NEUTRON STAR SYSTEMS

THE FUTURE IS ELECTRIC

NATO MODELLING AND SIMULATION GROUP (NMSG) SYMPOSIUM

ENABLING ELEMENTS OF SIMULATIONS DIGITAL TWINS AND ITS APPLICABILITY FOR INFORMATION SUPERIORITY IN DEFENCE DOMAIN

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Definitions of Digital Twin (DT)

- IBM[1]: A digital twin is a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning and reasoning to help decision-making.
- Slingshot Simulations[2]: A Digital Twin is a simulated portrayal of an authentic entity or system. A virtual representation of real-world objects, physical assets or systems.
- AIAA / AIA[3]: A set of virtual information constructs that mimics the structure, context and behavior of an individual / unique physical asset, or a group of physical assets, is dynamically updated with data from its physical twin throughout its life cycle and informs decisions that realize value.

[1] https://www.ibm.com/in-en/topics/what-is-a-digital-twin
[2] https://www.slingshotsimulations.com/digital-twins/
[3] Digital Twin: Definition & Value: An AIAA and AIA Position Paper, December 2020

Relevance

- Significant reduction of costs and man-hours required for technology development
  - Rapid prototyping and qualification
  - Accelerated manufacturing
  - Reduced testing time
- Agile and autonomous systems
- Prediction of threats, failures and maintenance requirements

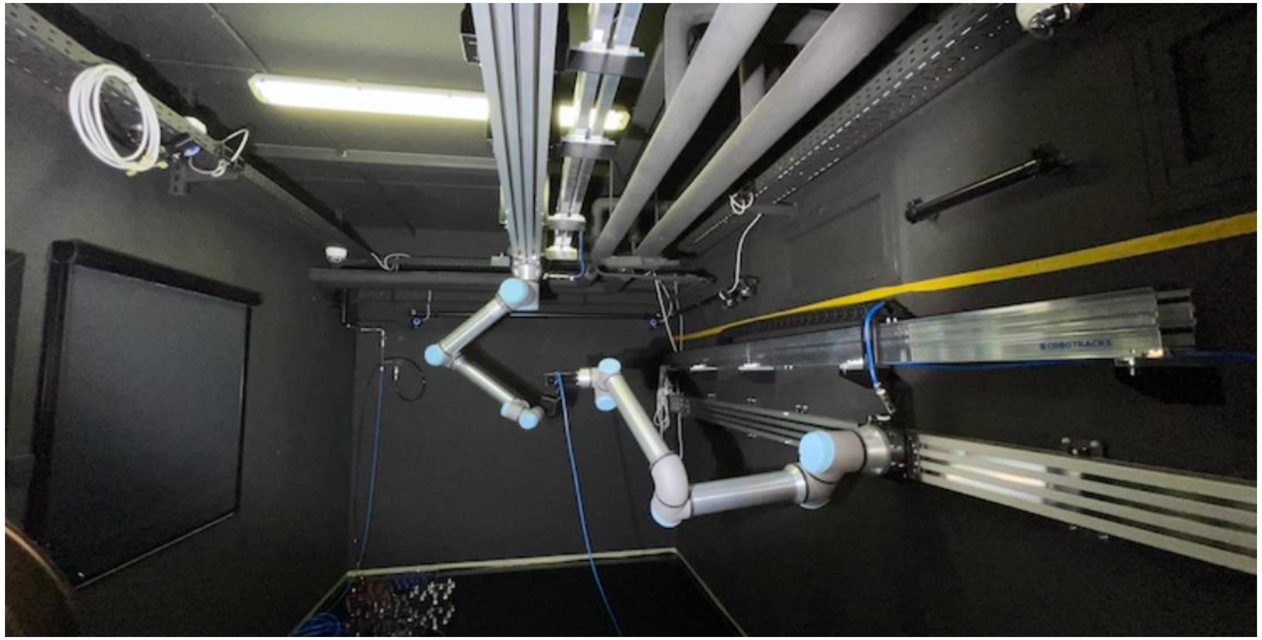
Seamless interplay between data and multiphysics models.

Simulations DT analogous to contraption.
Source: https://scienceworld.scholastic.com/issues/2019-20/031620/crazy-contraption.html#960L

DIGITAL TWINS STATE OF THE ART

Software / Hardware Simulations

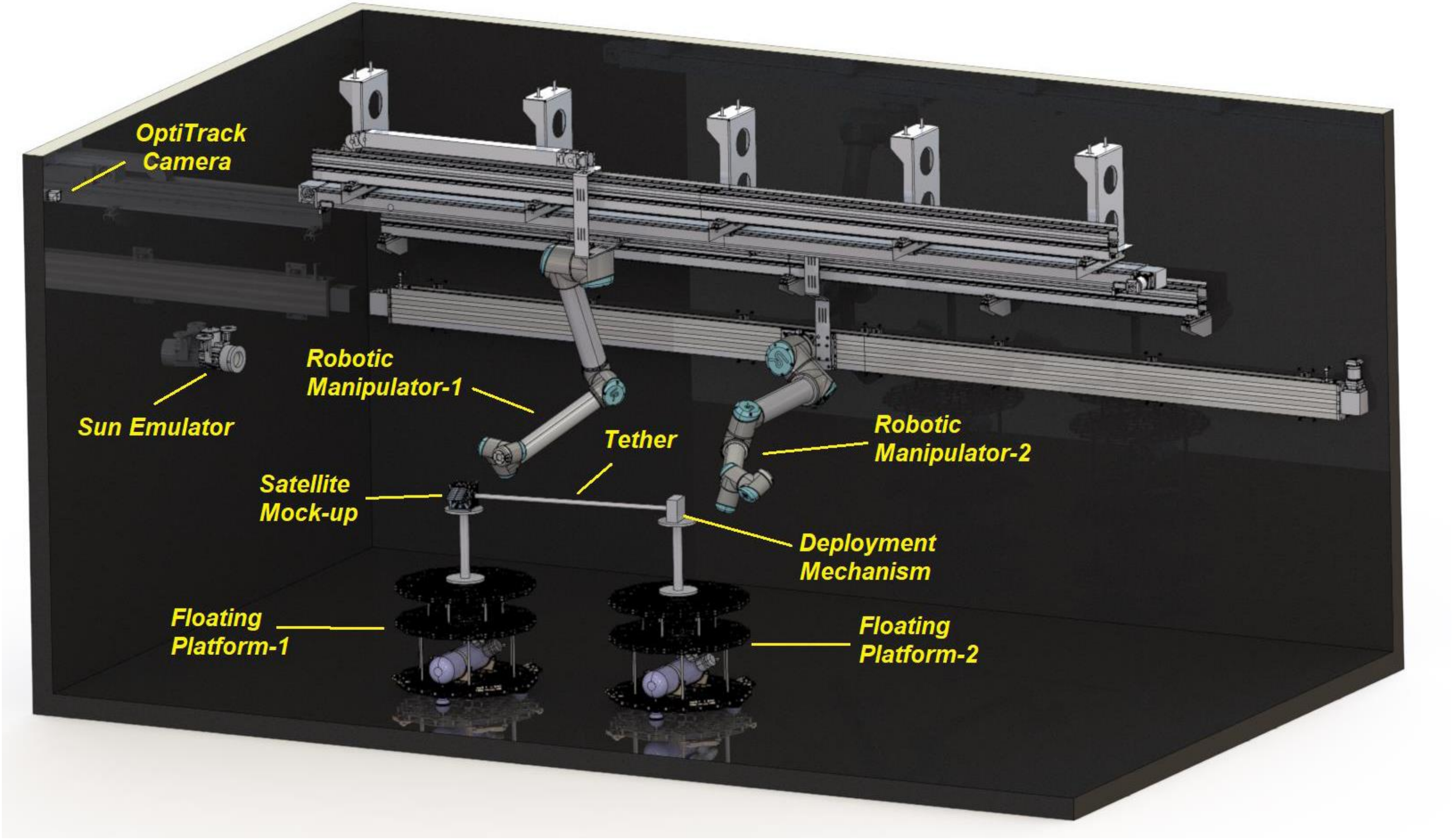
- Off-the-shelf and open-source software for creating DT environments
  - E.g. Autodesk Digital Twin, Bosch IoT Suite, Eclipse Ditto, iTwin.js, etc.
- *Gazebo* software for modelling space related engineering scenarios under microgravity conditions



Zero-G Lab (SnT-University of Luxembourg).

- Digital twin structure synchronized with the hardware (Zero-G Lab)
- The lab supports test, verification and validation steps of any space related product (micro-satellites, robotic manipulators, active and passive space debris removal systems, etc.)

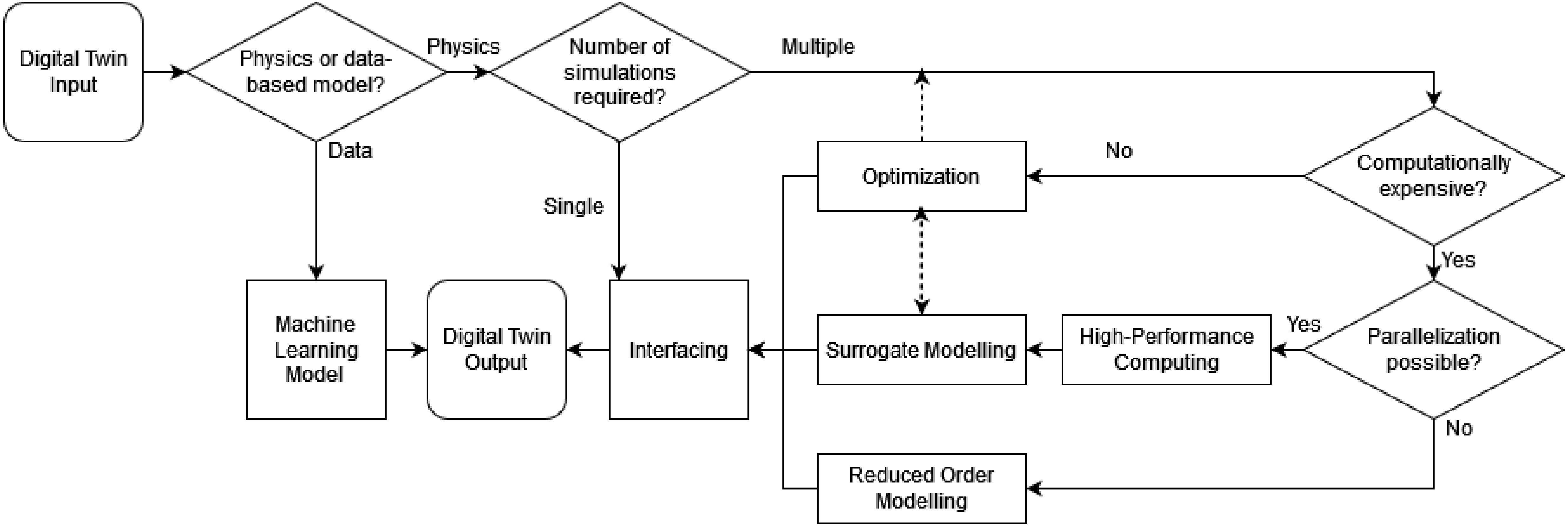
Software / Hardware Simulations



Digital Twin Interface of Zero-G Lab.

Digital twin of Zero-G Lab can be used for any Software-in-the-loop and Hardware-in-the-loop applications as integrated with physical infrastructure of Zero-G Lab.

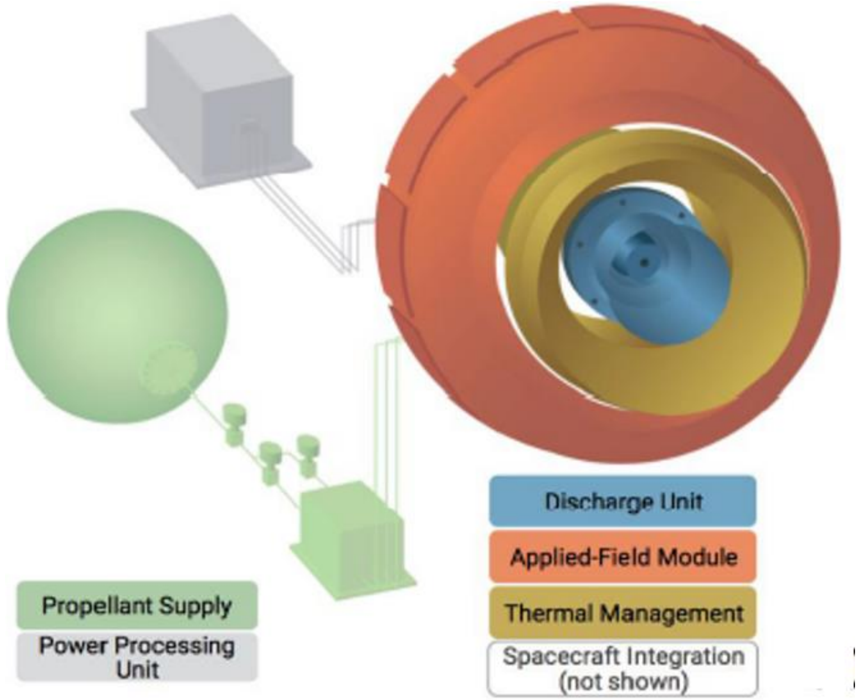
Framework for designing simulations digital twin



Optimization

- Viewing simulations as purely mathematical optimization problems

  ➔ Physics acts as a black-box, mathematical algorithms achieve optimal design
- Relevant for scalable systems or systems involving multiple design parameters
- Mathematical optimization enables arriving at the optimal design configuration in less computation effort than that required for a full design-of-experiments methodology.



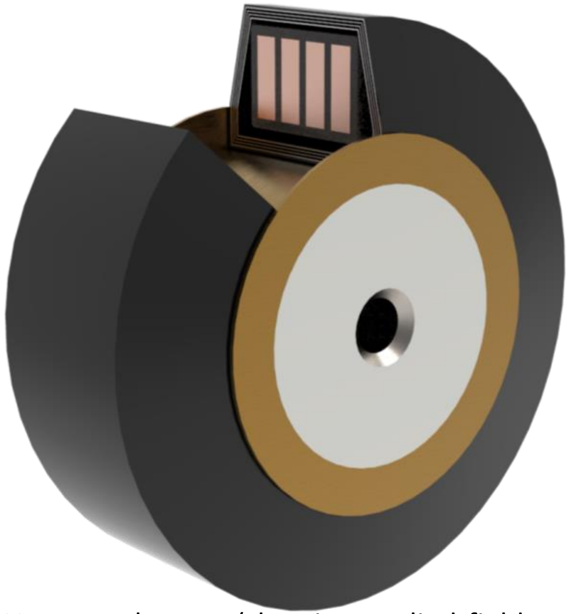
Conceptual design of SUPREME thruster - subsystem breakdown.

ENABLING TECHNOLOGIES AND THEIR BENEFITS

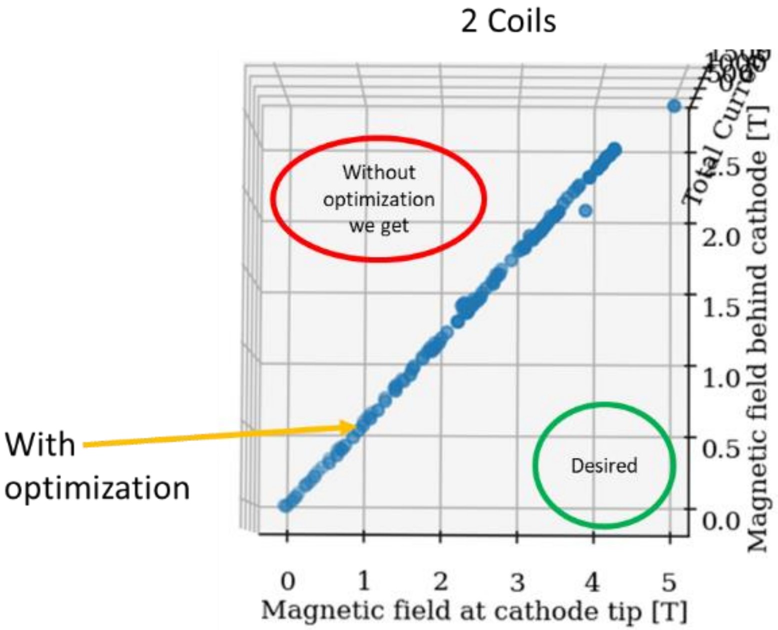
Optimization

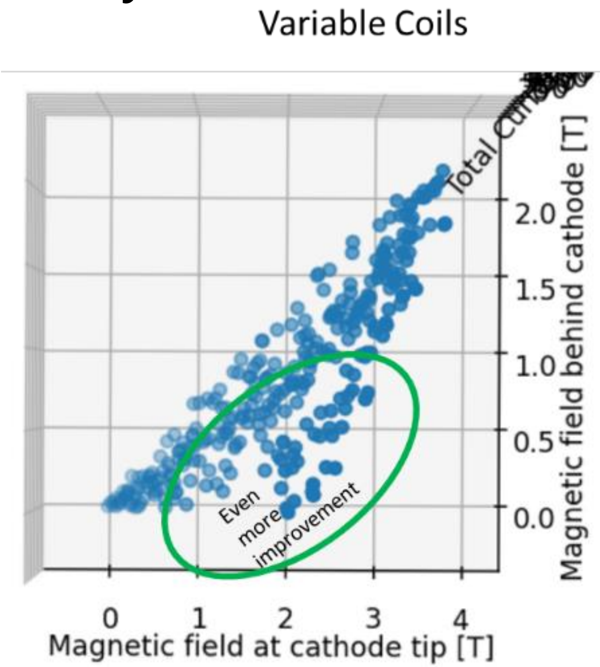
Example application: Optimal coil configuration in applied-field module

- Variables: Number of coils, coils positioning, current through coils
- Objectives: maximizing field strength at cathode tip, minimizing field strength at 70 mm behind the cathode, and minimizing total current density



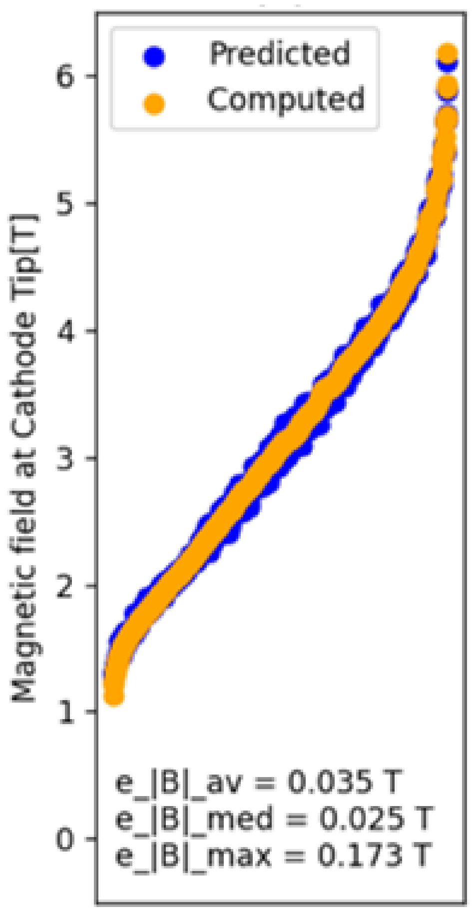
SUPREME thruster (showing applied-field module's cross-section)





Surrogate Modelling

- Simplified approximations of the complex links between the inputs and outputs of any simulations
- Other names: response surfaces, black-box models, metamodels, emulators, etc.
- Machine learning algorithms can be used
- Enables (fairly) accurate prediction of the outputs of non-physics-simulated inputs

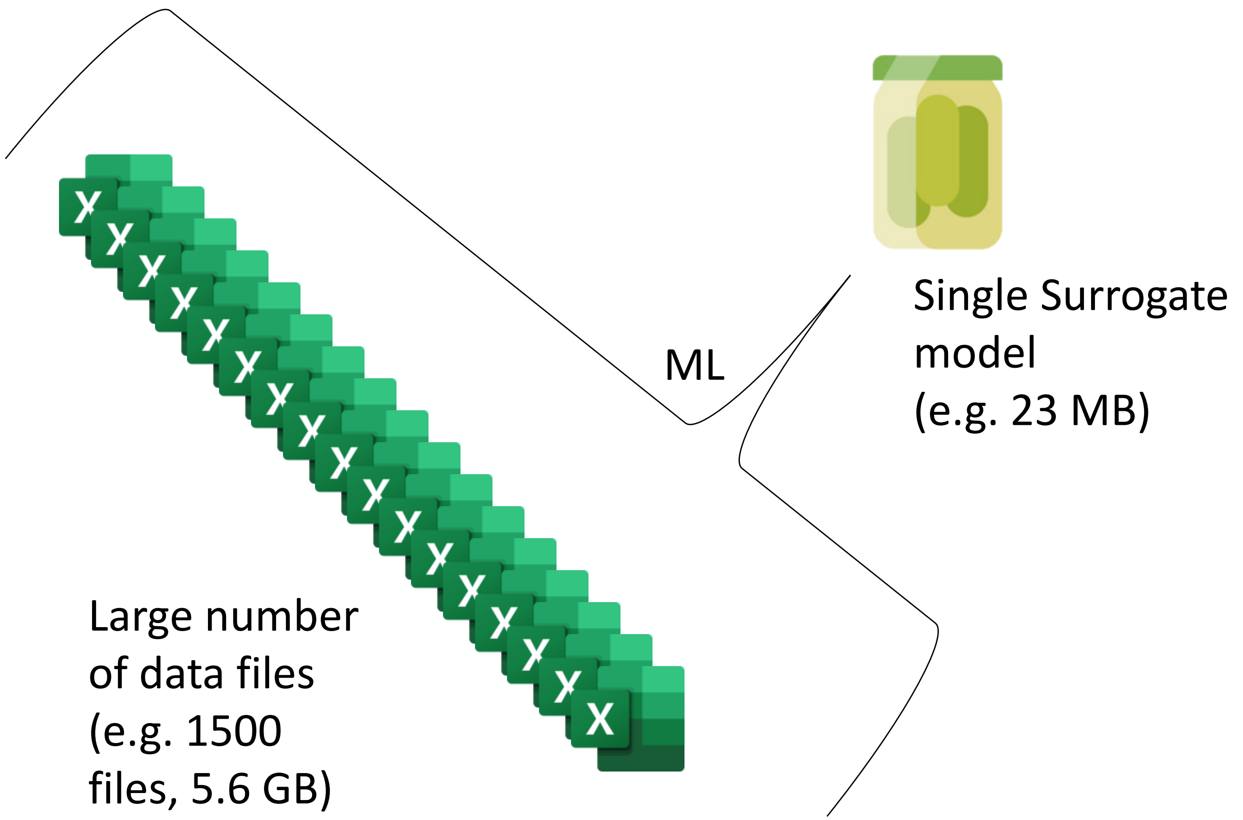


Accuracy of surrogate model for an electromagnetic simulation

Surrogate Modelling

Benefits:

- Quick data extraction
  - Simulated (known) and non-simulated (unknown) configurations
- Less storage space required => Low storage infrastructural costs
- High Accuracy
- Less data needs to be generated (e.g. 30% enough) => Less computation and human time => Reduced cost



Parallelization

- Breaking down complex computations into many smaller parts that can be computed in parallel on different computing units
- Increased speed of computation
- Application to DT:
  - Different parts of simulations executed parallelly on different hardware.

    e.g. thermal, plasma and electromagnetic physics simulations
  - Splitting computationally heavy simulations into small individual calculations.

    e.g. tracking of thousands of different assets world-wide at the same time, processing information from a large number of sources at the same time.
- Higher number of CPU cores and parallel architectures of GPUs reduce computation times of DT by many times.

Microsoft Azure – OnDemand Infrastructure provider

- Leveraging secure cloud based compute power to run simulations more efficiently – from processing time as well as cost perspective

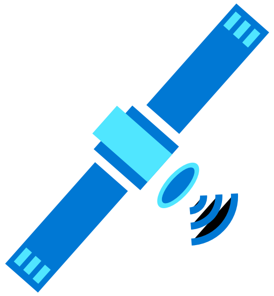
  ➔Achieved 3x shorter calculations times for the simulations (compared to on-prem) and therefore improved operational efficiency.

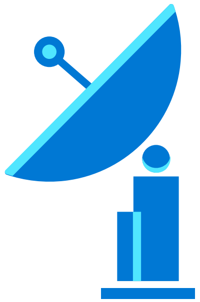
- Using Artificial Intelligence Services to find the best possible algorithm for the calculations.
- Leveraging Confidential compute on demand to ensure highest security needs.

Microsoft Mesh : Helping others everywhere.

Microsoft Azure Space – Connect beyond the planet

- Use Ground stations as a service across the planet
- Enrich Digital Twins with near real time data from spacecrafts up in orbit
  - In the Metaverse
  - In digital feedback loops for simulations





Information Superiority using Digital Twins in Defence

- Fast diagnosis and health monitoring
- Lifecycle extension of satellites

- Enhanced cybersecurity through fast and effective use of data
- Synchronized and interoperable capabilities

  ➔ mitigate reversible and non-reversible physical and cyber threats to defence space infrastructure
- On-board threat assessment of space-based (defence) services

- Enabling defence connectivity in remote locations

  ➔ share data quickly and securely to enhance strategic awareness

CONCLUSIONS

1 Digital Twin (DT) definition

Virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity.

2 DTs reduce costs and enhance robustness

Enabling rapid prototyping, predictive maintenance, agility and autonomy.

3 Software - hardware synergy vital for DT

Plethora of software exist for developing DT environments. Including hardware-in-the-loop aids testing, verification and validation of agile autonomous systems.

4 Combination of enabling technologies facilitate DT development

Mathematical optimization, surrogate modelling, parallelization, artificial intelligence and cloud computing are some of the major elements of simulations DTs.

5 DTs enhance defence operations

Using ground-station-as a service, building digital twins of satellite constellations, etc. improve strategic awareness, predictive maintenance and connectivity.

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