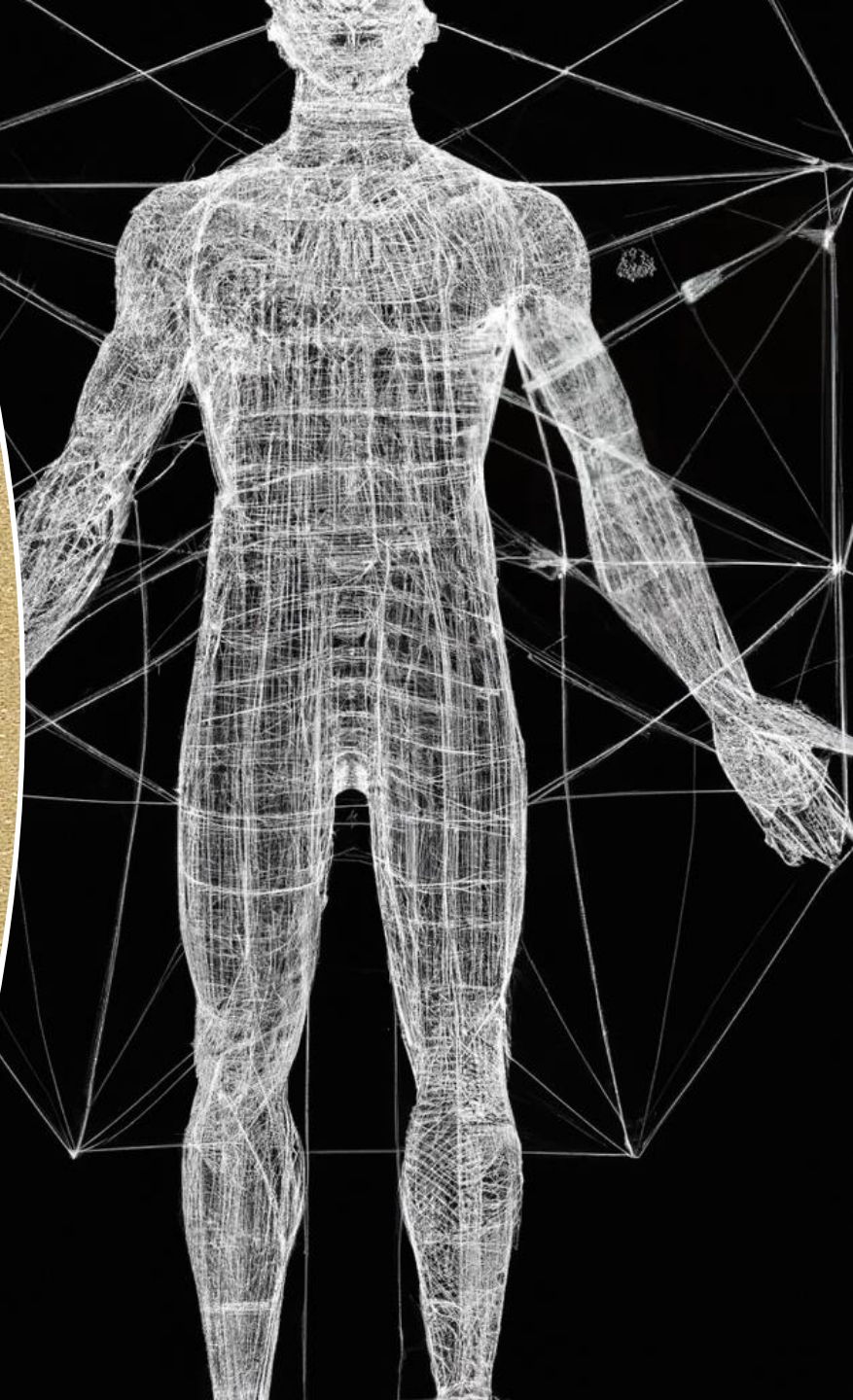
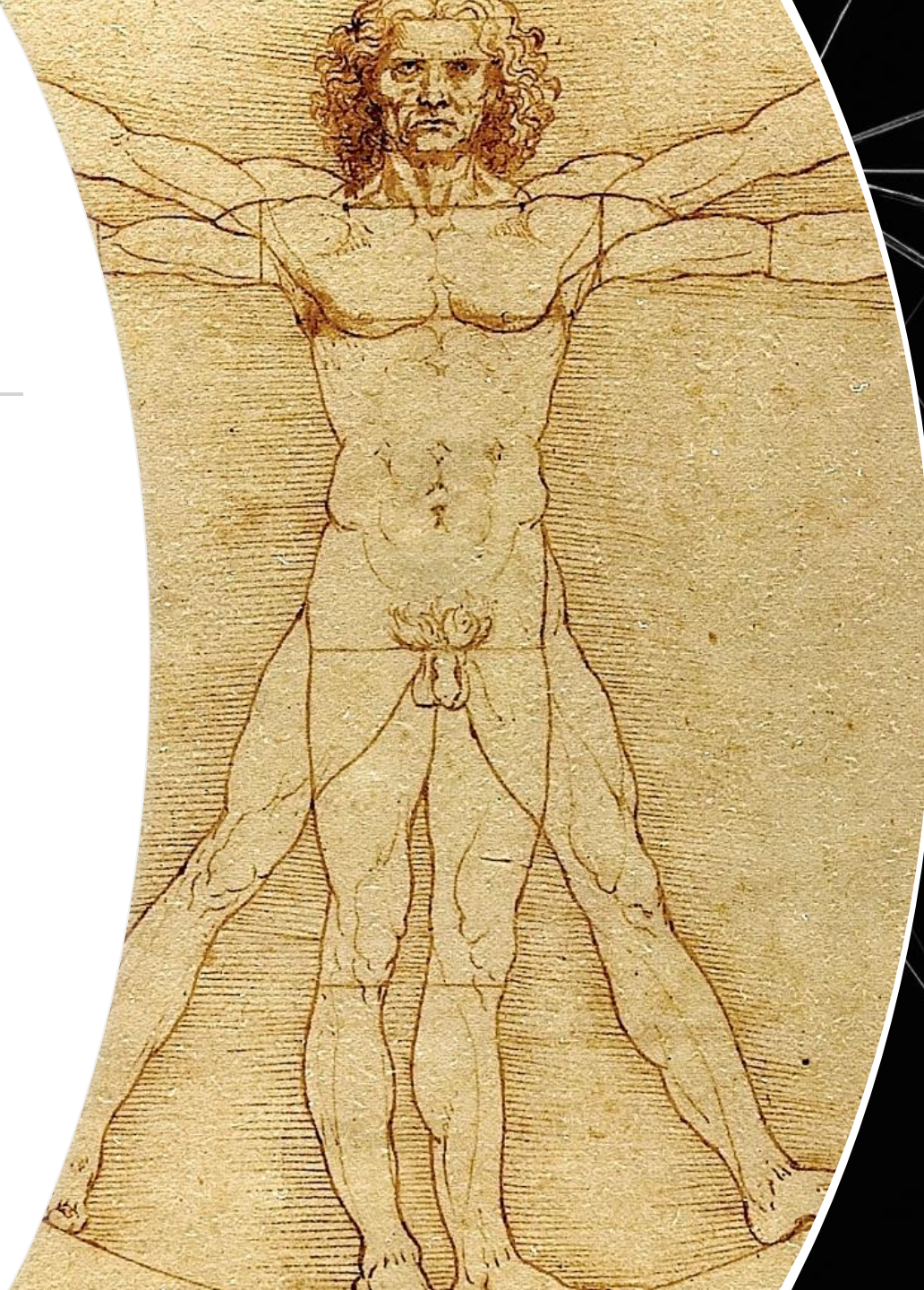
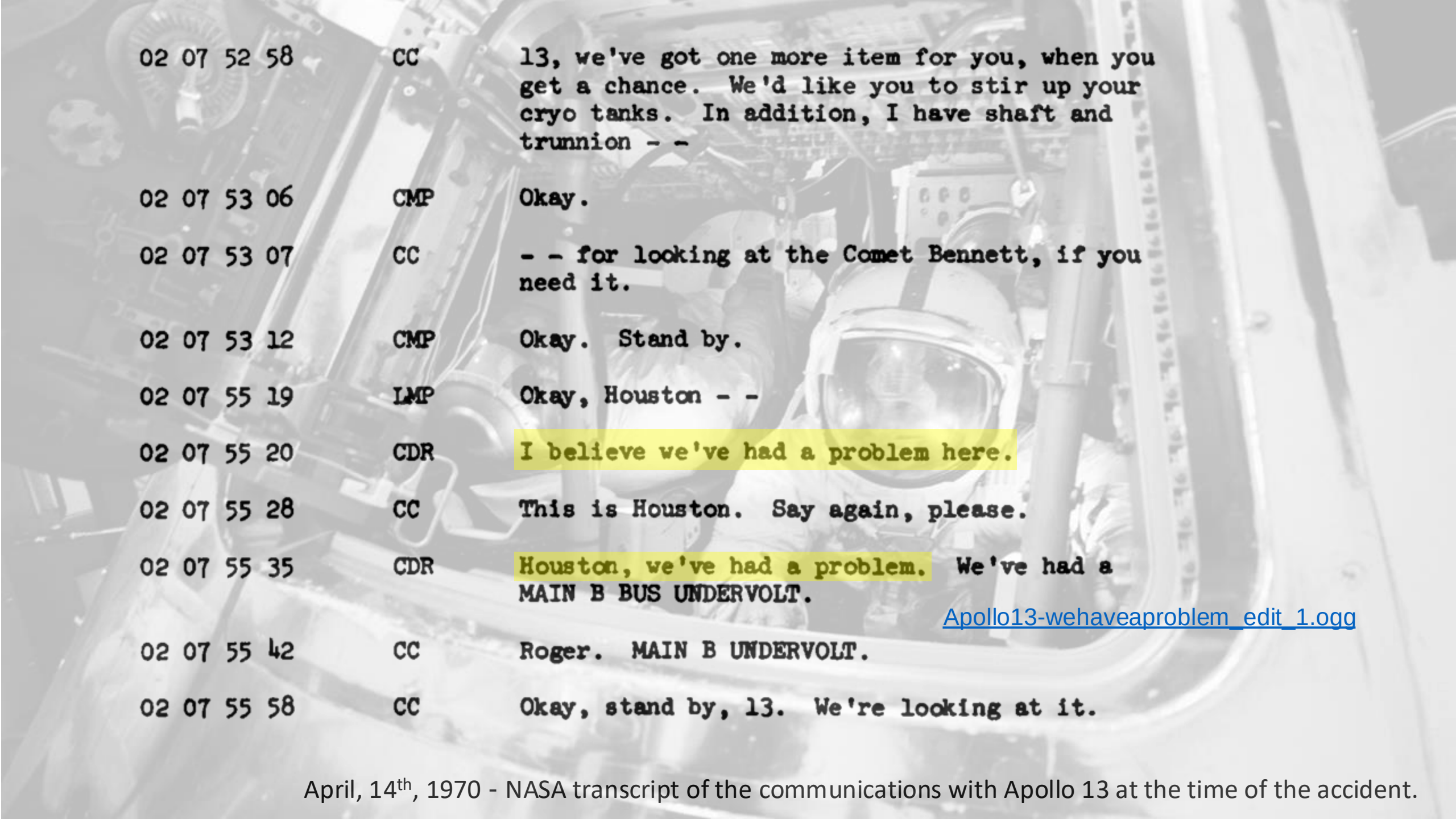


Digital Twins

Benoît Gallix

Strasbourg University
Inria, Paris
American Hospital, Paris
McGill University, Montreal





02 07 52 58 CC 13, we've got one more item for you, when you get a chance. We'd like you to stir up your cryo tanks. In addition, I have shaft and trunnion - -

02 07 53 06 CMP Okay.

02 07 53 07 CC - - for looking at the Comet Bennett, if you need it.

02 07 53 12 CMP Okay. Stand by.

02 07 55 19 LMP Okay, Houston - -

02 07 55 20 CDR **I believe we've had a problem here.**

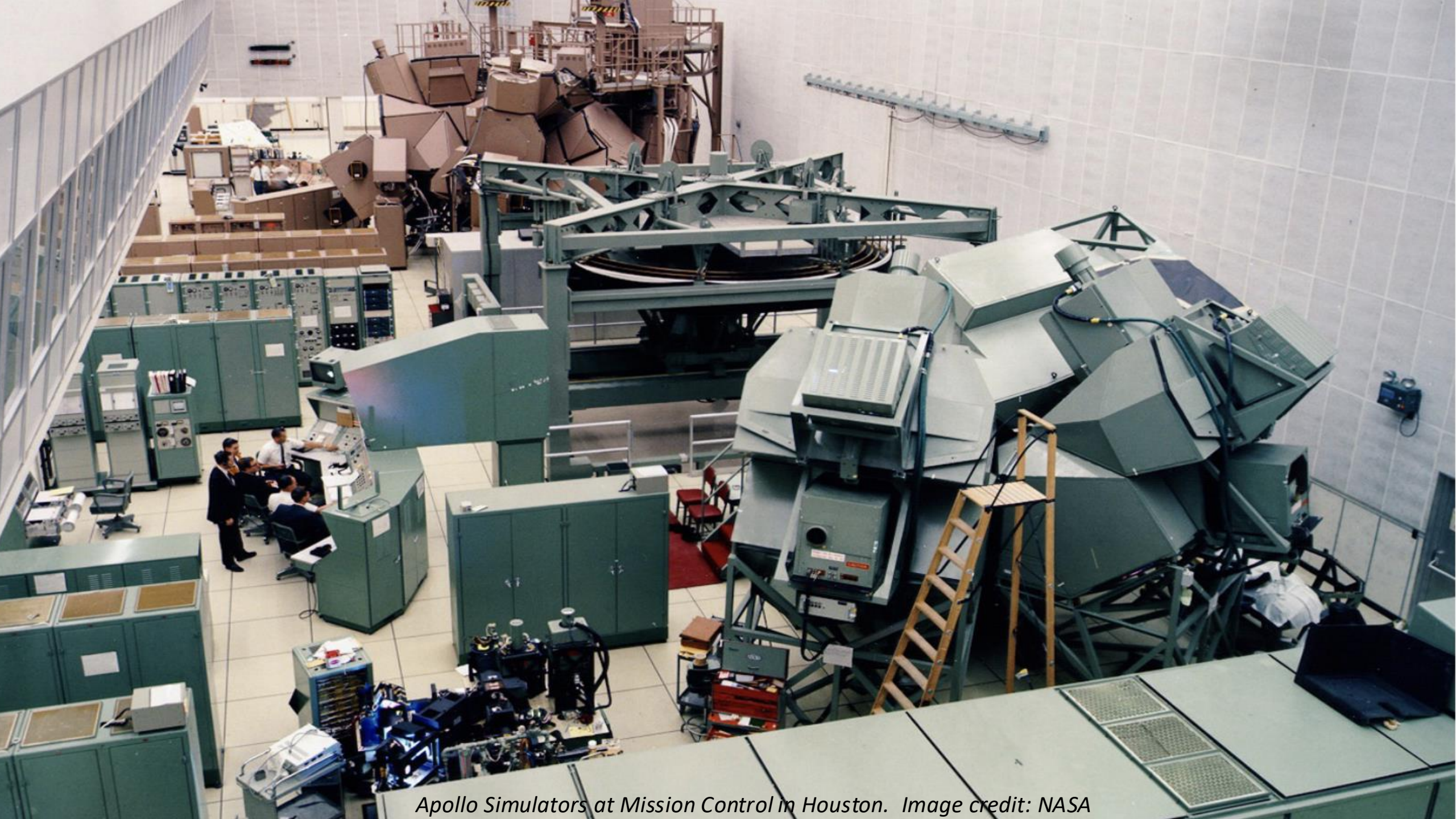
02 07 55 28 CC This is Houston. Say again, please.

02 07 55 35 CDR **Houston, we've had a problem. We've had a MAIN B BUS UNDERVOLT.**

02 07 55 42 CC Roger. MAIN B UNDERVOLT.

02 07 55 58 CC Okay, stand by, 13. We're looking at it.

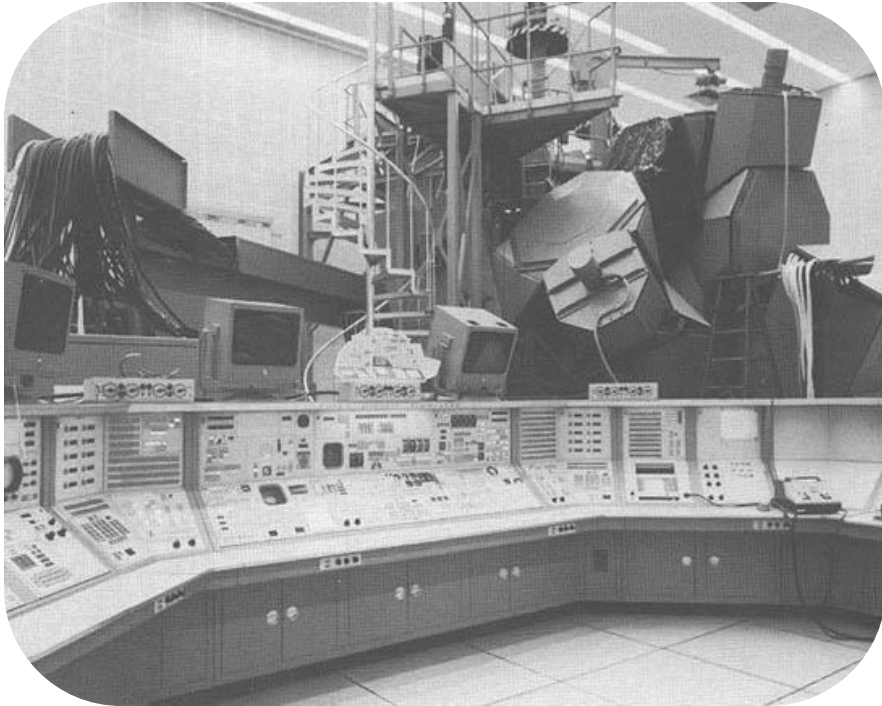
[Apollo13-wehaveaproblem_edit_1.ogg](#)



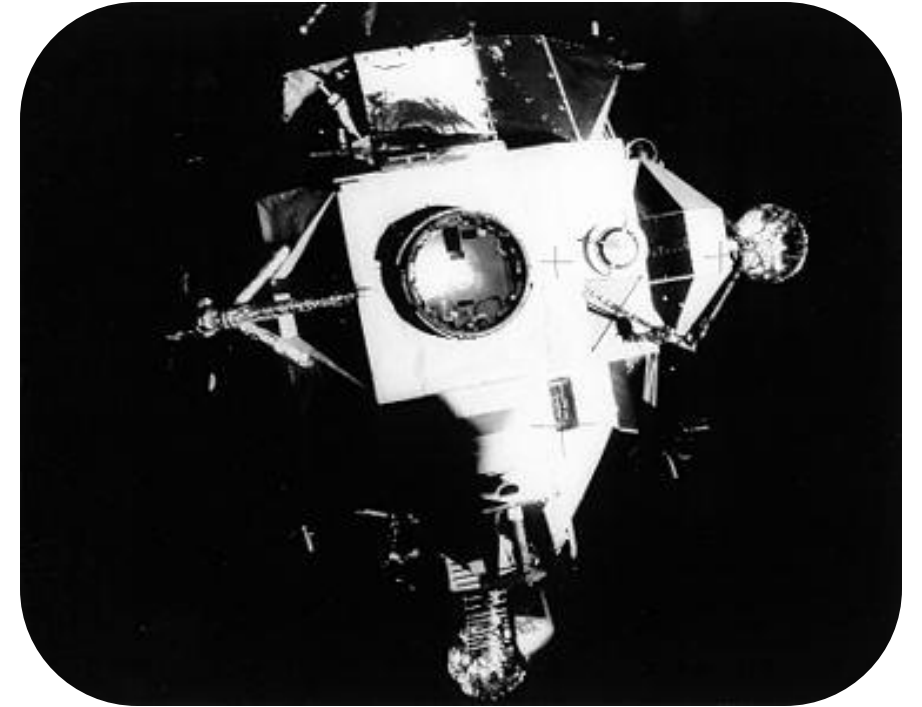
Apollo Simulators at Mission Control in Houston. Image credit: NASA

Apollo 13 Mission

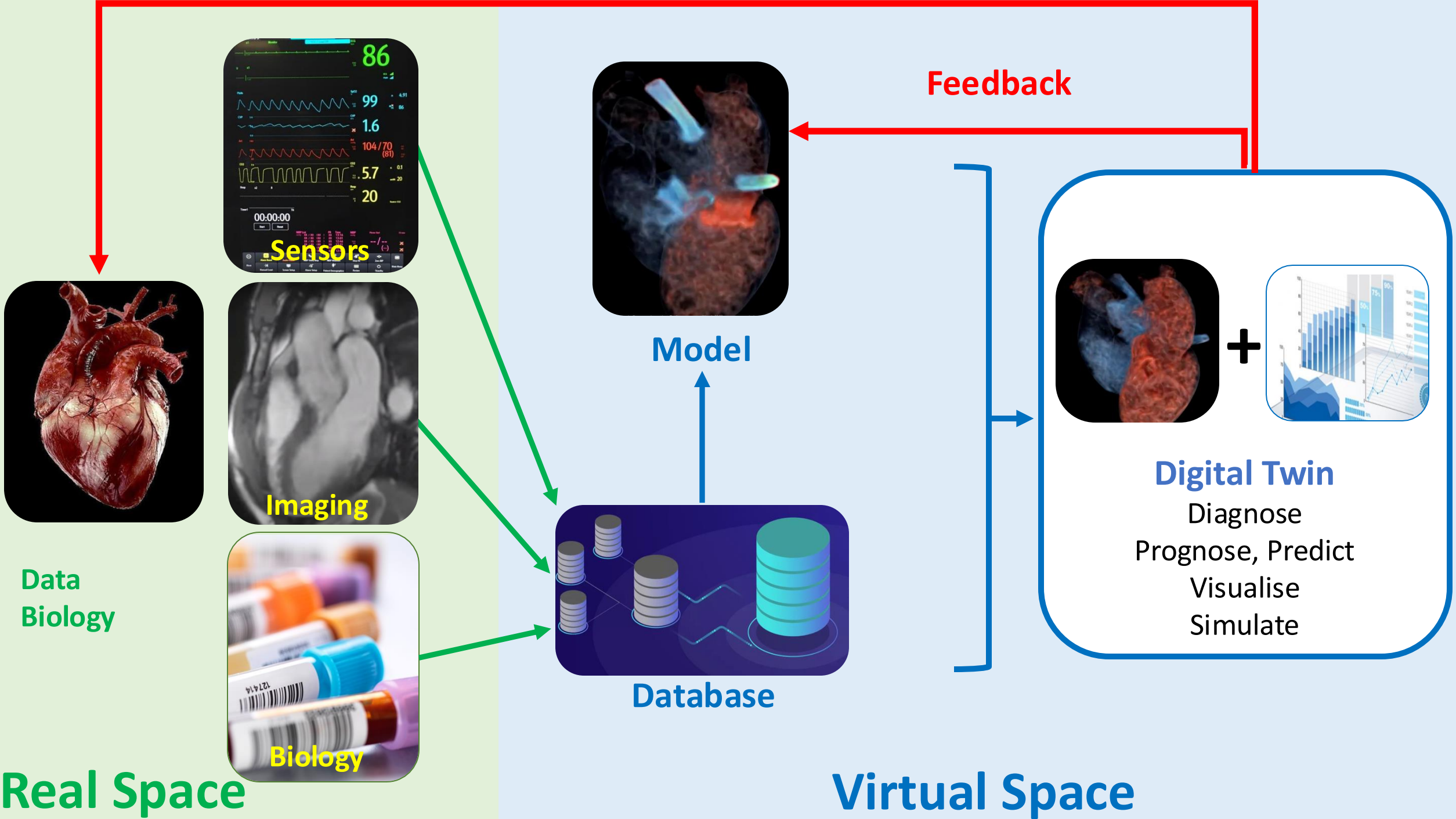
Action plan & orders



INACCESSIBILITY
CONNECTED
ADAPTABLE
NETWORK of MODELS
RESPONSIVE



Information from crew
Radio transmitted measurement



A Concept from the Industry

*Digital twins are an evolution,
more than a revolution,
combining mathematical
modelling and digital
simulation.*

Digital Twin can replicate:

- **an object**
an engine or an organ
- **a system**
a nuclear power plant or a hospital
- **an abstract process**
a production schedule or a therapeutic plan



Model Design

Data Driven

Domain Knowledge

Domain Knowledge approach

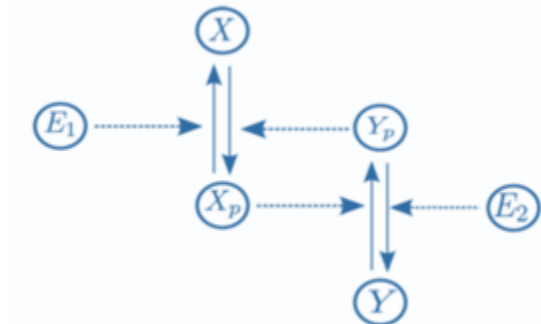
Scientific approach

Failure mechanism understood (explainability)

Small set of data required to extract model

Models mostly interpretable and transferable

Mechanisms need to be understood



Data driven approach

Fitting data set (know nothing approach)

Limited failure mechanism understanding

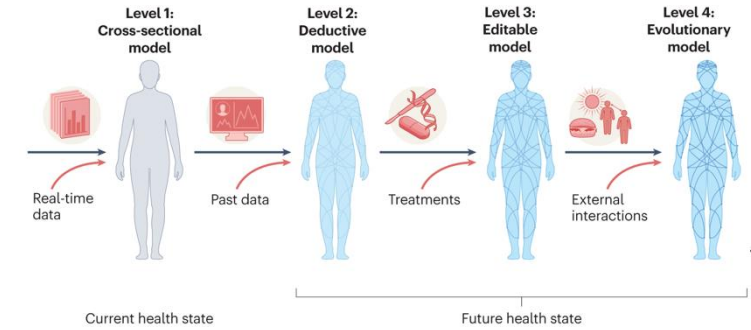
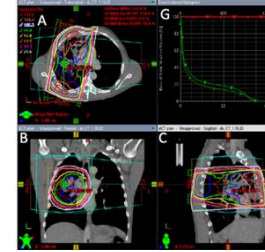
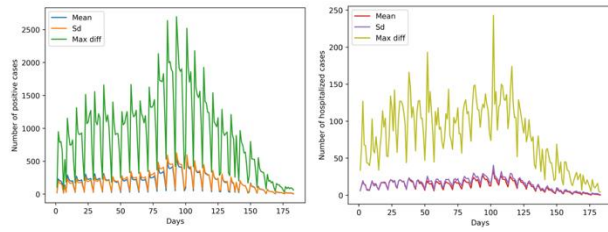
Large set of data required to extract model

Models often neither interpretable nor transferable

Models cheap to learn



Hybrid

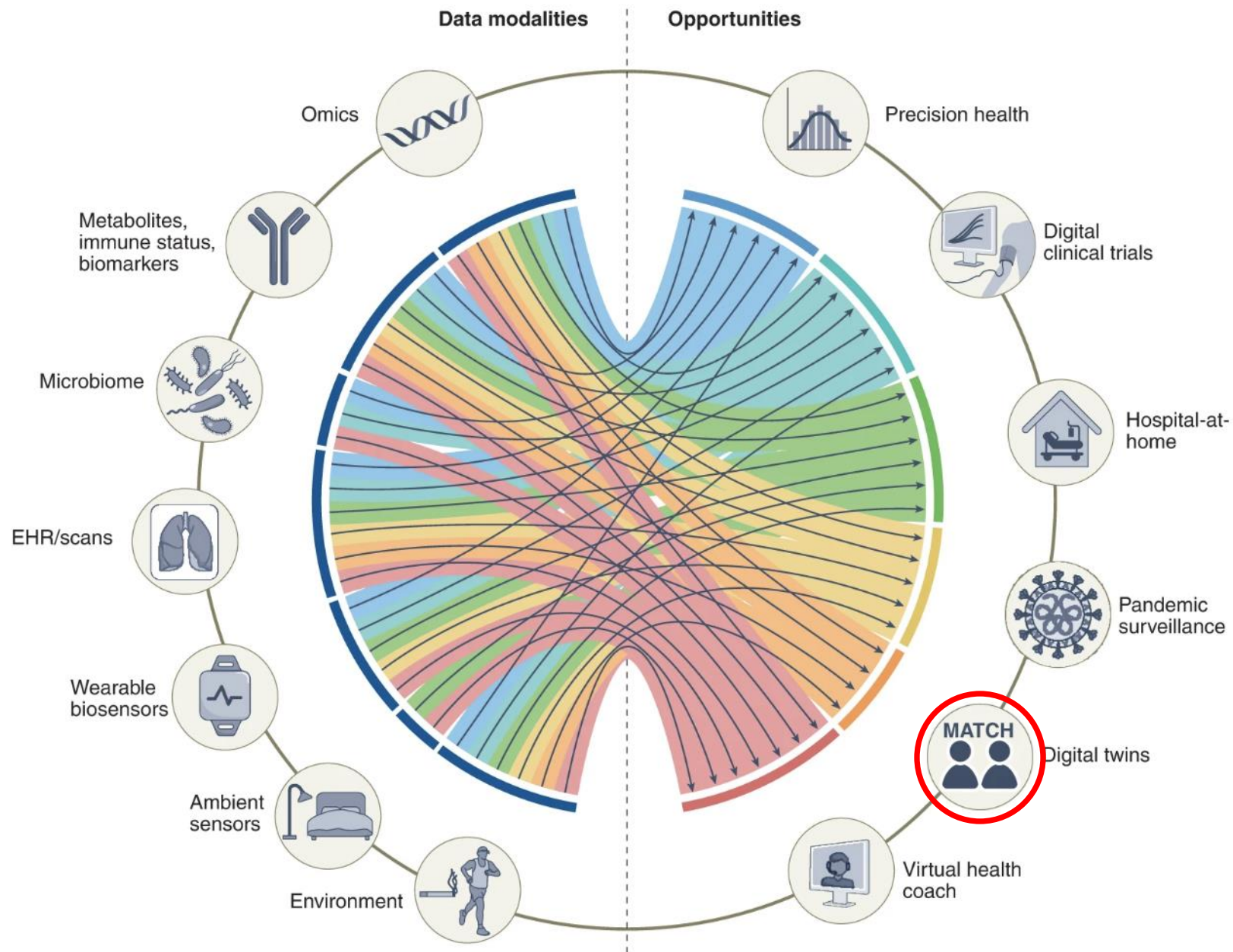


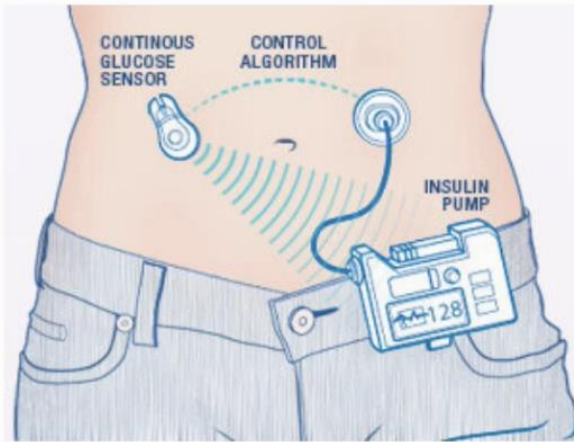
Feature/Characteristic	Numerical Model	Simulator	Digital Twin
Definition	Mathematical representation of a system/process.	Tool to imitate system behavior under specific conditions.	Virtual replica of a physical system, synchronized with real-time data.
Real-Time Interaction	No	Typically no	Yes, continuous synchronization.
Data Exchange	No	Limited, one-way	Two-way, dynamic.
Purpose	Theoretical analysis and understanding.	Scenario testing, training, and predictive modeling.	Monitoring, simulation, and real-time optimization.
Development Approach	Based on equations and physical laws.	Combines models with predefined scenarios.	Uses IoT, AI, machine learning, and real-time data integration.
Dynamic Updates	No	Limited to initial setup. Standard or case based	Yes, evolves with real-world changes.
Applications	Academic research, engineering design.	Training, operational planning.	Personalized medicine, predictive maintenance,

Digital Twins

“A digital twin is an integrated multi-physics, multi-scale, probabilistic simulation of a complex object and uses the best available physical models, sensor updates, etc., to mirror the life of its corresponding twin...

According to the Digital Twin Consortium, a digital twin is “a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity.”



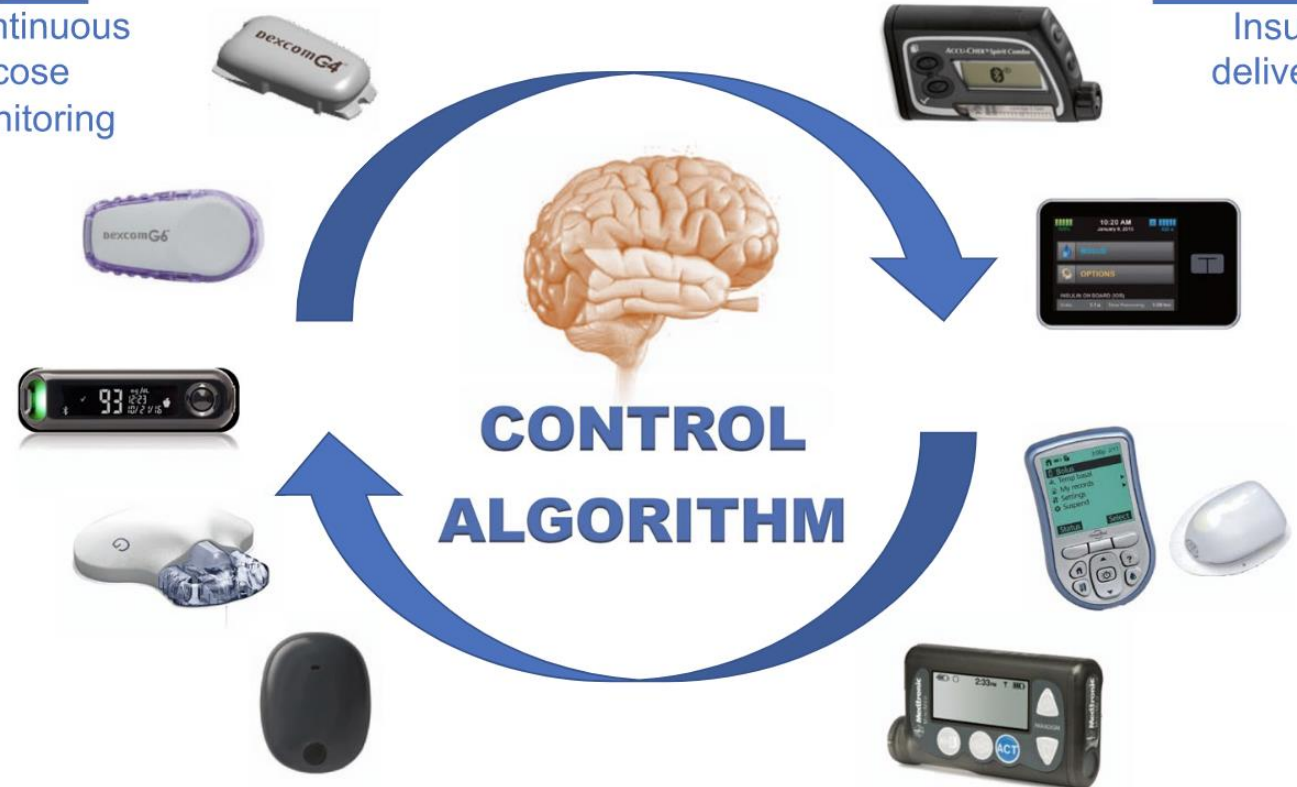


The artificial pancreas
(Kovatchev, 2019)

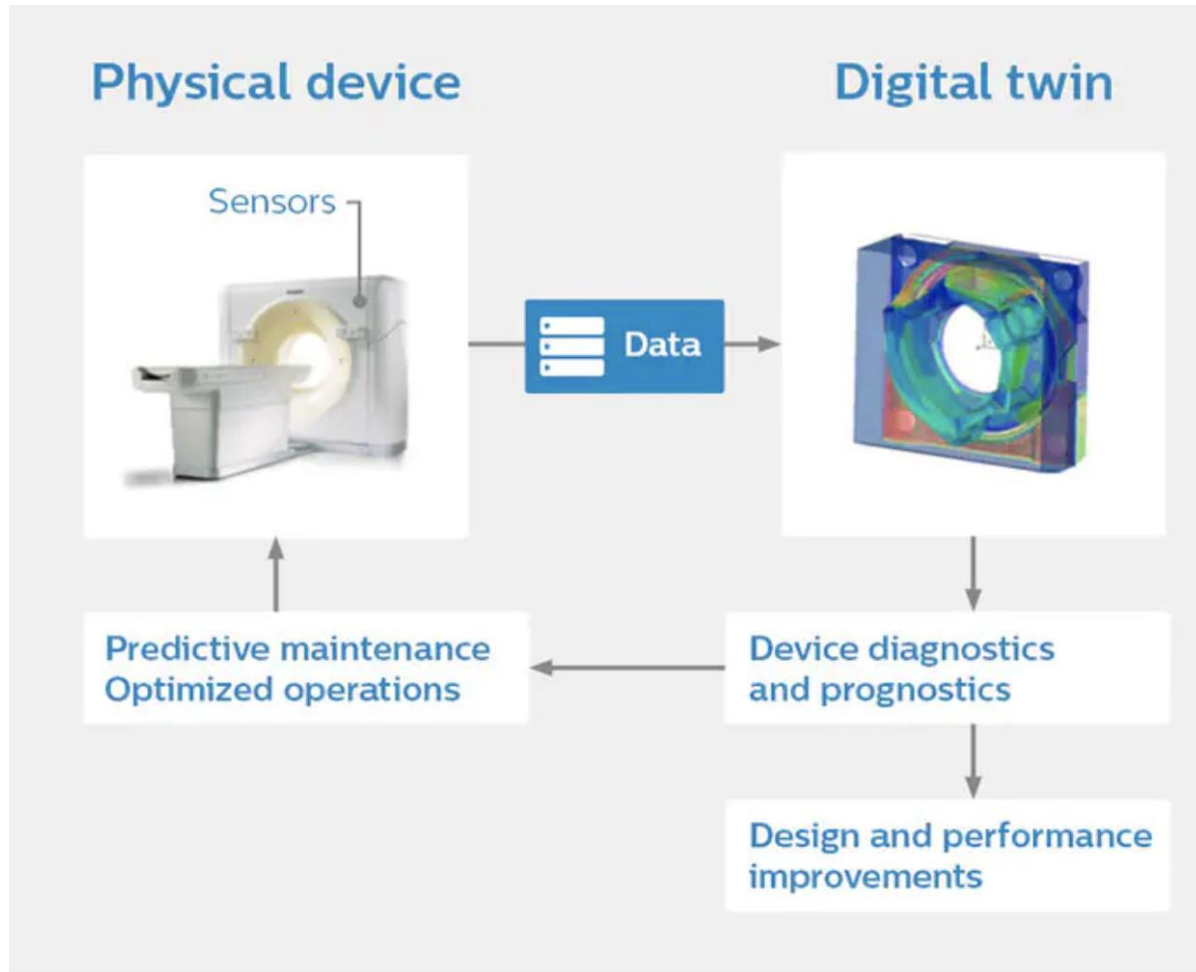
- Real-time signals monitoring
- Automated insulin delivery
- Control algorithms are capable of optimising blood glucose fluctuation

Signals:
Continuous
glucose
monitoring

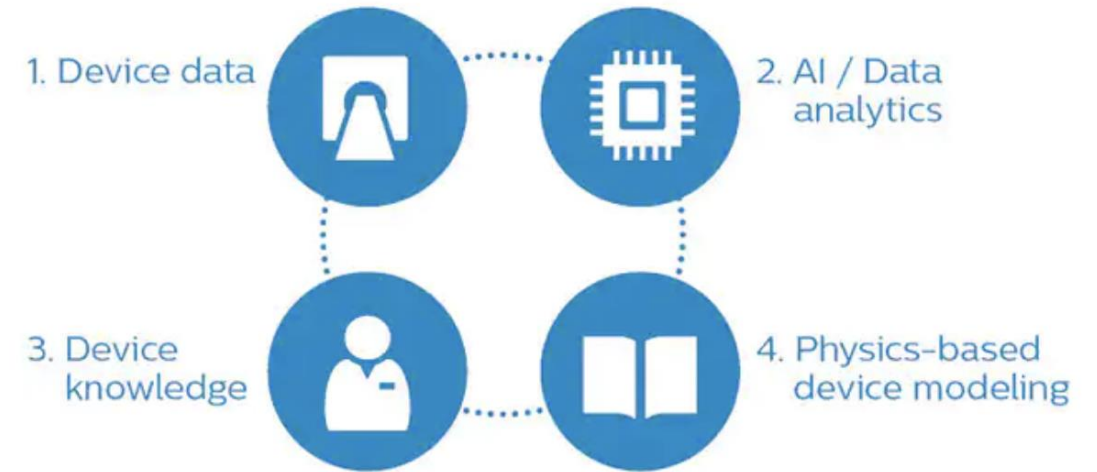
Actuators:
Insulin
delivery



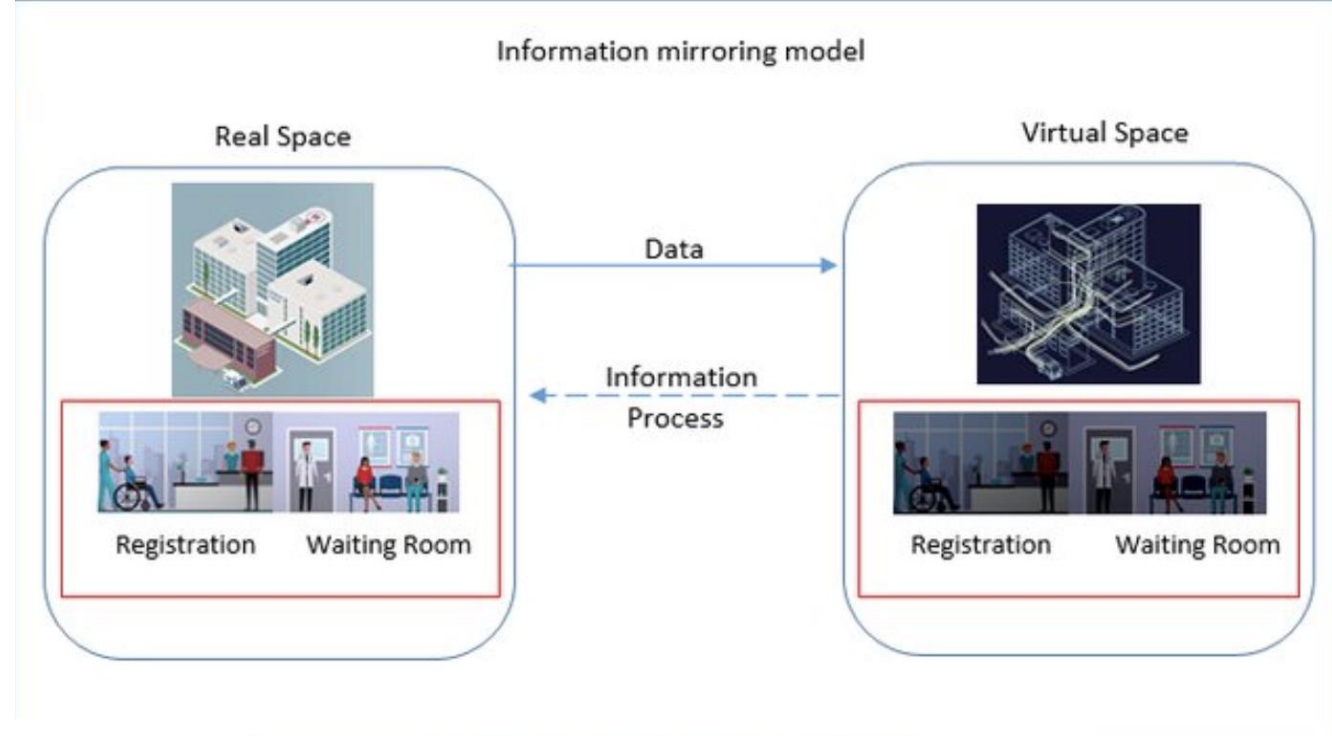
Digital Twin of a Medical Device



The four components of a digital twin of a device



Digital Twin of an Hospital



GE Healthcare

- Provides a solution to test changes in operating strategies, capabilities, staffing, and treatment delivery models by virtualizing the medical environment (hospital) using the digital twin function



Digital Twin for drug development

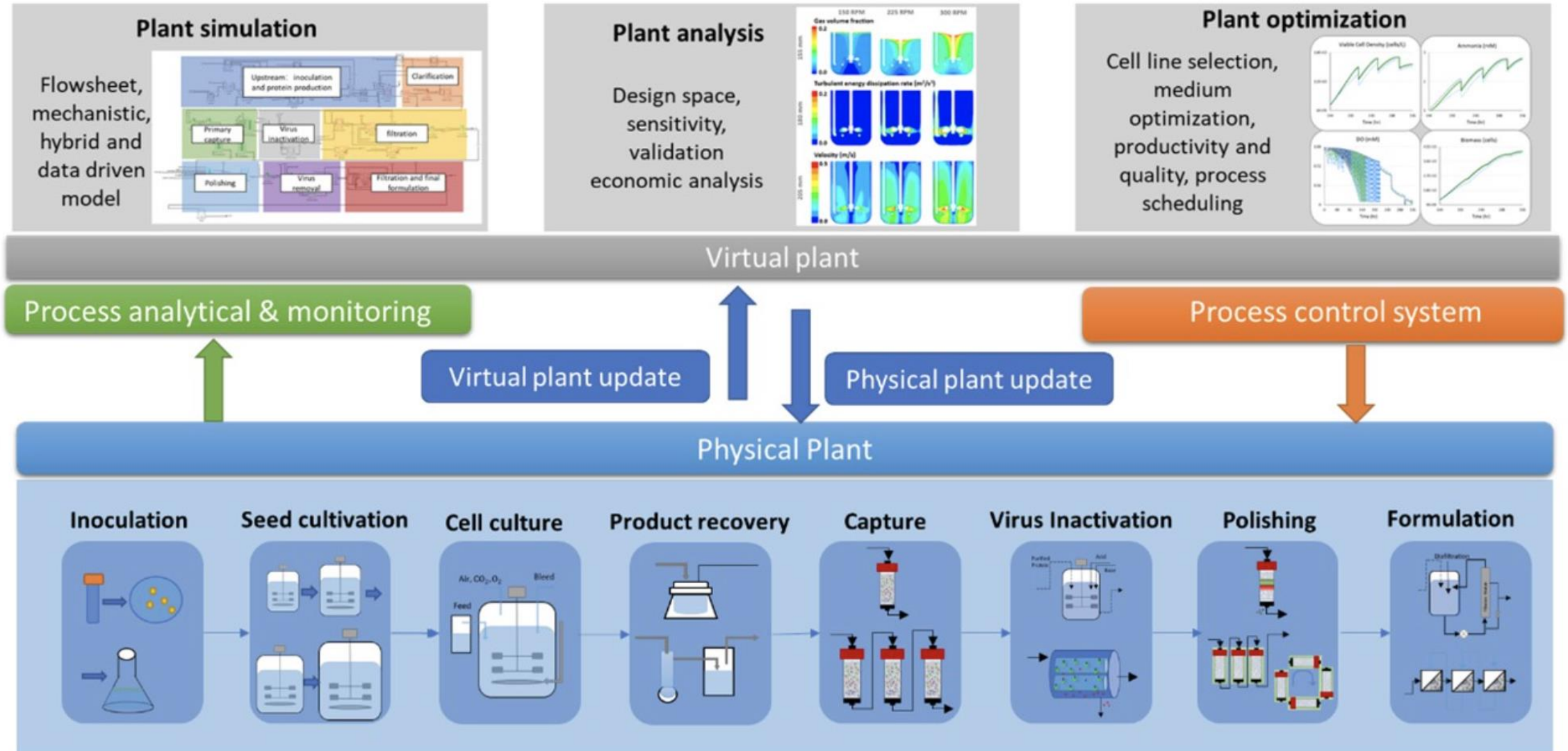
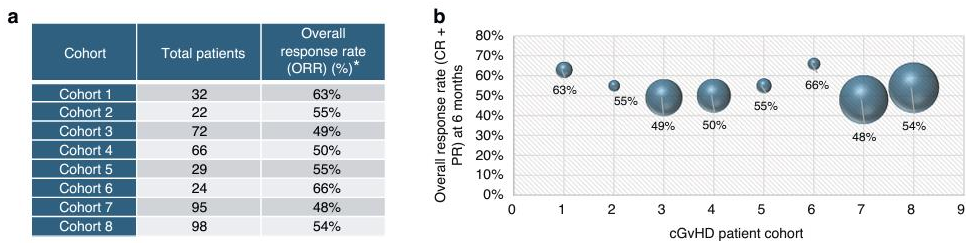


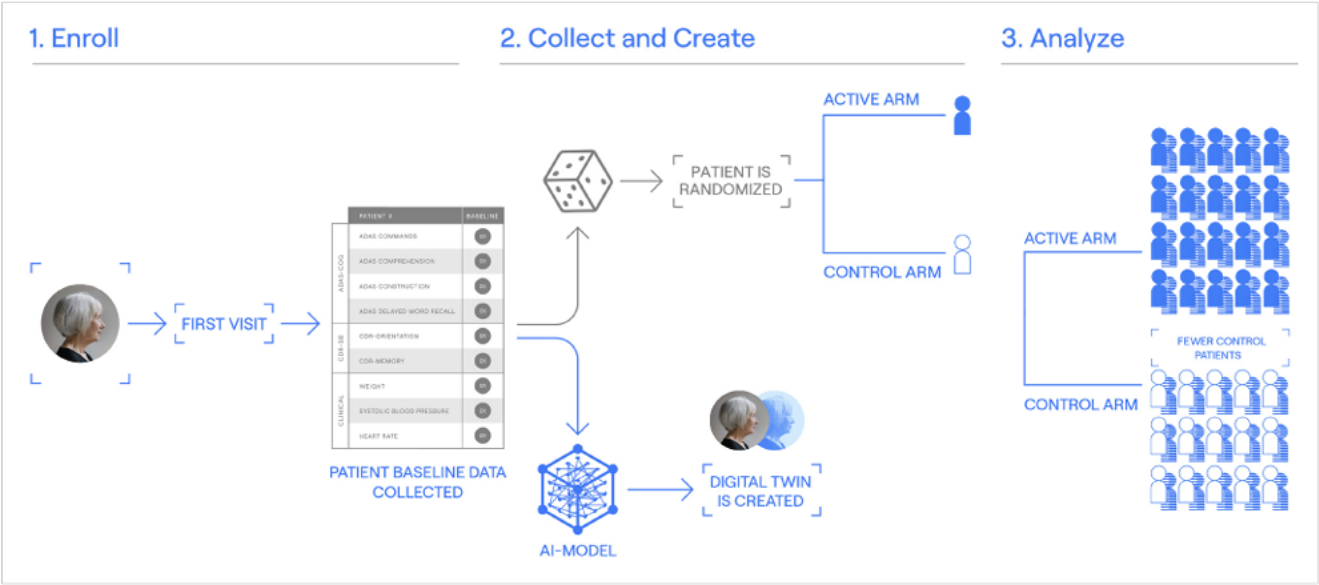
Figure 4. Biopharma process, benefits, and DT connections.

Construction of a digital twin of chronic graft vs. host disease patients with standard of care

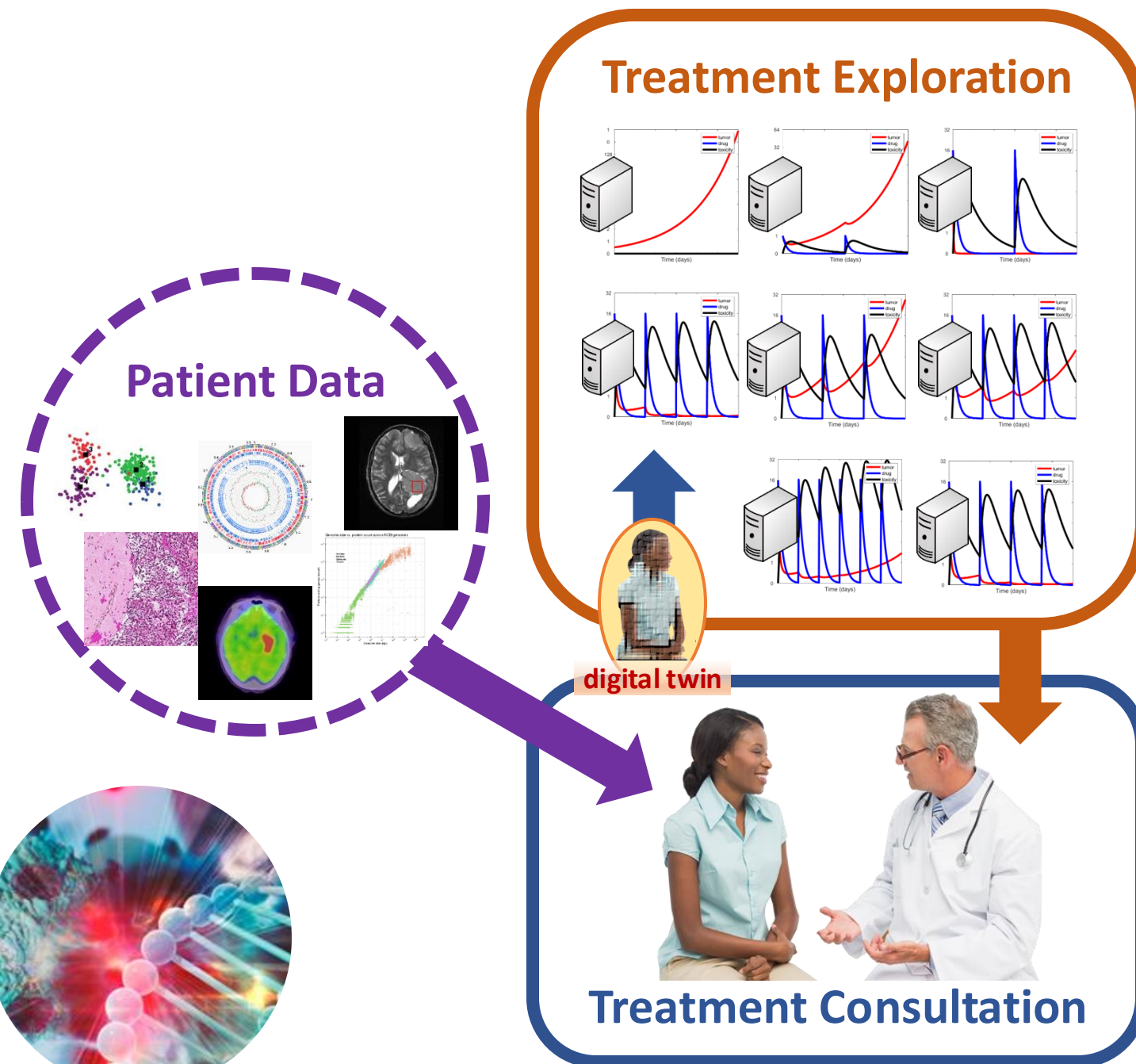
Gen Li¹, Yi-Bin Chen² and Jonathan Peachey¹



^{*}The ORR values of the cohorts were compared using the Chi-square test of independence. The Chi-square value for testing the null hypothesis (ORR values are not different among the cohorts) was 4.66, with *P*-value = 0.7012, showing that the ORR values of the cohorts were not significantly different.



AI-driven clinical trials have the potential to achieve higher power with fewer subjects, to provide actionable insights into which patients achieve the greatest benefit, and to design faster, more efficient clinical trials — all while ensuring reliable evidence about safety and efficacy.

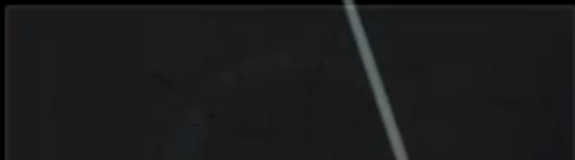


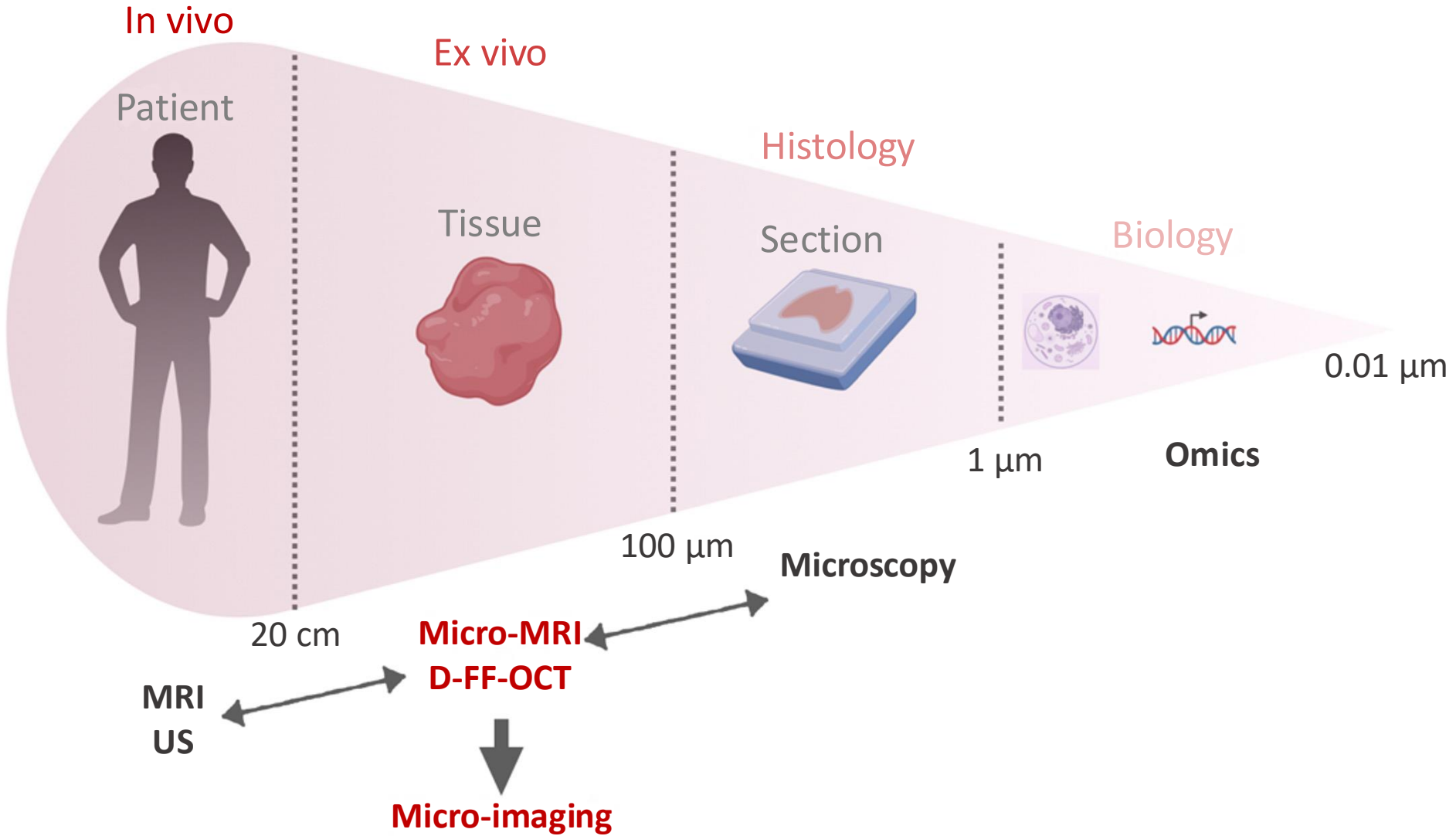
Digital Twin: The big idea

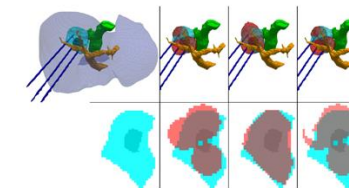
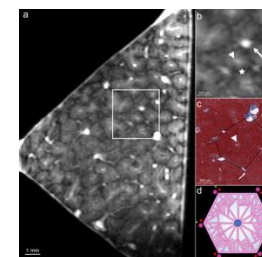
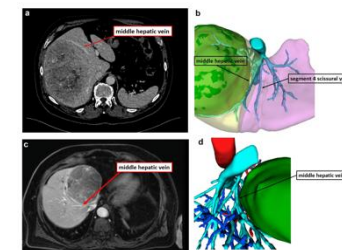
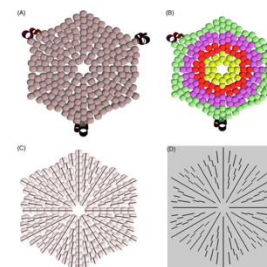
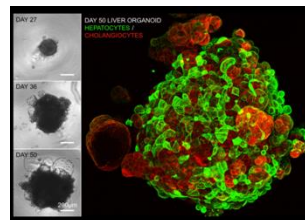
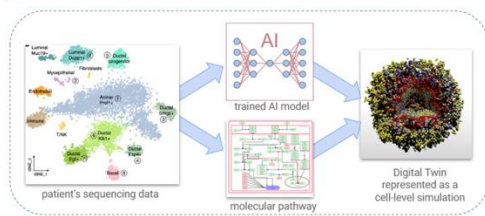
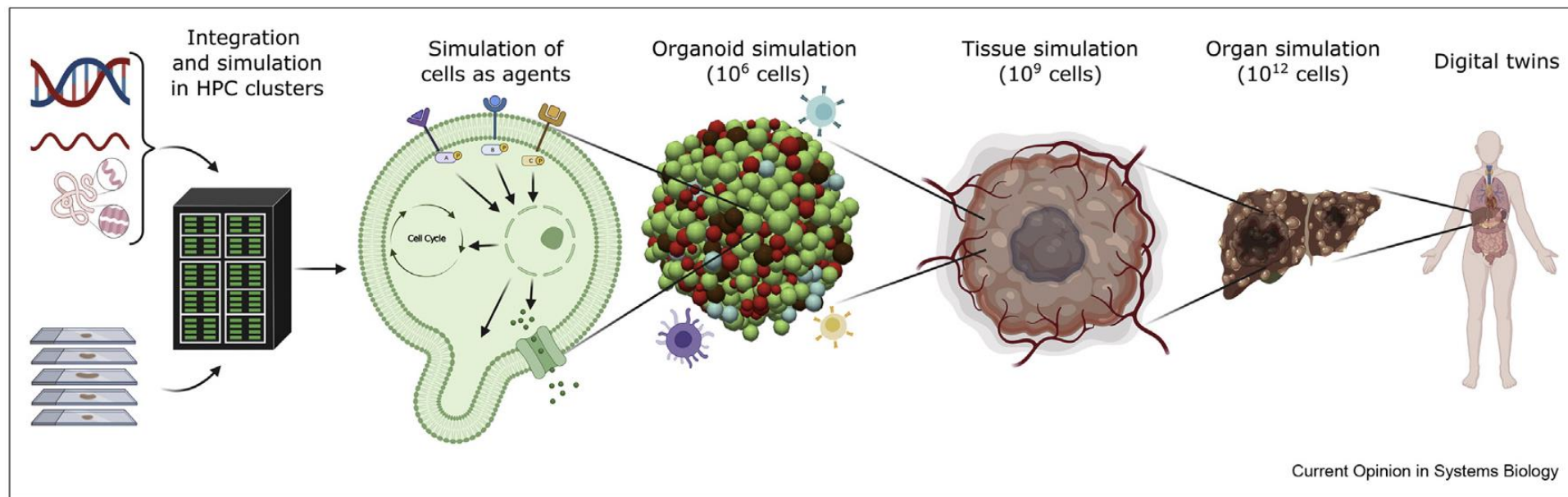
1. Patient and oncologist discuss **goals** and **preferences**
2. Clinicians build a "**digital twin**"
3. Clinicians use HPC to simulate **all treatment options** on the virtual twin
4. Patient and clinician explore risks, benefits, side effects
5. They **choose a plan** and predict progress using their digital twin



⤴ Faites glisser vers le haut
pour une recherche plus
précise







HPC, high-performance computing.

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Integrating mechanism-based modeling with biomedical imaging to build practical digital twins for clinical oncology

Cite as: Biophysics Rev. **3**, 021304 (2022); doi: [10.1063/5.0086789](https://doi.org/10.1063/5.0086789)

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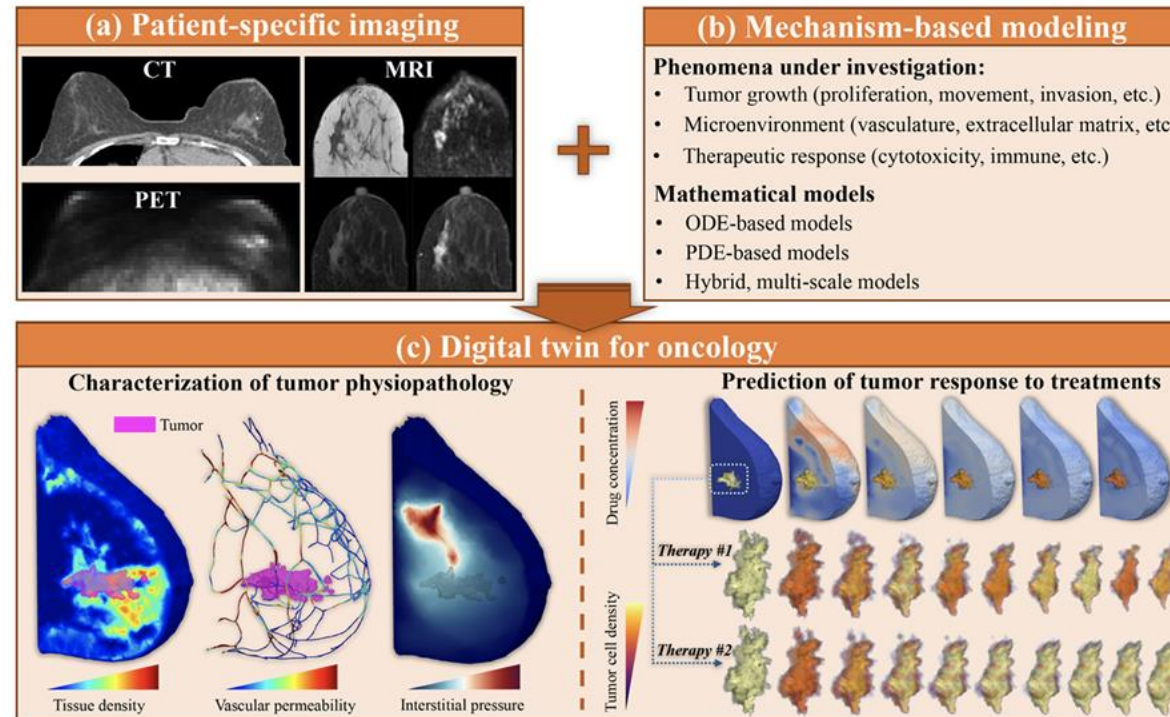


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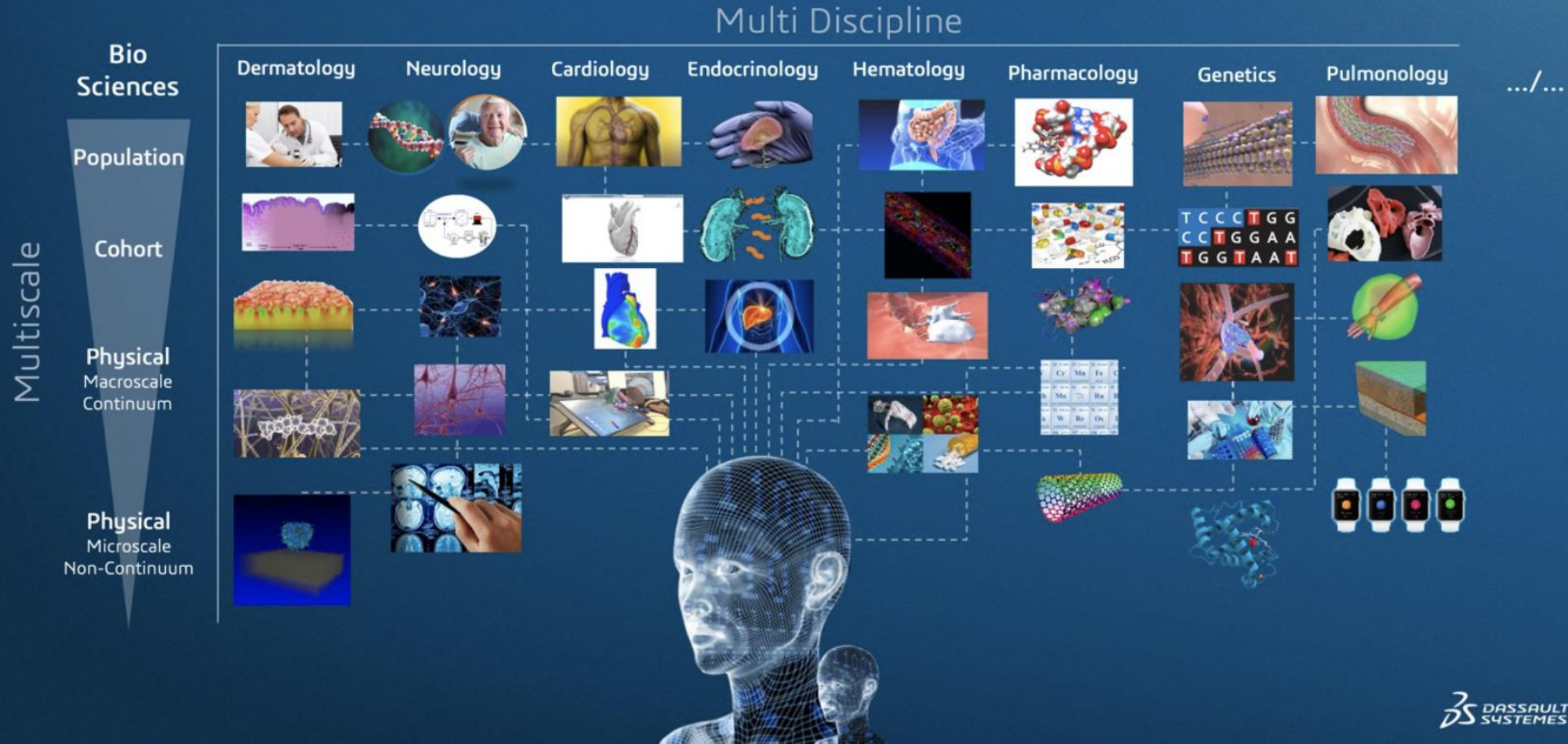
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VIRTUAL TWIN FOR NEXT GENERATION OF HEALTH CARE



Virtual Twin of Human



« If digital twins live up to their promise, they will ultimately signal the advent of personalised medicine. »