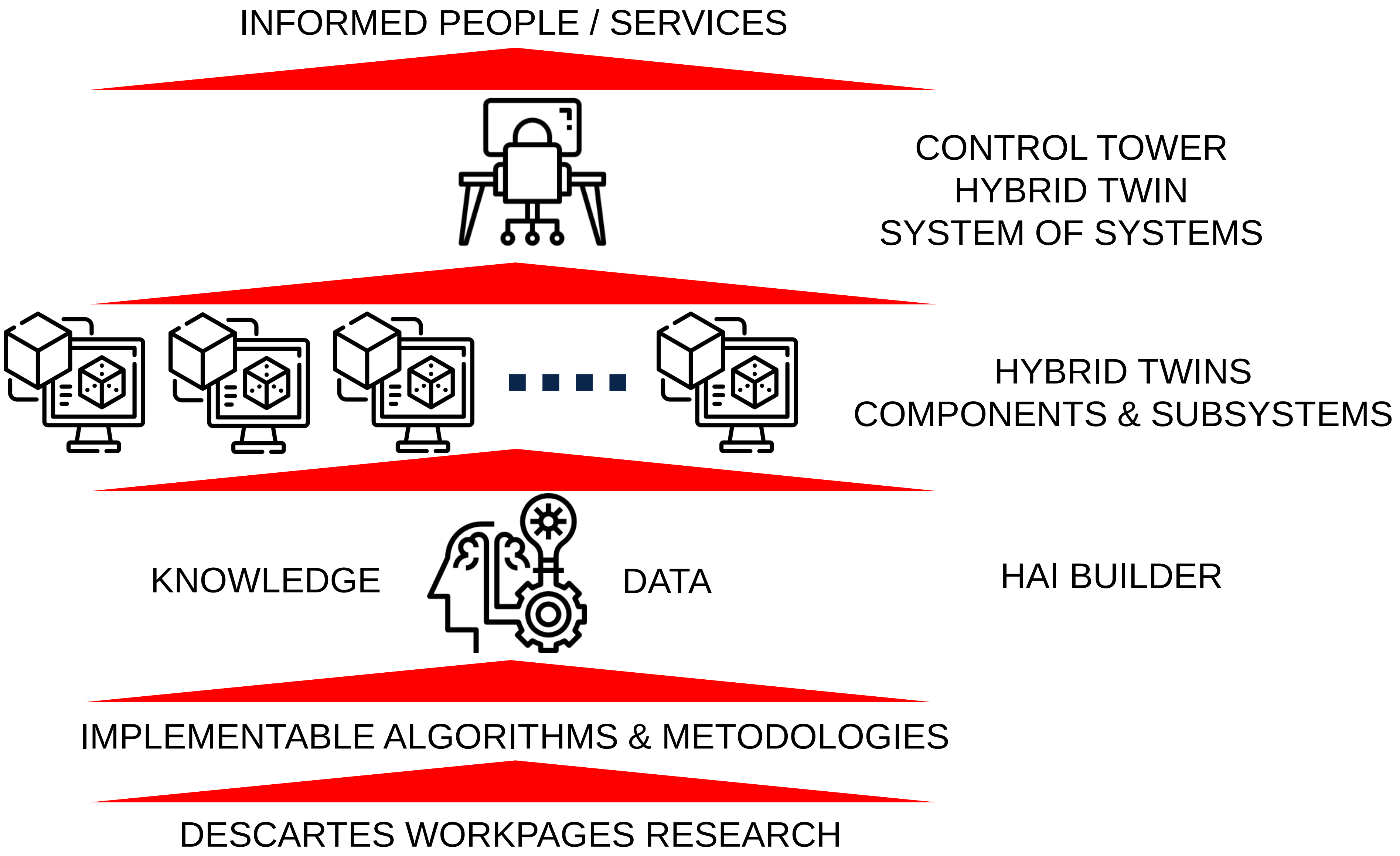
City Digital Twin

technologies enabling digital
twins of critical urban systems

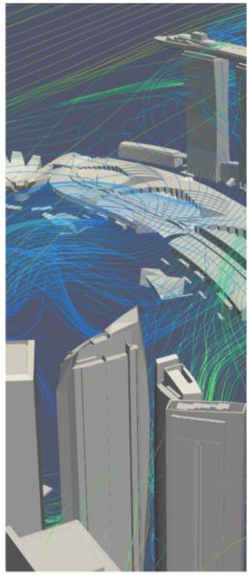
DesCartes

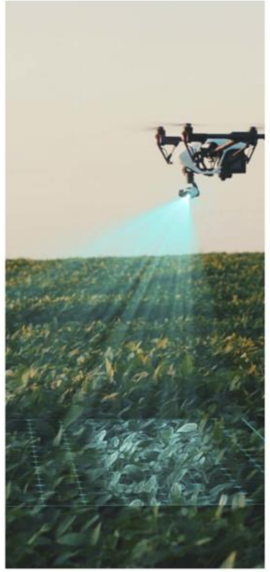
THALES
AZUR DRONES
NAVAL GROUP
EDF
(expleo)
esi get it right
IMMERSION IMAGINATION, INTERACTION ...
SKF
suez
cetim
MATCOR a cetim company
FLYING WHALES

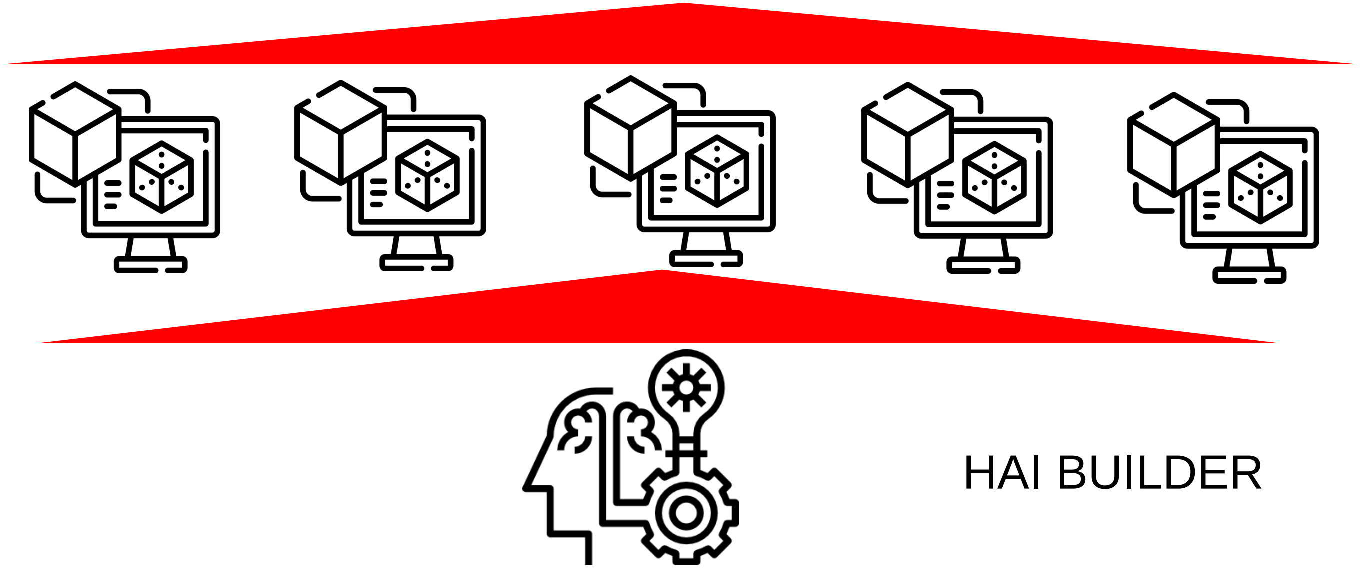
FROM RESEARCH TO APPLICATION



FROM RESEARCH TO APPLICATION



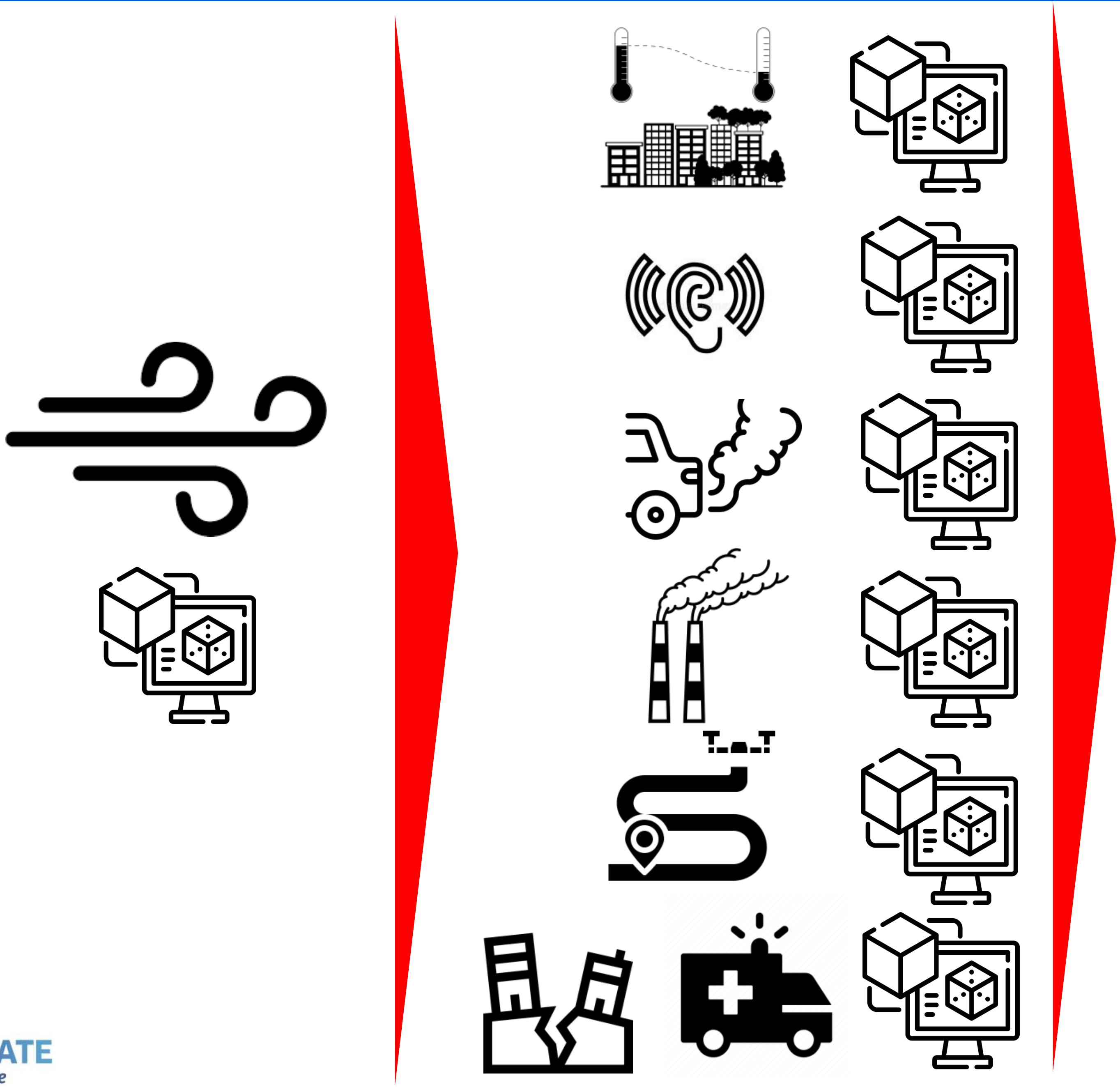


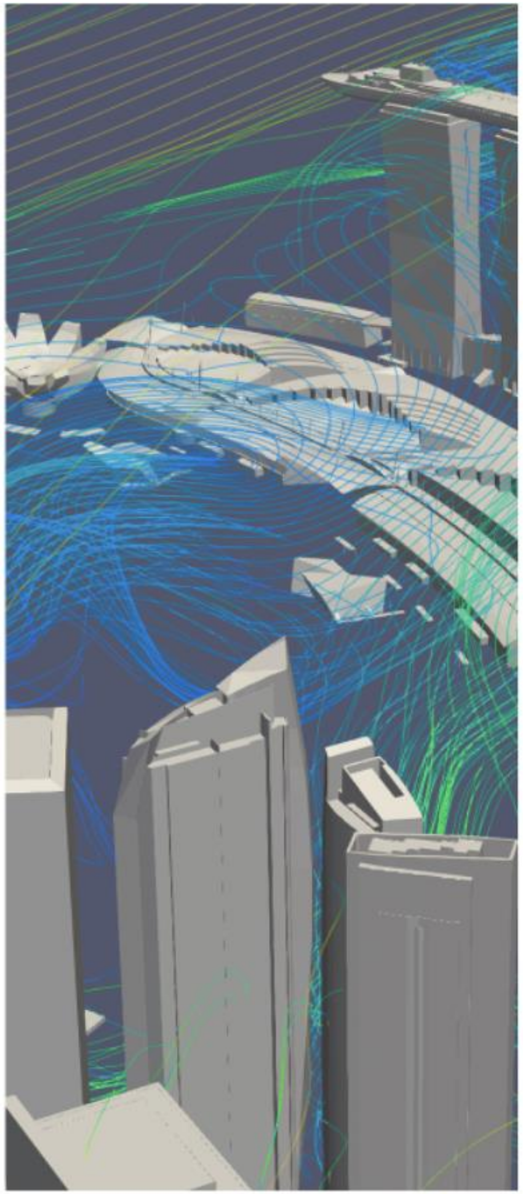



HYBRID TWINS

HAI BUILDER

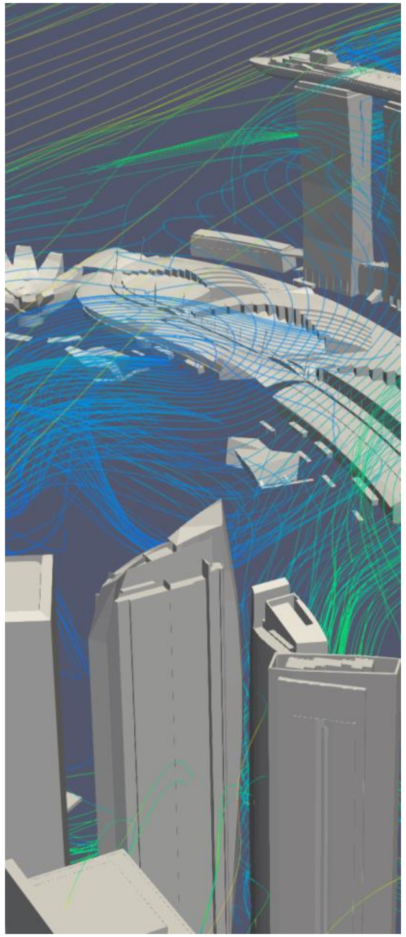
FROM RESEARCH TO APPLICATION





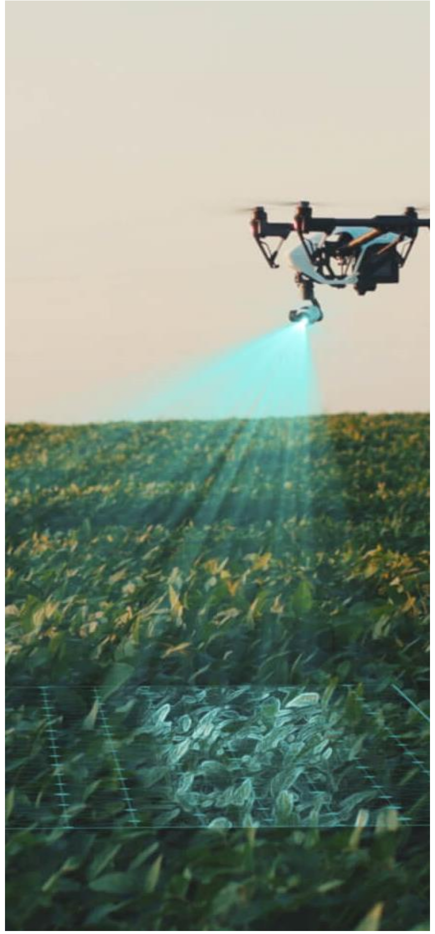
Augmented Marina Bay Twin

DEMONSTRATORS & USE CASES



Augmented Marina Bay Twin

Digital Energy

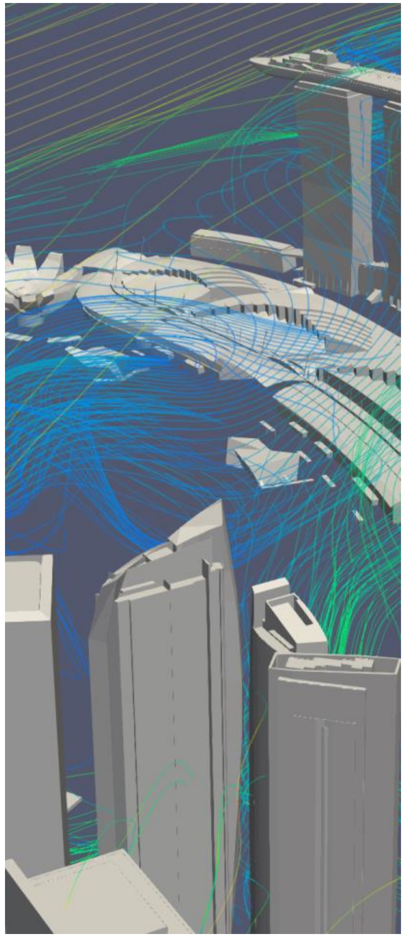


Remote Sensing

Drone Trajectory Planning

Emergency crisis

ENVIRONMENTAL DIGITAL TWIN



Augmented Marina Bay Twin

Digital Energy

Remote Sensing

Drone Trajectory Planning

Emergency crisis

Interest of having a wind map at the city level

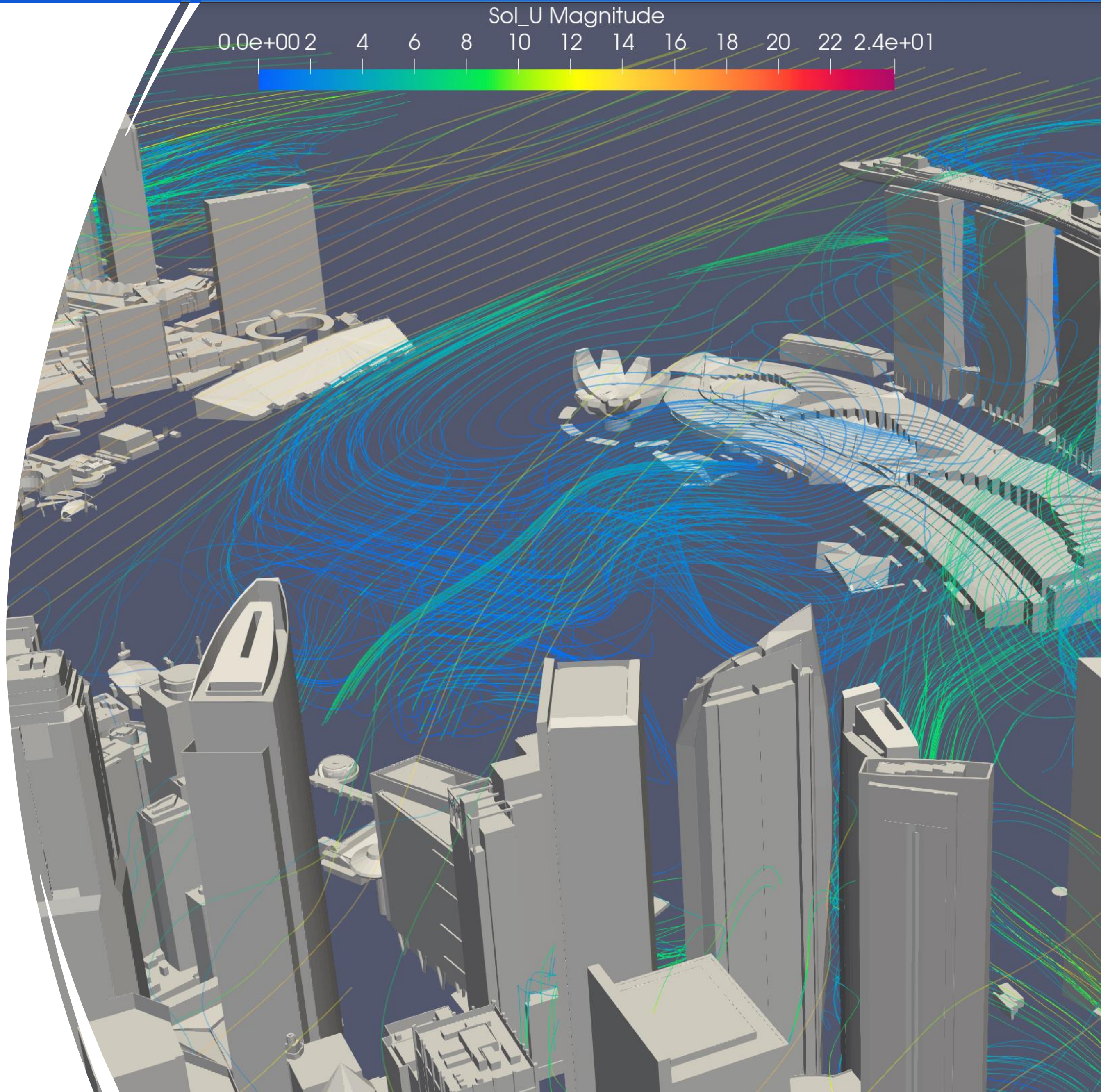
- Inferring emissions dispersion
- Inferring air quality
- Inferring temperature and thermo-convective flows
- Drone trajectory optimal planning
- … and many others …

SINGAPORE LAND AUTHORITY

HTX

get it right

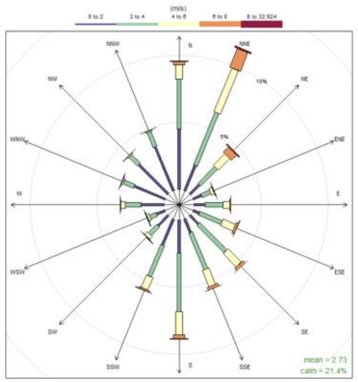
ARIA TECHNOLOGIES

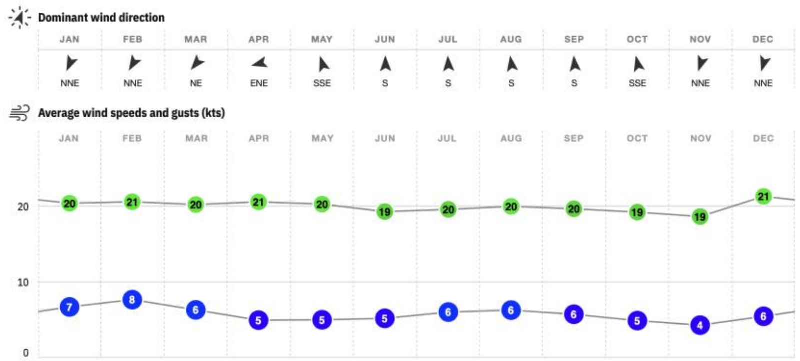


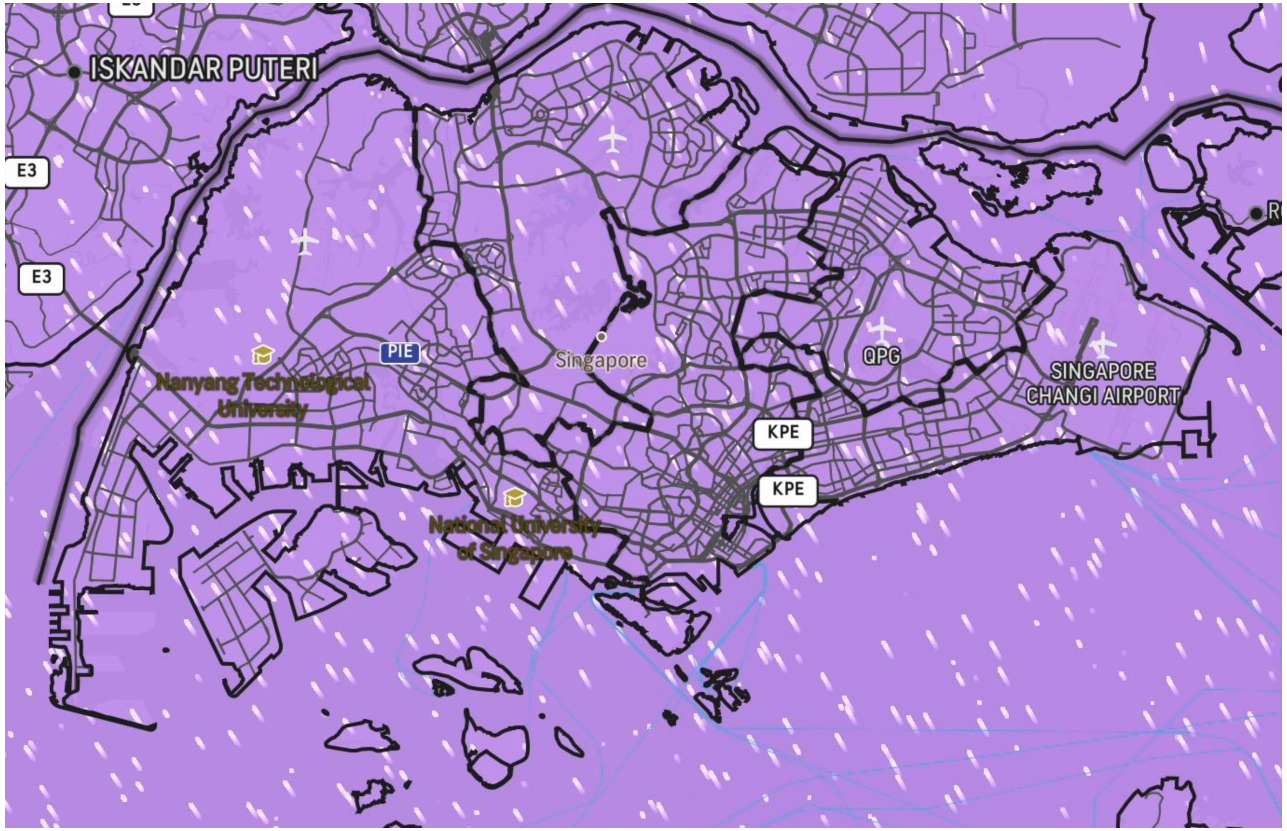
Available forecast is too coarse for providing local (street level) information on the wind velocity.

However, it provides the boundary conditions for district-level calculations

That solution is computationally too expensive

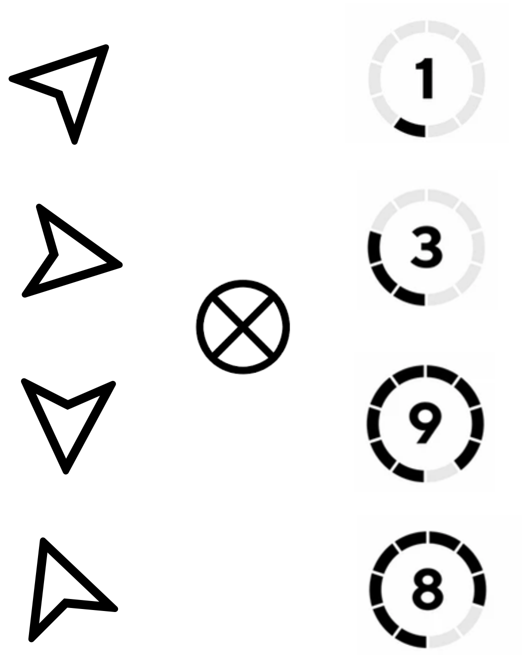




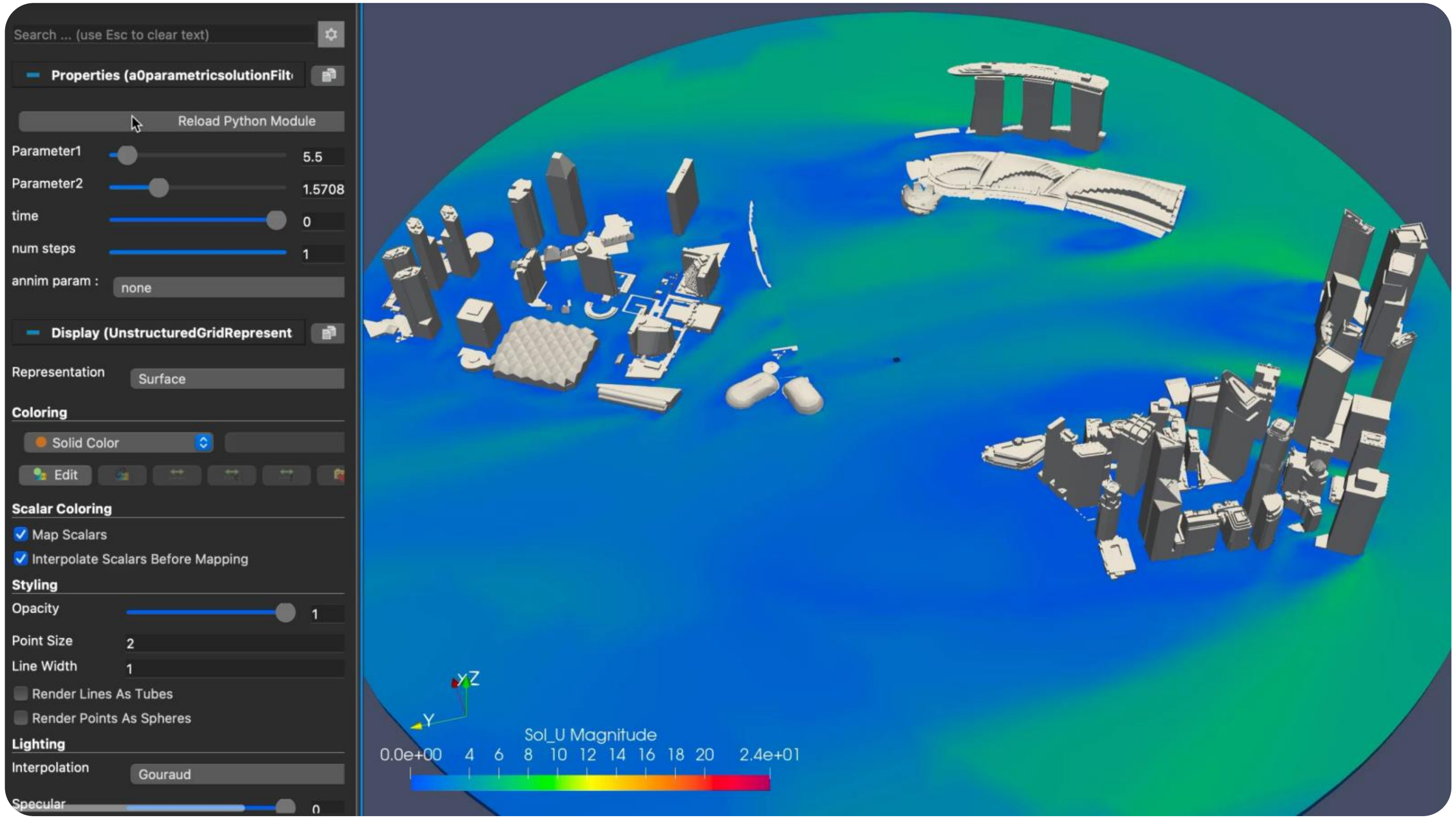


WIND MAP

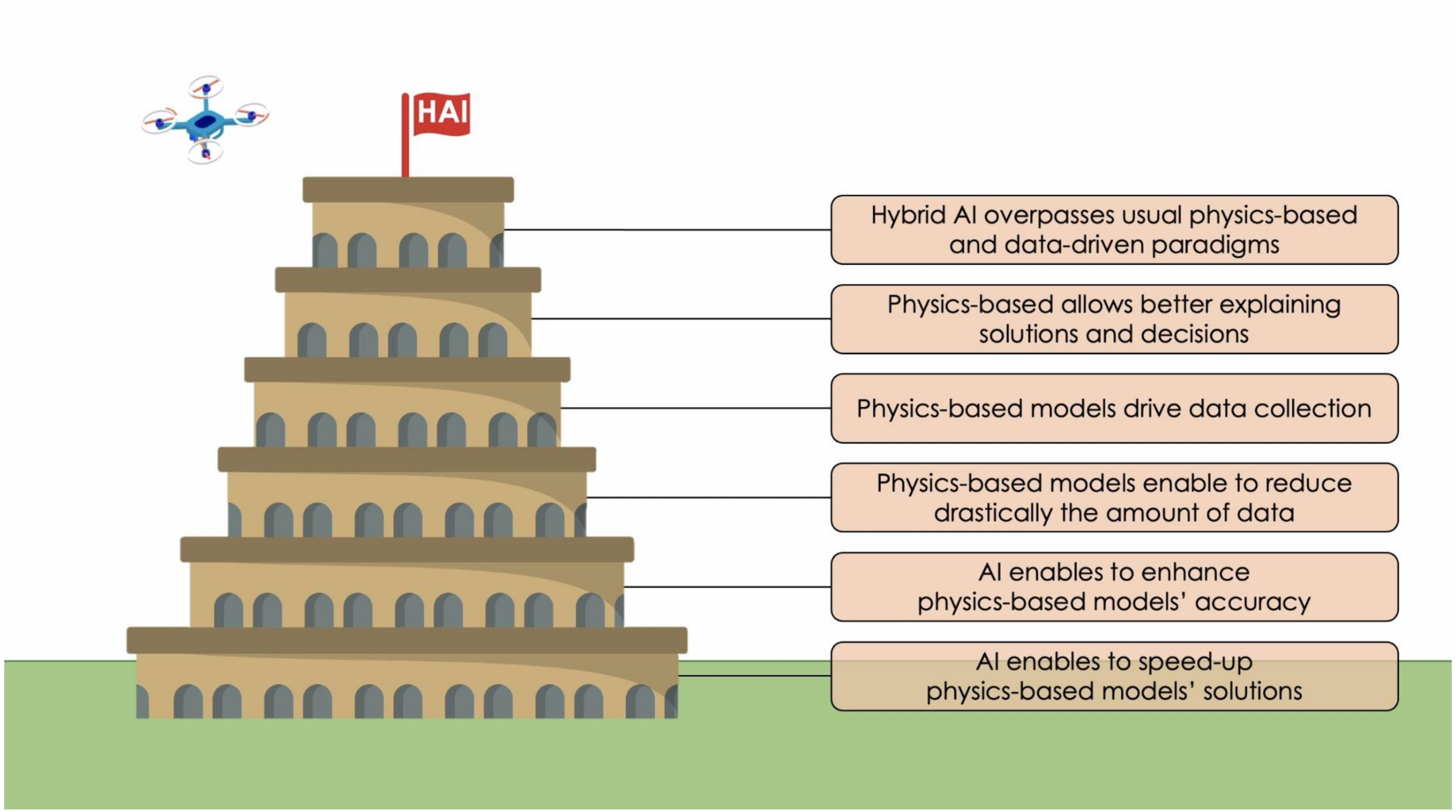
Direction Intensity



Marina Bay Wind-map



CONCLUSION


HAI
Hybrid AI overpasses usual physics-based and data-driven paradigms
Physics-based allows better explaining solutions and decisions
Physics-based models drive data collection
Physics-based models enable to reduce drastically the amount of data
AI enables to enhance physics-based models' accuracy
AI enables to speed-up physics-based models' solutions