The Alan Turing Institute

Digital Twins: Building an Open and Trustworthy Ecosystem

Dr Christopher Burr

Jean Golding institute, University of Bristol
Wednesday 20th November

Background and Context

A digital twin is a set of virtual information constructs that mimics the structure, context, and behavior of a natural, engineered, or social system (or system-of-systems), is dynamically updated with data from its physical twin, has a predictive capability, and informs decisions that realize value. The bidirectional interaction between the virtual and the physical is central to the digital twin.

— Committee on Foundational Research Gaps and Future Directions for Digital Twins (2024)

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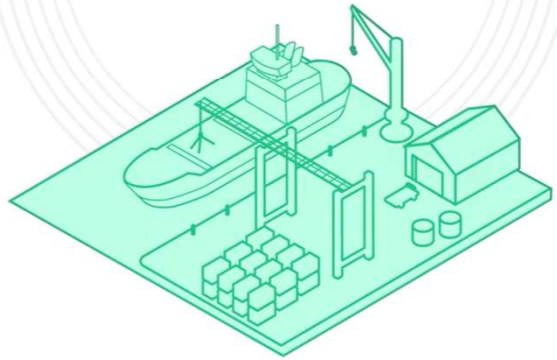
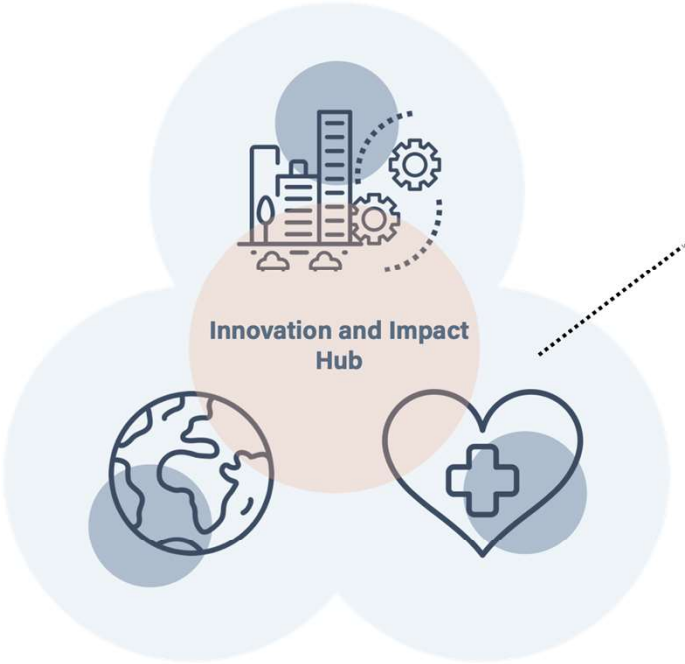


Towards ecosystems of connected digital twins to address global challenges

- Elevate cross-disciplinary activities and spaces for digital twins
- Invest in open infrastructure, with a focus on data and technical standards
- Prioritise tools for building trust in digital twins

Turing Research and Innovation Cluster for Digital Twins (TRIC-DT)

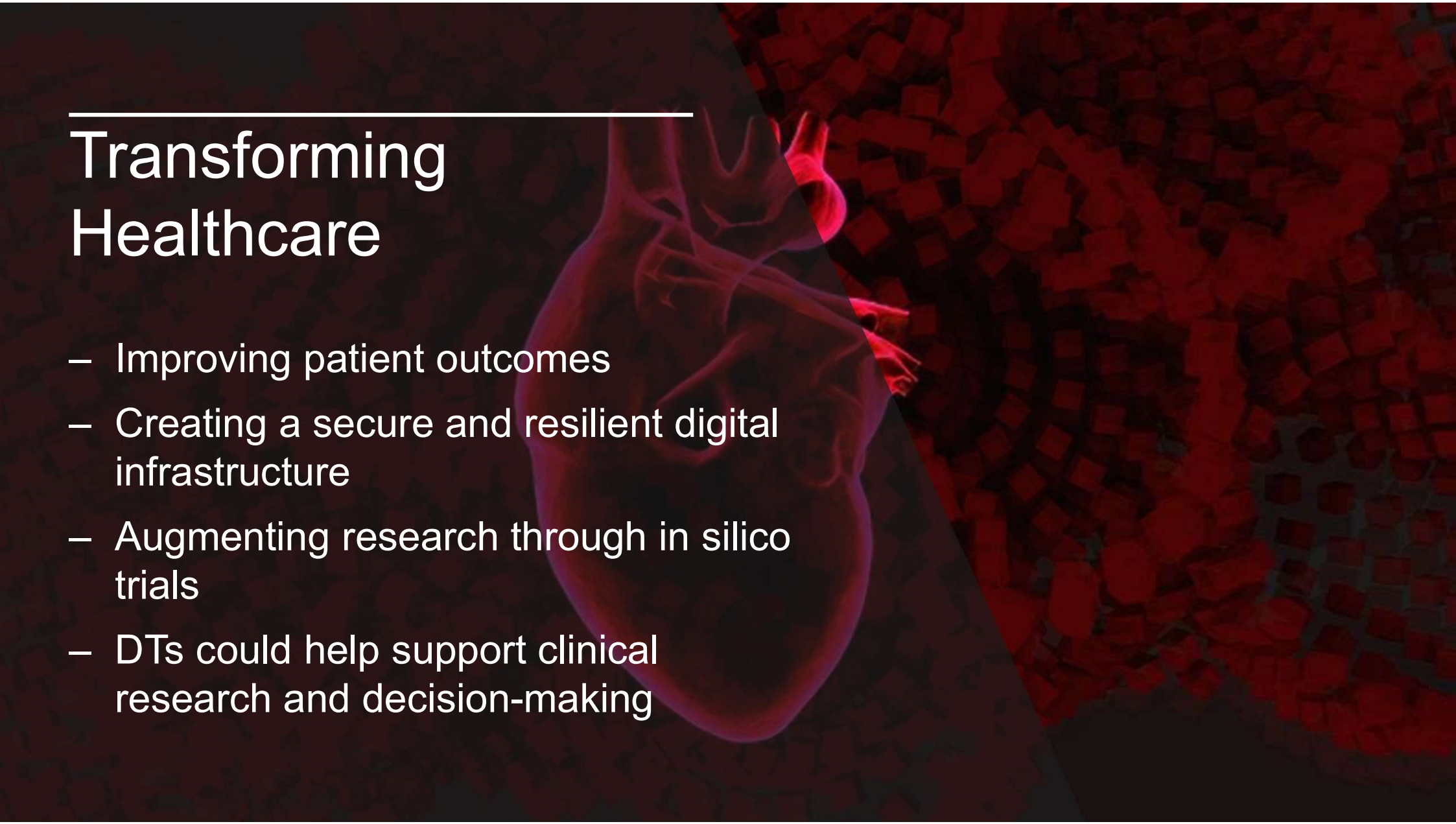


Advance the science and implementation of digital twinning and **use these advances** to address important **technological and societal challenges**.

Produce **open and reproducible computational tools** for DT design, development, and deployment that facilitate scaling of DTs and provide these tools as a freely available resource.

Build a **multidisciplinary community of practice** in digital twinning that **democratises access to DT technology**.

Transforming Healthcare



- Improving patient outcomes
- Creating a secure and resilient digital infrastructure
- Augmenting research through in silico trials
- DTs could help support clinical research and decision-making

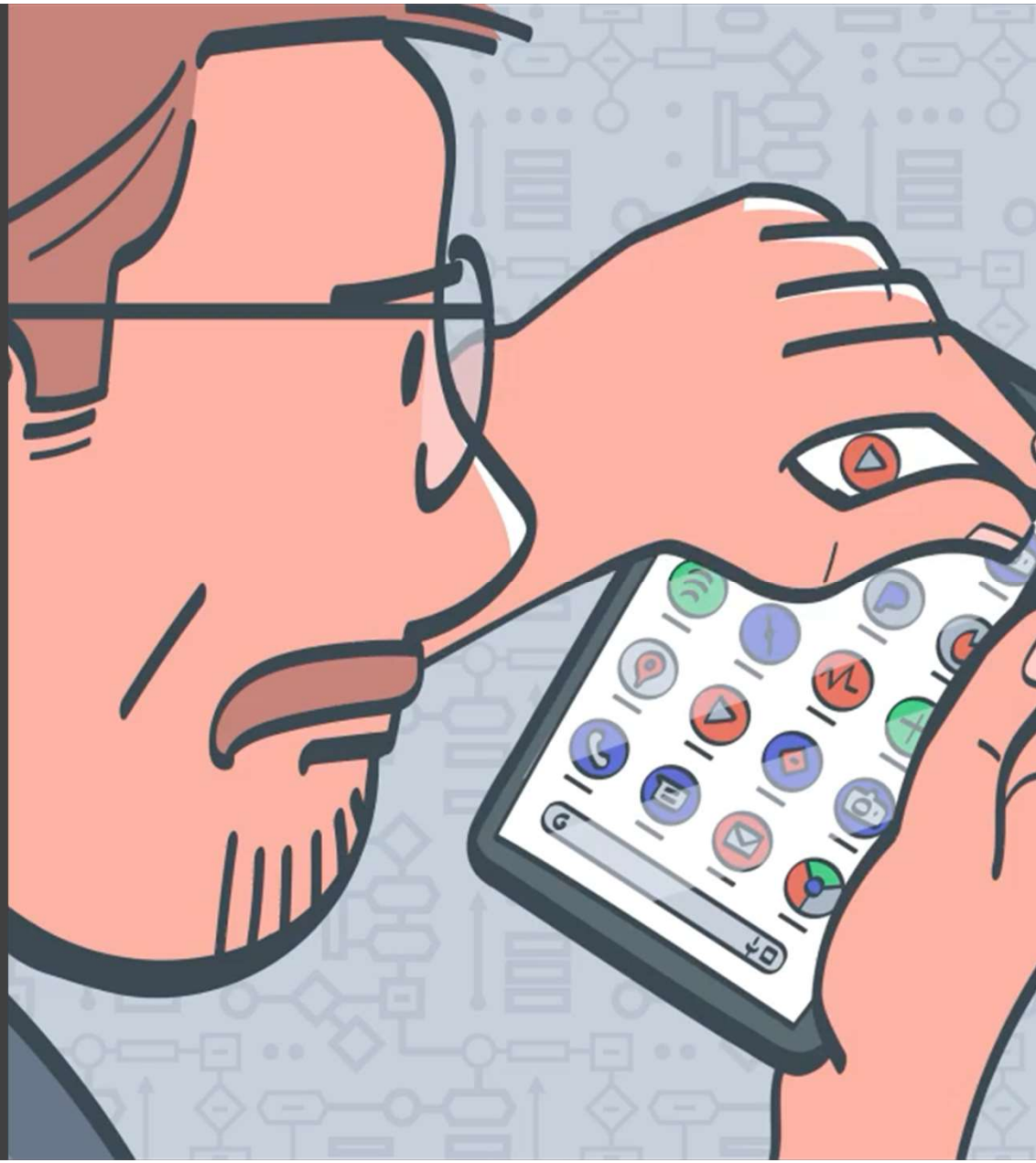
Protecting the Natural Environment

- Mitigating the effects of climate change
- Forecasting sea ice loss
- Optimising navigation for autonomous marine vessels
- DTs can help exploit environmental data, monitoring, and modelling expertise

Decarbonising the Economy

- Designing cyber-physical infrastructure for low carbon technologies
- Expanding the life of existing assets and infrastructure
- Managing intermittent and decentralized energy sources to aid transition to net zero

Projects and Research Questions



– AutoEmulate

– Knowledge Graphs

– Trustworthy and Ethical Assurance

A fundamental challenge for digital twins is the vast range of spatial and temporal scales that the virtual representation may need to address […] An additional challenge is that as finer scales are resolved and a given model achieves greater fidelity to the physical counterpart it simulates, the computational and data storage/analysis requirements increase.

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AutoEmulate

- Real-world simulations are **slow** (days to weeks) and computationally **expensive** (hundreds of cores)
- *Machine learning* models can **emulate** these simulations
- Emulators are **fast** (seconds) and **computationally cheap** (few cores), but choosing models and parameters is difficult.

AutoEmulate

- AutoEmulate is an open-source **python package that m**akes **emulation** easy!
- It automatically **fits** and **optimises** various machine learning/AI models to find the **best emulator** for your simulation
- Early-stage and very open to **user-feedback** and **collaboration**

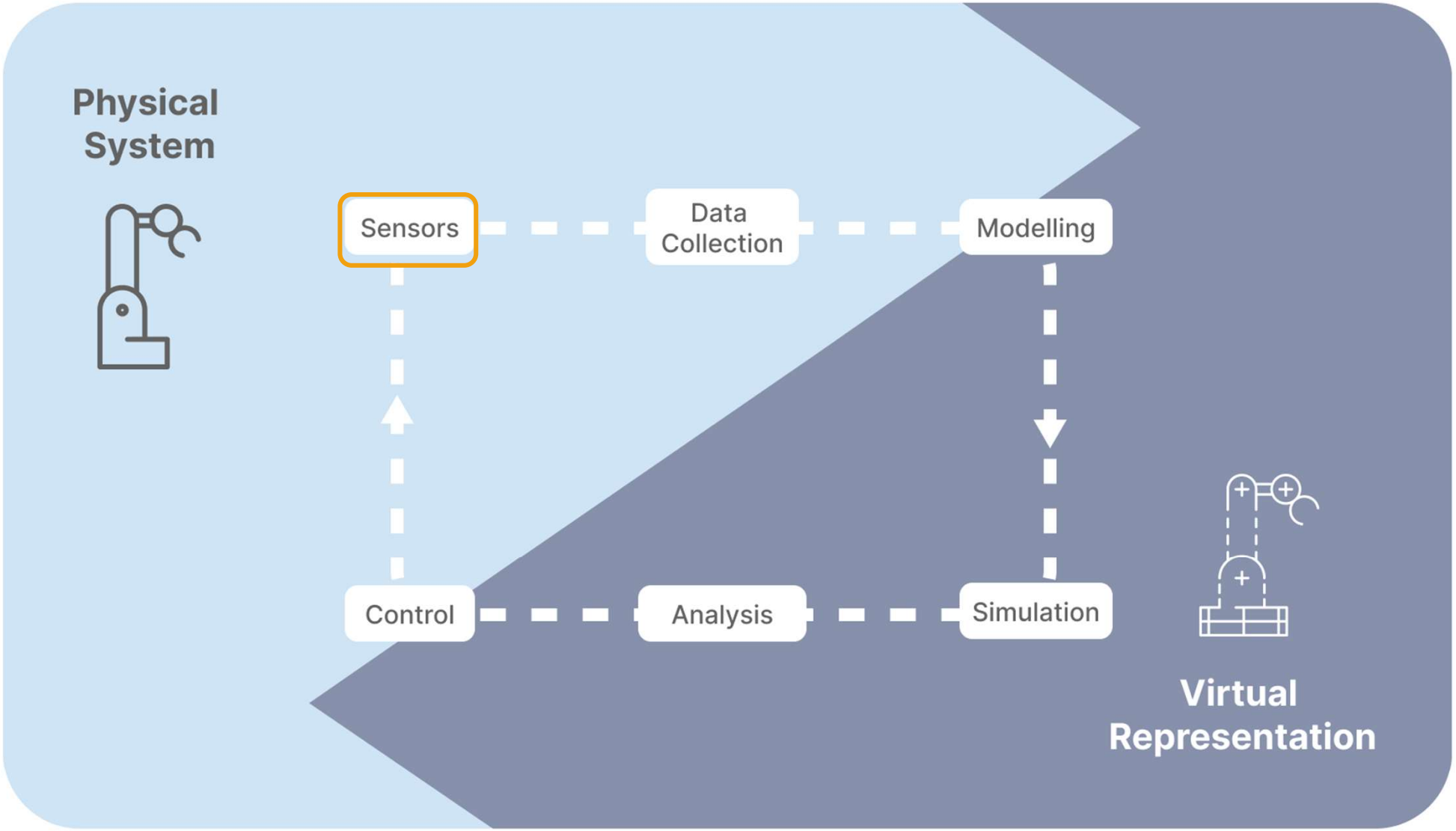
README | Code of conduct | MIT license

AutoEmulate

ci passing | codecov 91% | code style black | all contributors 5

Simulations of physical systems are often slow and need lots of compute, which makes them unpractical for applications like digital twins, or when they have to run thousands of times to do uncertainty quantification or sensitivity analyses. The goal of `AutoEmulate` is to make it easy to replace simulations with fast, accurate emulators. To do this, `AutoEmulate` automatically fits and compares lots of models, like *Radial Basis Functions*, *Gaussian Processes* or *Neural Networks* to find the best emulator for a simulation.

The project is in early development.


Physical System
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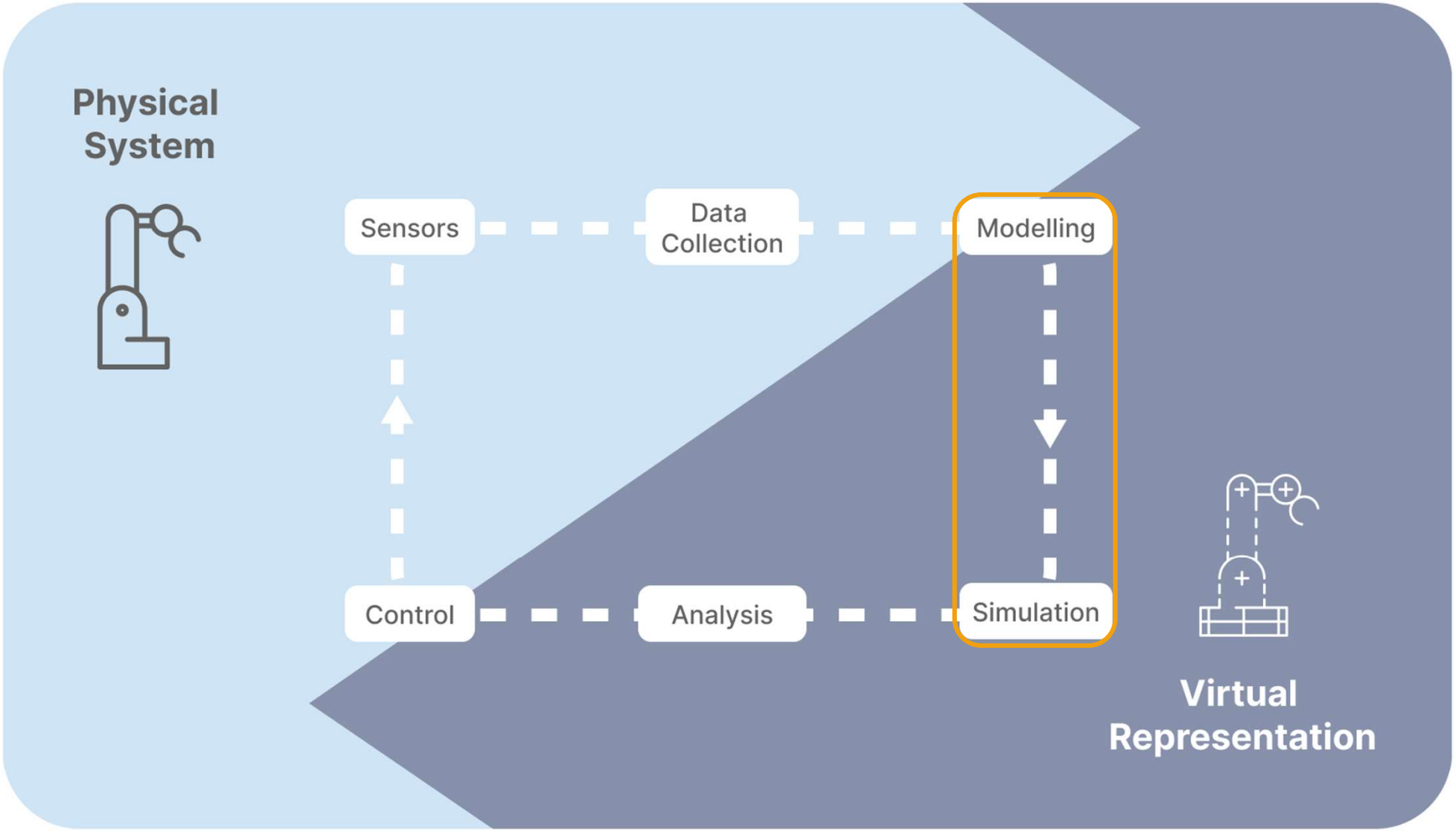
Data Collection
Modelling
Control
Analysis
Simulation
Virtual Representation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Virtual Representation

Looking to the future, as emerging advances in the field of artificial intelligence (AI) allow for verbal and visual communication of concepts and processes, AI-mediated communications may be incorporated into digital twins to accelerate their creation, maintain their tight alignment with physical twins, and expand their capabilities.

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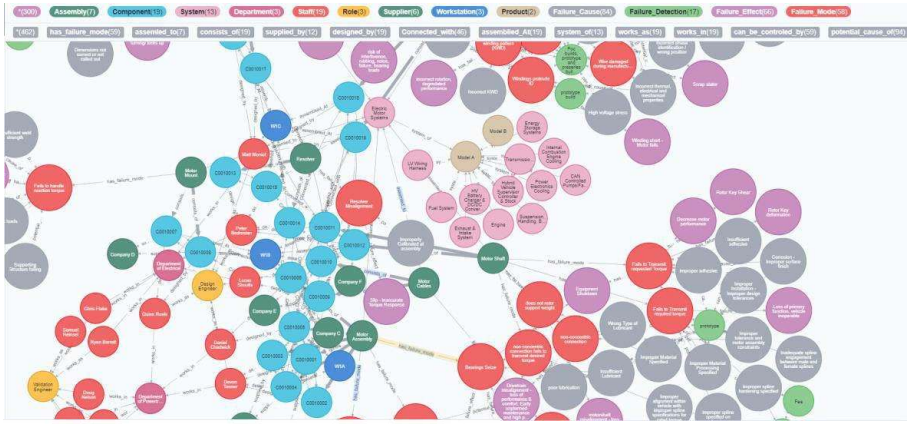
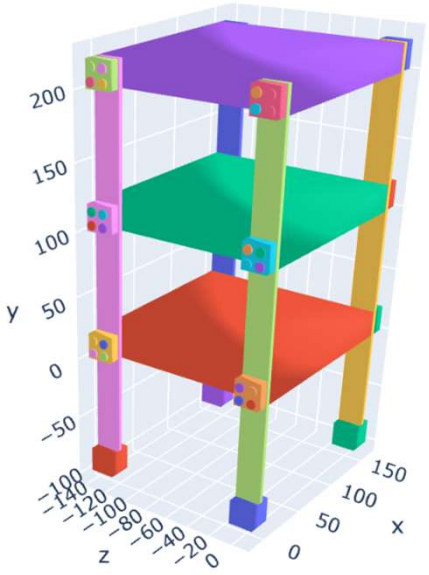
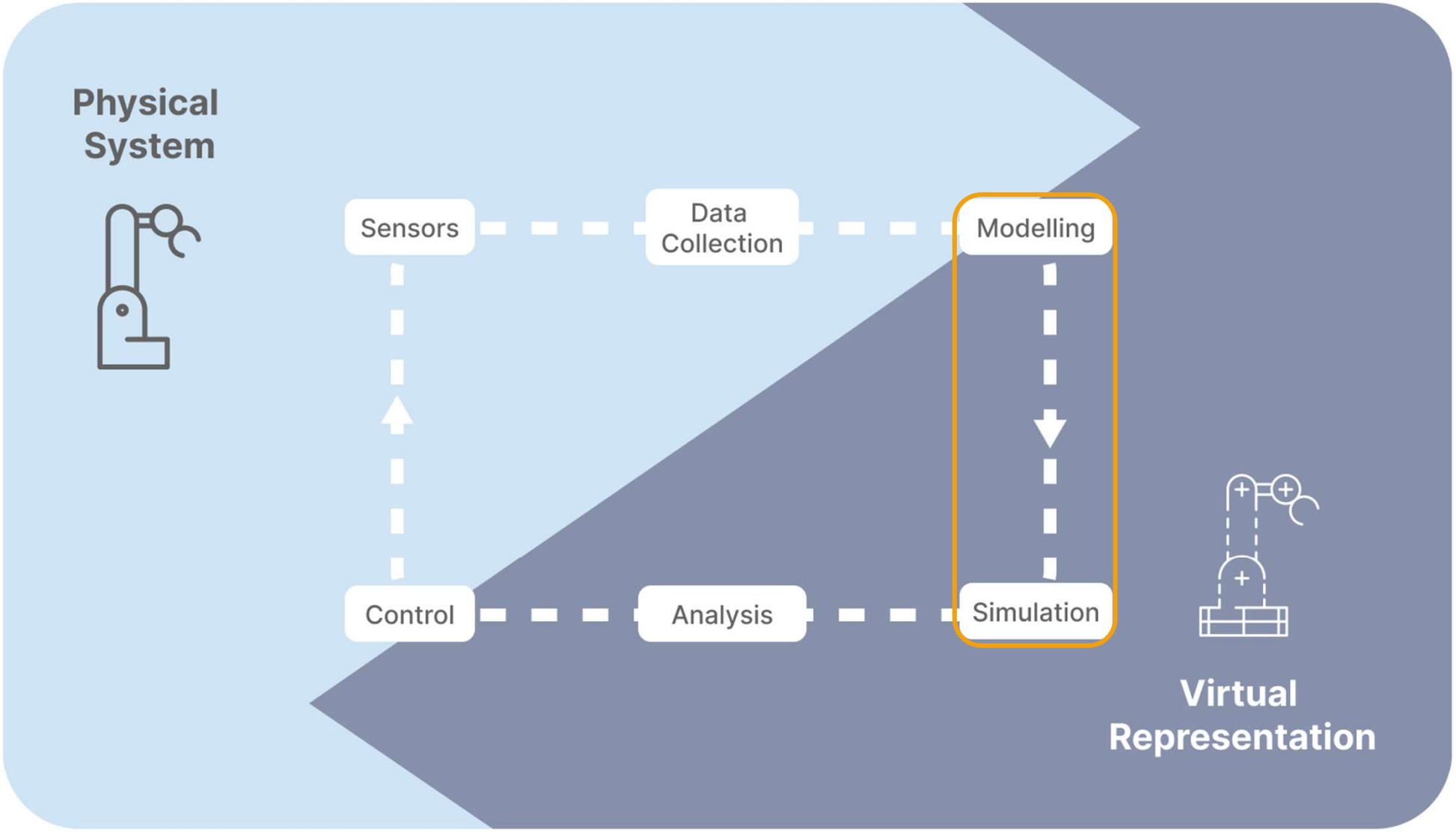




Knowledge Graphs and Embeddings for Decision Support

- Knowledge graphs enable a range of functionalities to be integrated into digital twins
- A potential mechanism for creating a `digital thread' (i.e. time evolving knowledge graph)
- Supports interoperability by bringing together heterogenous data types
- Integration of LLM-enabled multi-agent systems (i.e. RAG and function tool calling)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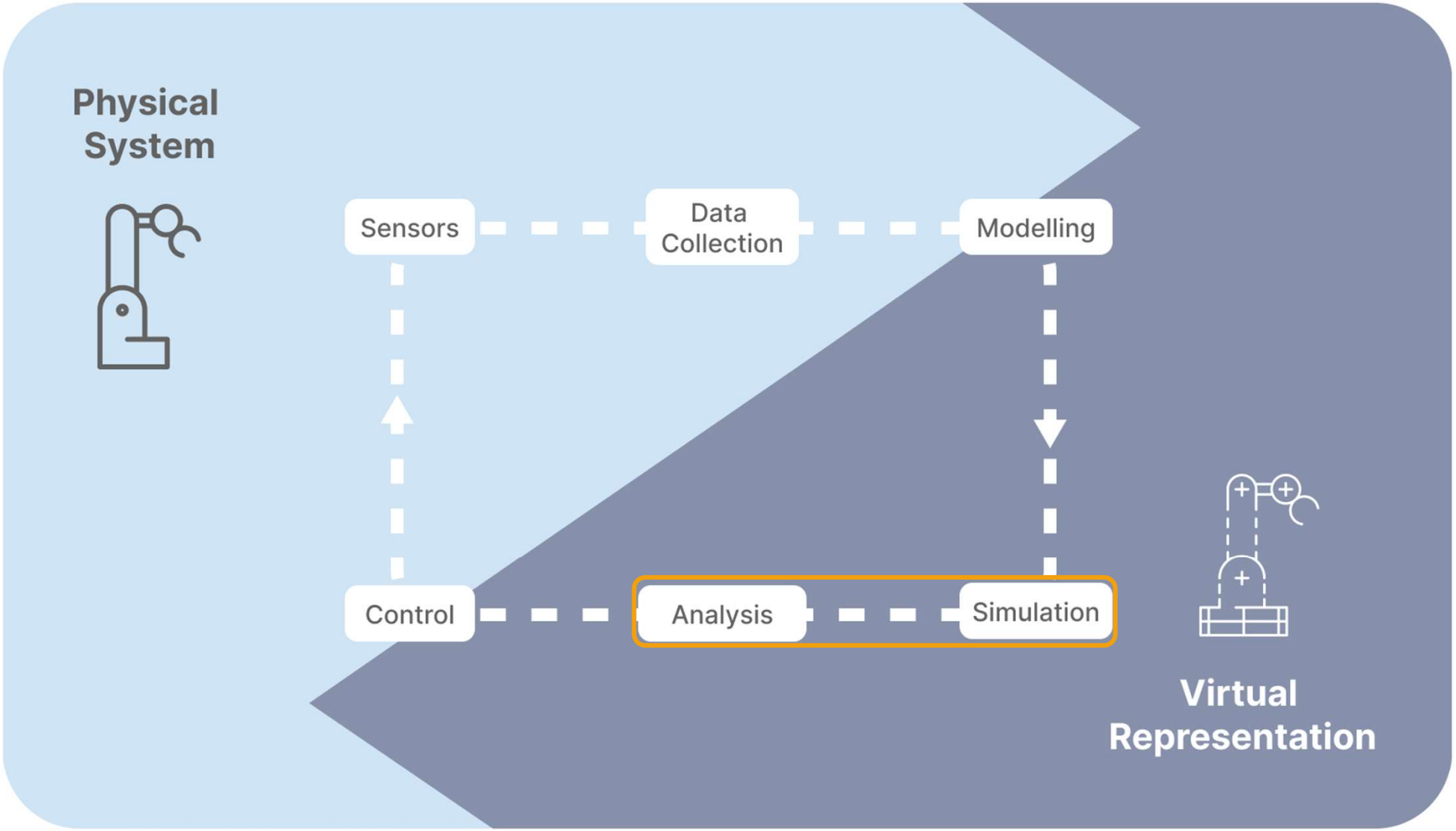
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In the digital twin virtual representation, verification and validation play key roles in building trustworthiness, while uncertainty quantification gives measures of the quality of prediction.

Digital twins require VVUQ to be a continual process that must adapt to changes in the physical counterpart.

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Trustworthy and Ethical Assurance of Digital Twins

1. Scoping research for DT assurance
2. Co-creation of tools and resources
3. Multi-disciplinary and multi-sector community of practice

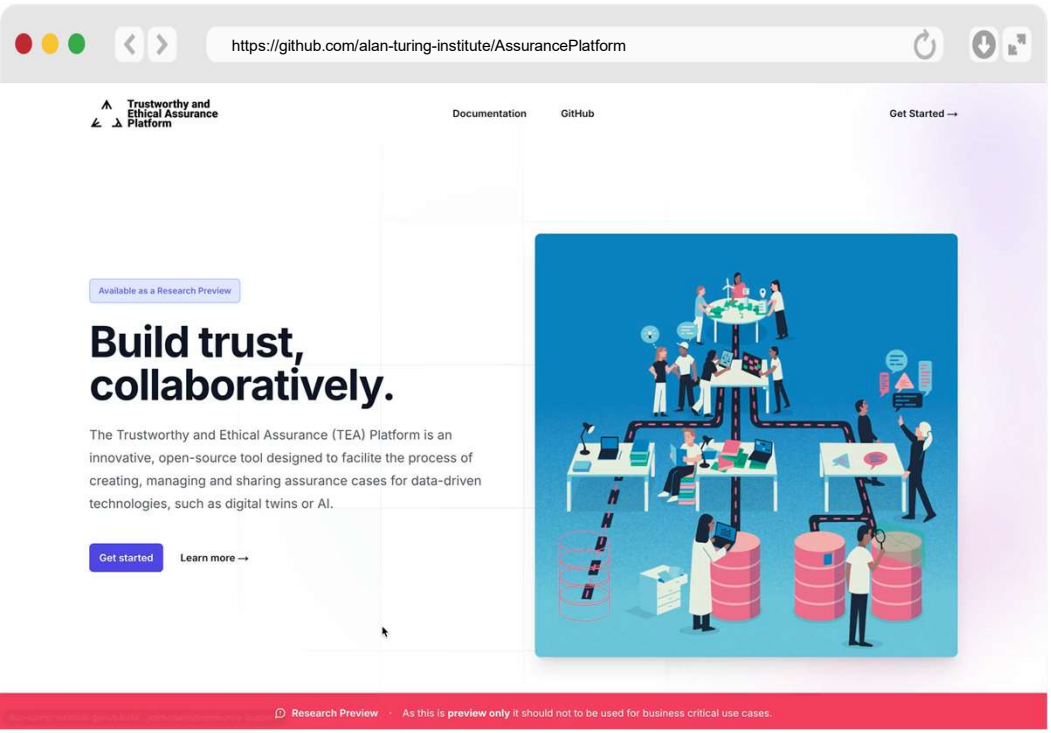
DIGITAL TWIN HUB

CFAA

Responsible Technology Adoption Unit

BRAID
Bridging Responsible AI Divides

UK Research and Innovation



Trustworthy and Ethical Assurance Platform

- Free and open-source software
- Collaborate on structured assurance cases to develop best practices
- Community guidance, feedback, and training
- News about upcoming events and workshops

DIGITAL TWIN HUB

CFAA

Responsible Technology Adoption Unit

BRAID
Bridging Responsible AI Divides

UKRI
UK Research and Innovation

Participatory Assurance

- Identifying and co-creating assurance cases and patterns for shared goals (e.g. interoperability, data quality)
- Making resources and tools open and freely available
- Convening domain experts and organisations (e.g. standards bodies)

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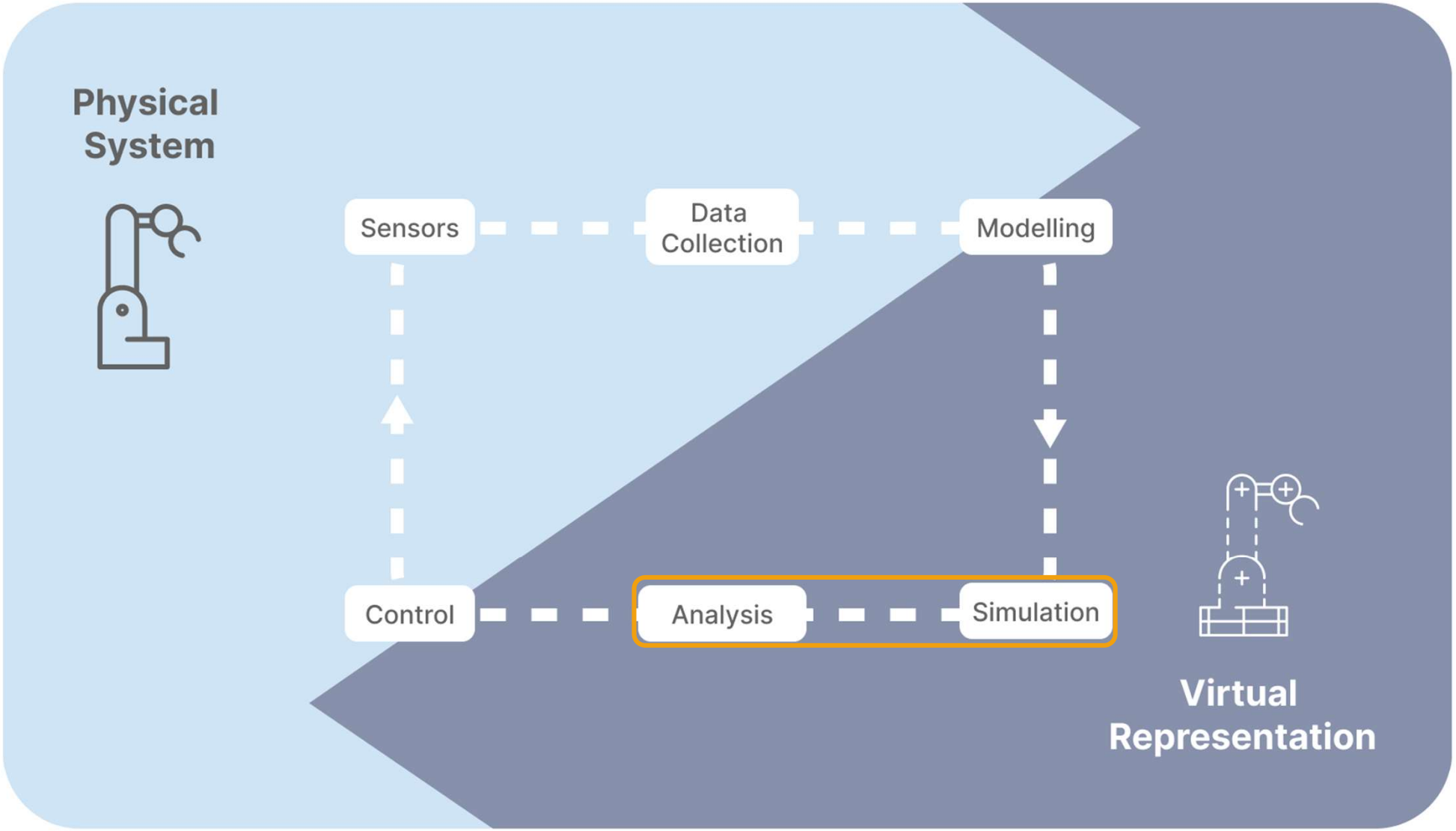
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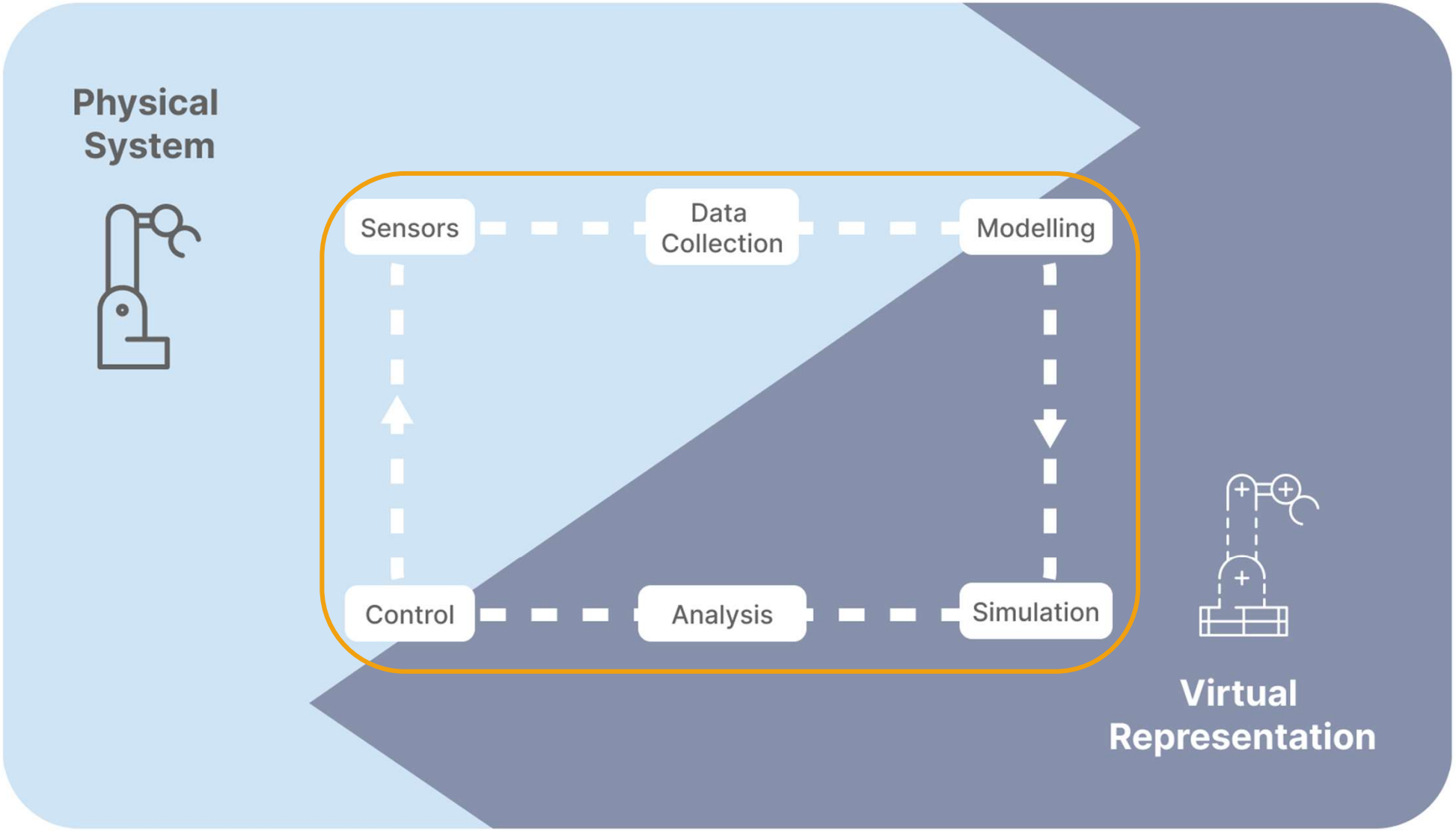
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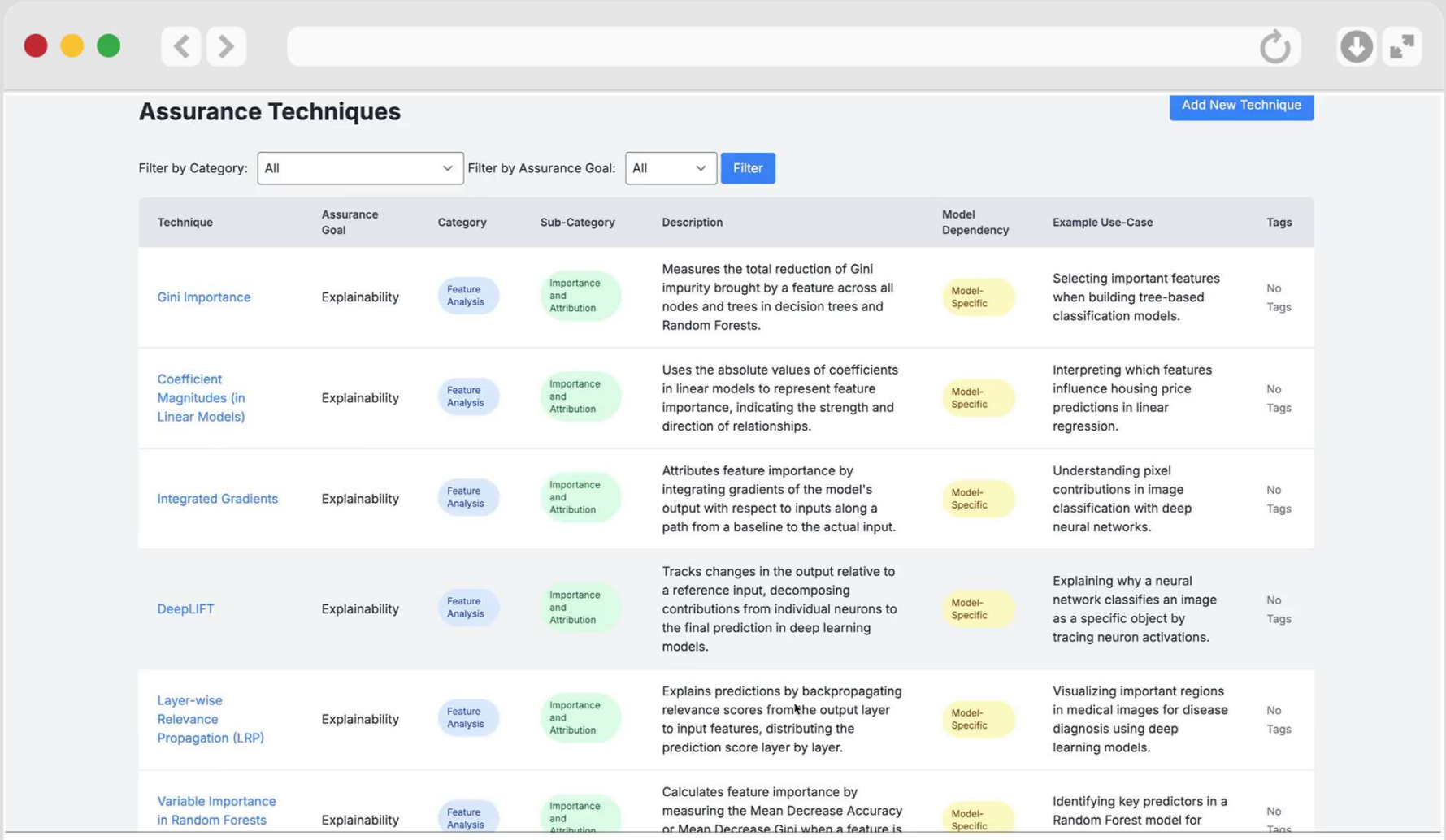
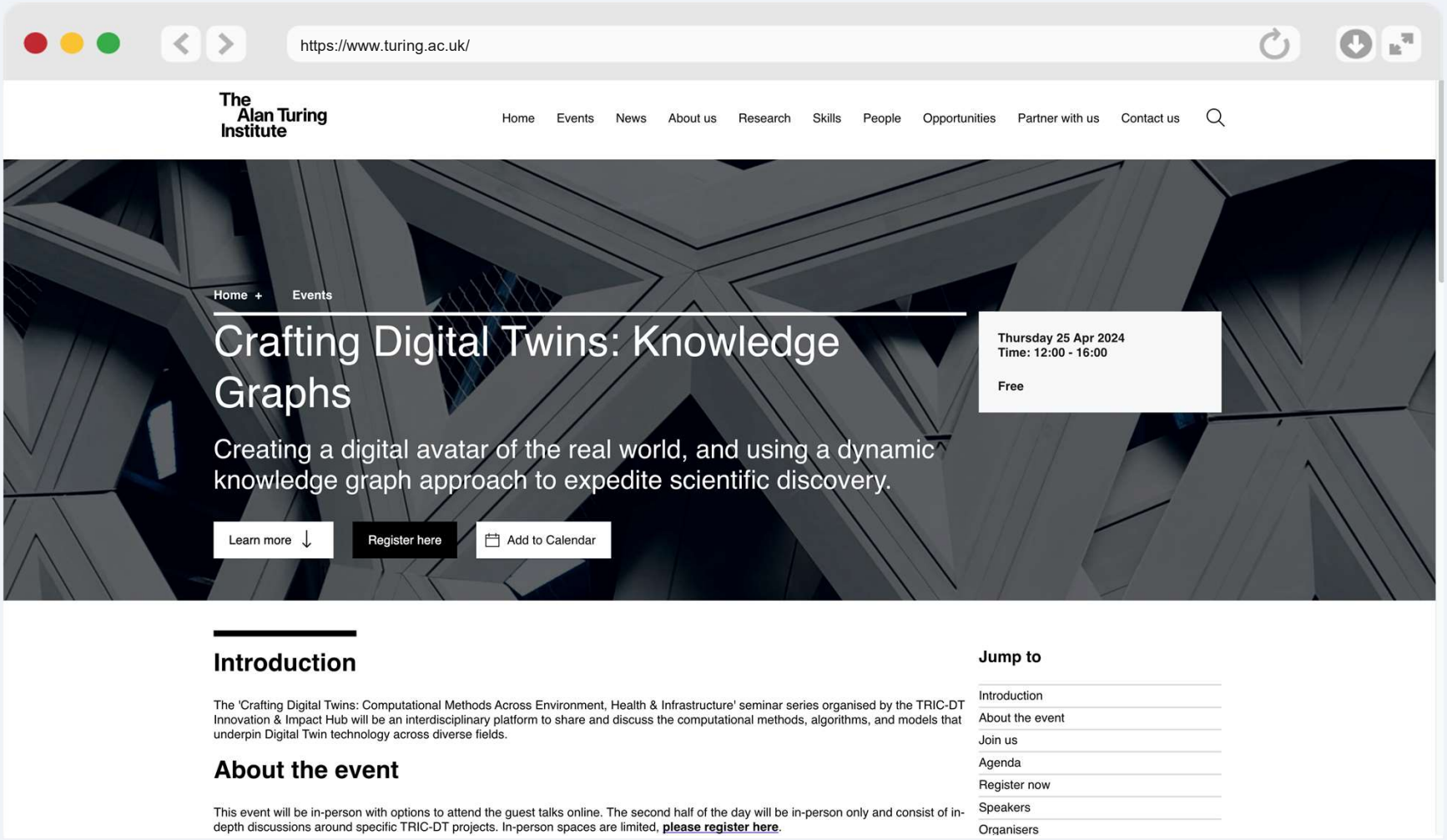

Assurance Techniques
Add New Technique
Filter by Category: All
Filter by Assurance Goal: All
Filter
Technique
Assurance Goal
Category
Sub-Category
Description
Model Dependency
Example Use-Case
Tags
Gini Importance
Explainability
Feature Analysis
Importance and Attribution
Measures the total reduction of Gini impurity brought by a feature across all nodes and trees in decision trees and Random Forests.
Model-Specific
Selecting important features when building tree-based classification models.
No Tags
Coefficient Magnitudes (in Linear Models)
Explainability
Feature Analysis
Importance and Attribution
Uses the absolute values of coefficients in linear models to represent feature importance, indicating the strength and direction of relationships.
Model-Specific
Interpreting which features influence housing price predictions in linear regression.
No Tags
Integrated Gradients
Explainability
Feature Analysis
Importance and Attribution
Attributes feature importance by integrating gradients of the model's output with respect to inputs along a path from a baseline to the actual input.
Model-Specific
Understanding pixel contributions in image classification with deep neural networks.
No Tags
DeepLIFT
Explainability
Feature Analysis
Importance and Attribution
Tracks changes in the output relative to a reference input, decomposing contributions from individual neurons to the final prediction in deep learning models.
Model-Specific
Explaining why a neural network classifies an image as a specific object by tracing neuron activations.
No Tags
Layer-wise Relevance Propagation (LRP)
Explainability
Feature Analysis
Importance and Attribution
Explains predictions by backpropagating relevance scores from the output layer to input features, distributing the prediction score layer by layer.
Model-Specific
Visualizing important regions in medical images for disease diagnosis using deep learning models.
No Tags
Variable Importance in Random Forests
Explainability
Feature Analysis
Importance and Attribution
Calculates feature importance by measuring the Mean Decrease Accuracy or Mean Decrease Gini when a feature is
Model-Specific
Identifying key predictors in a Random Forest model for
No Tags

How to get involved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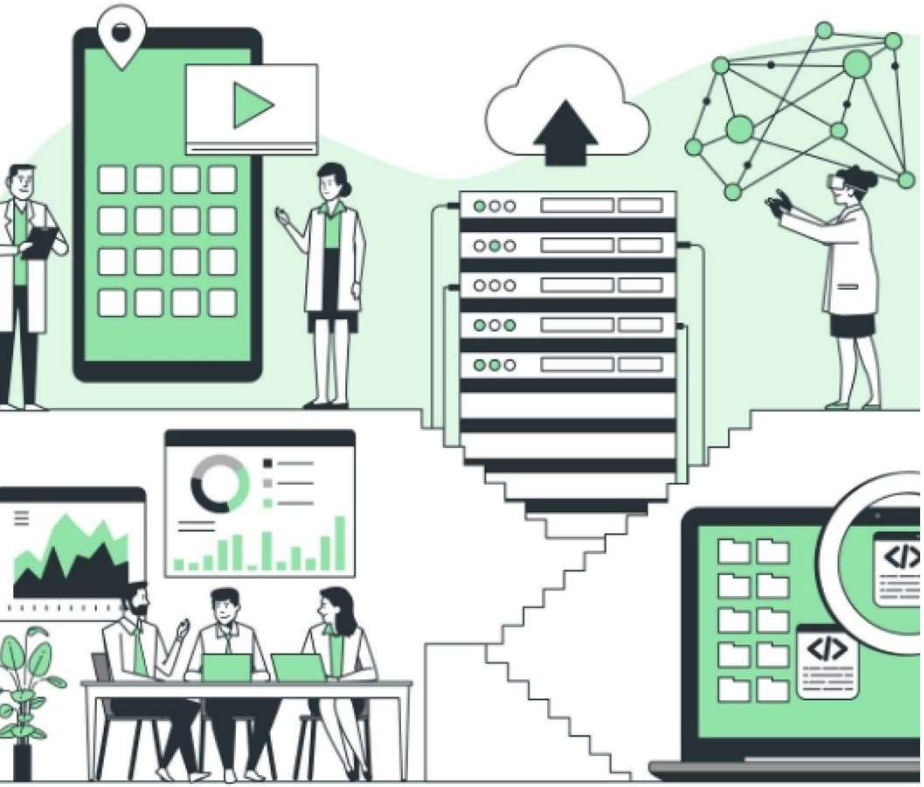
Crafting Digital Twins: Knowledge Graphs
Creating a digital avatar of the real world, and using a dynamic knowledge graph approach to expedite scientific discovery.
Learn more
Register here
Add to Calendar
Thursday 25 Apr 2024
Time: 12:00 - 16:00
Free
Introduction
The 'Crafting Digital Twins: Computational Methods Across Environment, Health & Infrastructure' seminar series organised by the TRIC-DT Innovation & Impact Hub will be an interdisciplinary platform to share and discuss the computational methods, algorithms, and models that underpin Digital Twin technology across diverse fields.
About the event
This event will be in-person with options to attend the guest talks online. The second half of the day will be in-person only and consist of in-depth discussions around specific TRIC-DT projects. In-person spaces are limited, please register here.
Jump to
Introduction
About the event
Join us
Agenda
Register now
Speakers
Organisers



DTNet+

1. UKRI funded, UK-wide inter-disciplinary research network, hosted by the Alan Turing Institute.
2. Designed to facilitate research advancements that will contribute to the next generation of intelligent, resilient, and trusted digital twins.
3. News and events (including funding opportunities) on website (dtnetplus.ac.uk) and mailing list.

UKRI Engineering and Physical Sciences Research Council

Ulster University

CATAPULT High Value Manufacturing

University of Exeter

DTNet+

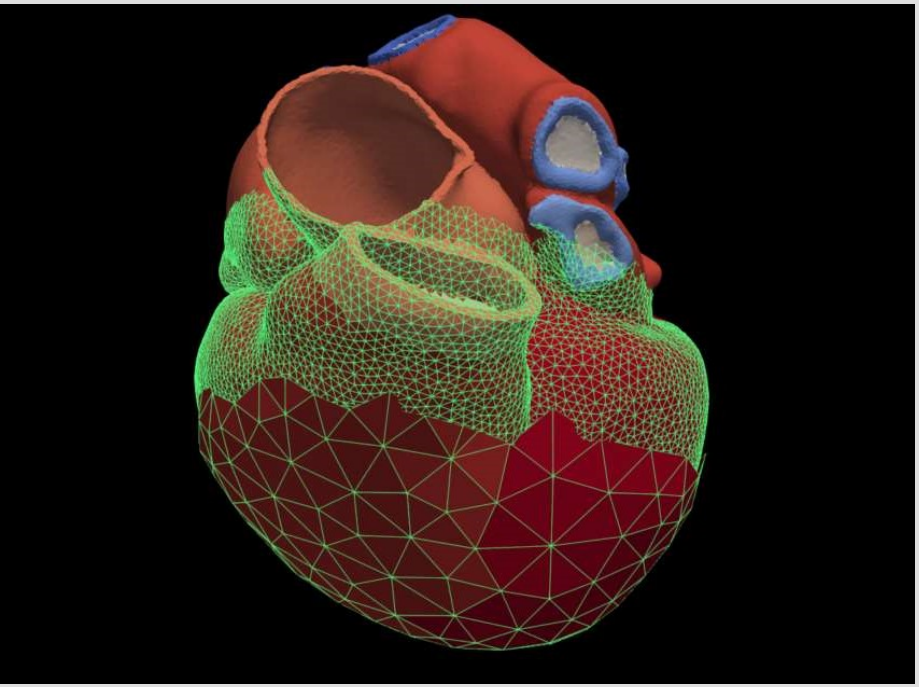
- Uncertainty and Trust
- Scaling of DTs
- Design and Implementation
- Societal Impacts
- Health
- Languages, Logic, and Ontologies
- Human Interaction and Representation
- Resilience and Security

UKRI Engineering and Physical Sciences Research Council

Ulster University

CATAPULT High Value Manufacturing

University of Exeter



CVD-Net

- £8million EPSRC project
- Personalised digital twins for patients with pulmonary arterial hypertension
- WP6 focused on assurance and PPIE
- Focused case studies

Thanks for listening

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