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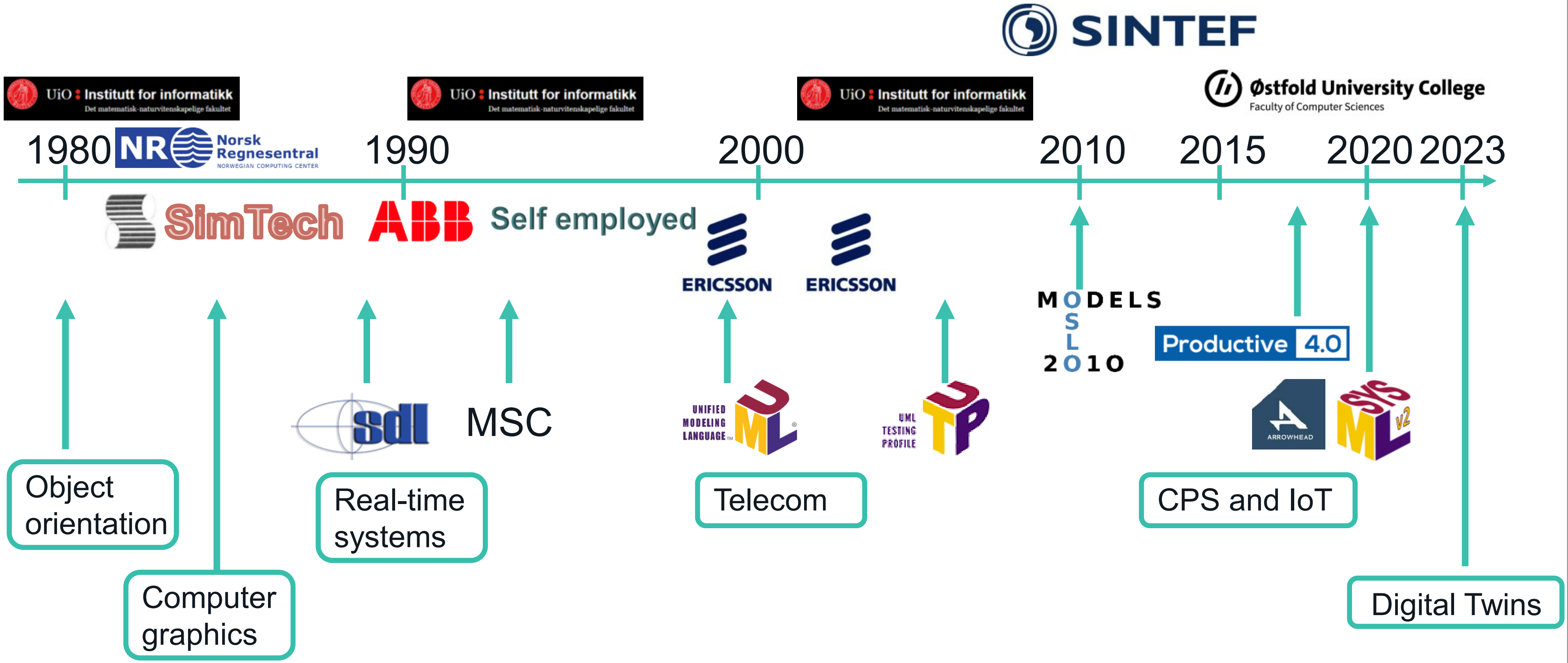
Digital Twins: models everywhere

Øystein Haugen

Øystein Haugen – Professor@ Østfold University College



A History of Modeling Languages

A history of modeling languages

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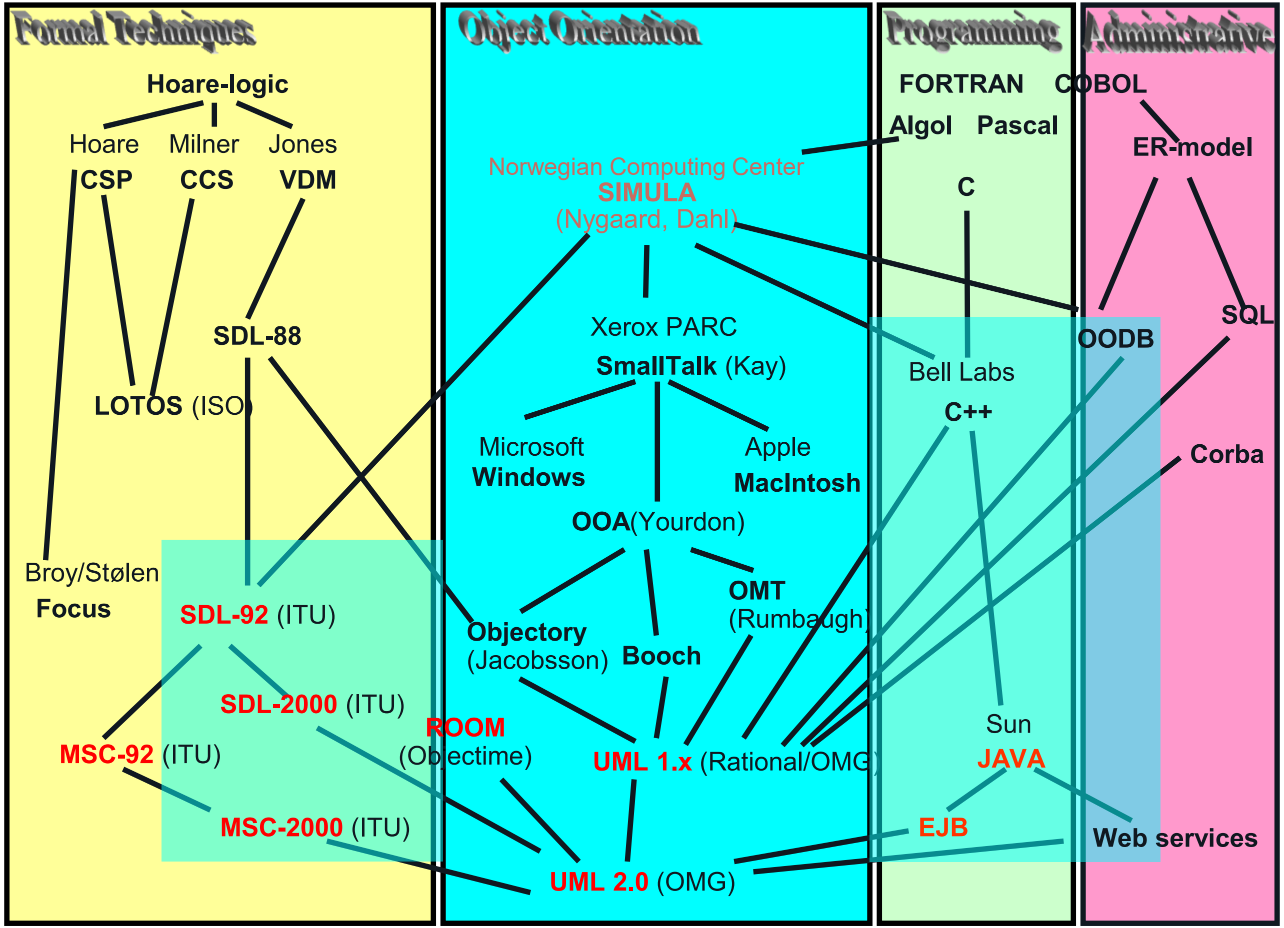

The founding fathers

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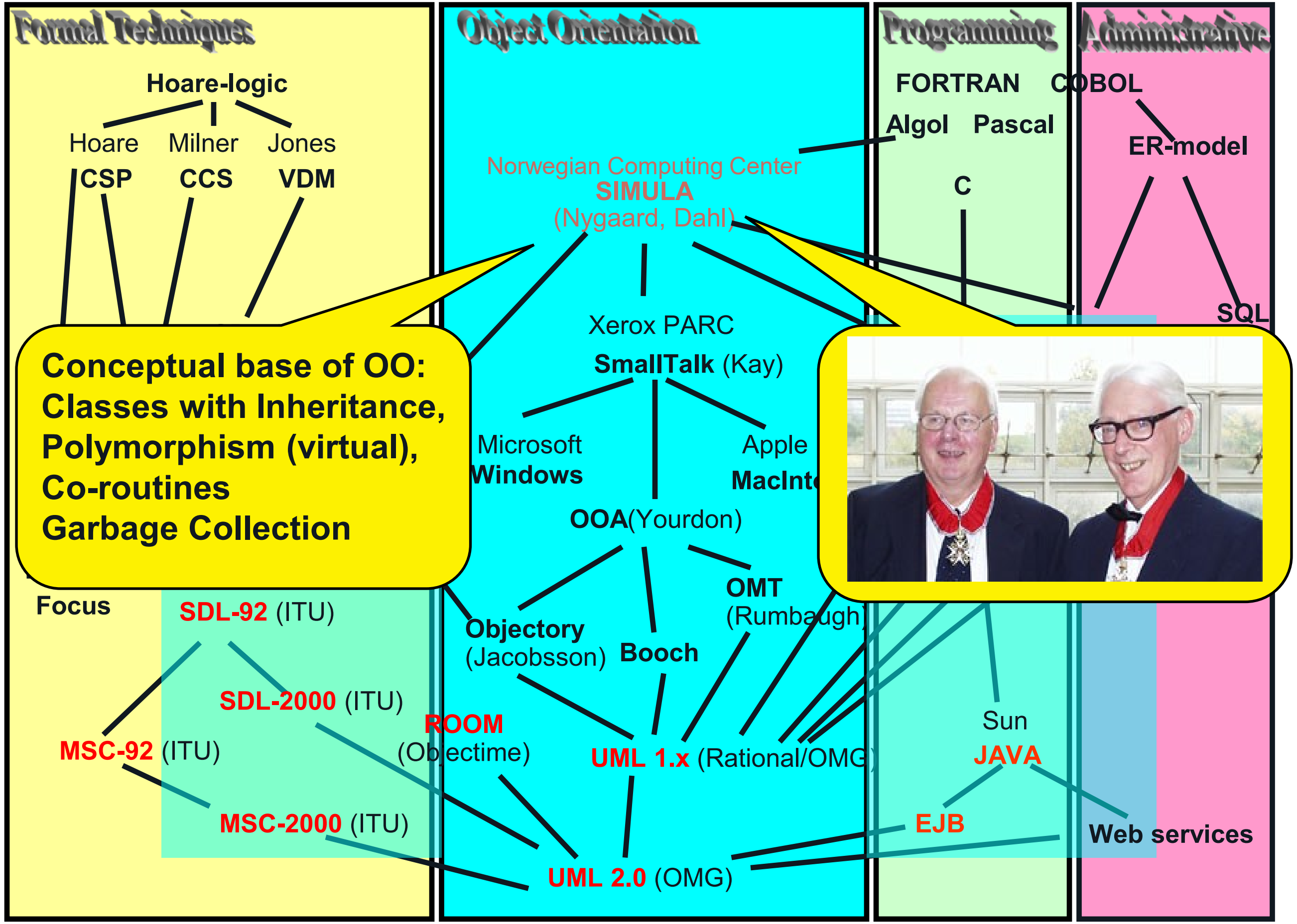
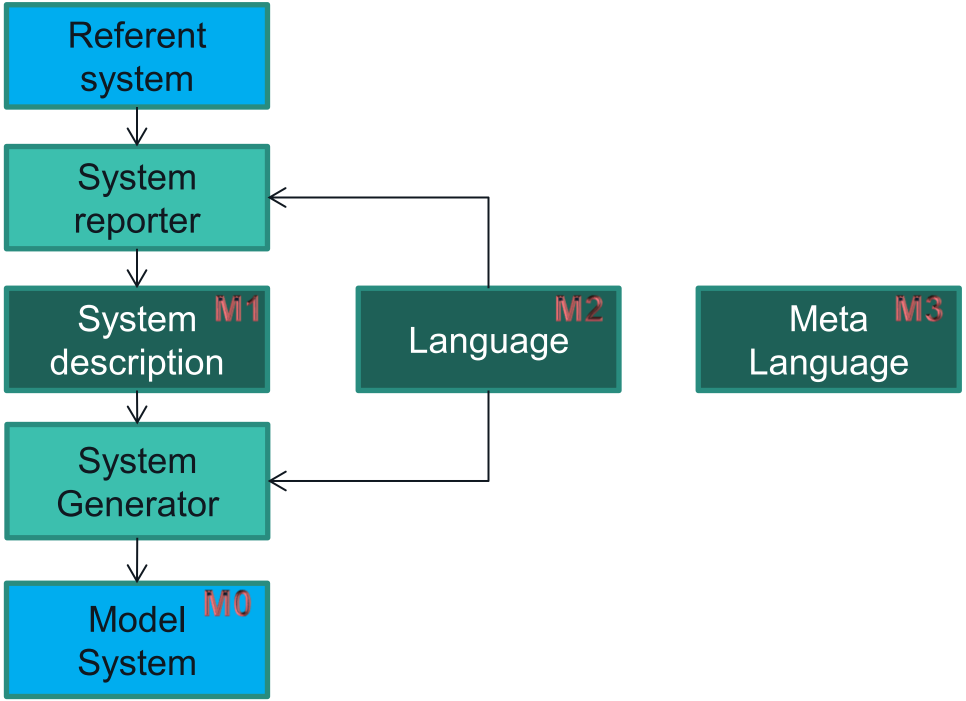


Modeling a system

- A system is a part of the world
  - which *we choose to regard as a whole*, separated from the rest of the world *during some period* of consideration, a whole which we choose to consider as *containing a collection of components*, each characterized by a selected set of associated *data items and patterns, and by actions* which may involve itself and other components
- Mental systems
  - Systems existing in the human mind, physically materialized as states of the cells of our brains
- Mental and manifest models
  - when a limited set of properties is selected from a system
- These definitions are from K. Nygaard and his DELTA team (in 1975)

A Model of Modeling



Modeling is abstraction

- By making a model you distinguish between
  - what is **important** and what is not important
  - for a given **purpose**
- There may be **several fruitful models** of the same reality
- Modeling is an act of **conscious thinking**
  - but it may be assisted by automatic means and tooling

Digital Twins

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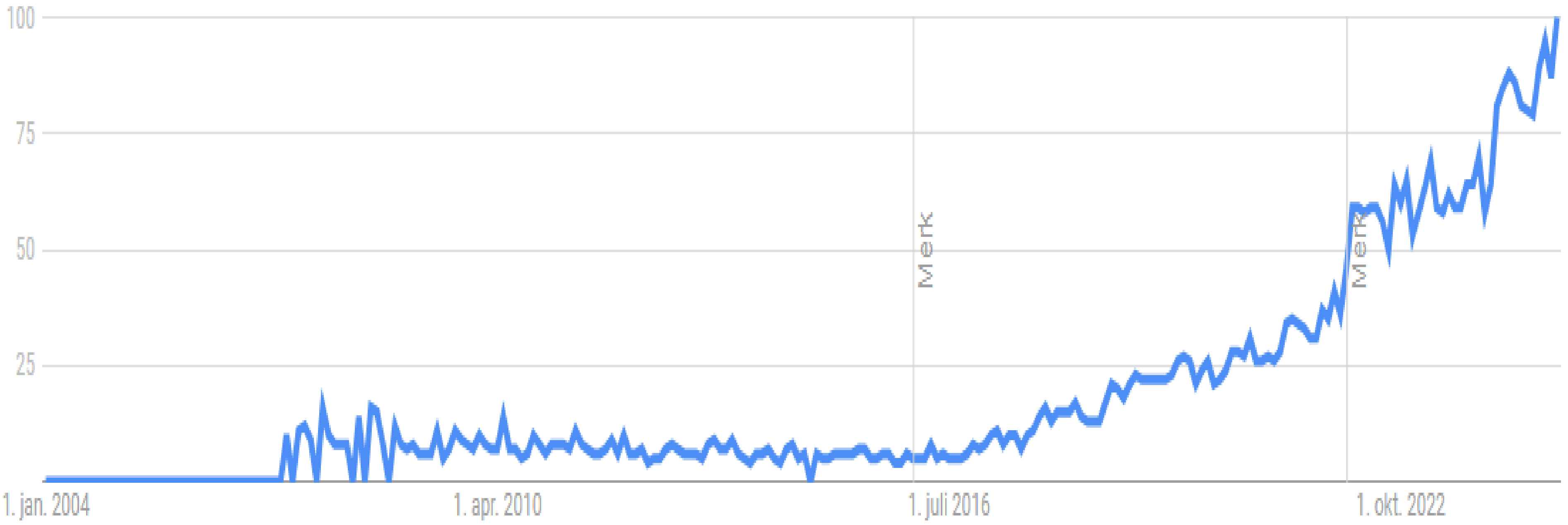
Google Trend on net search of Digital Twins



Once upon a time …

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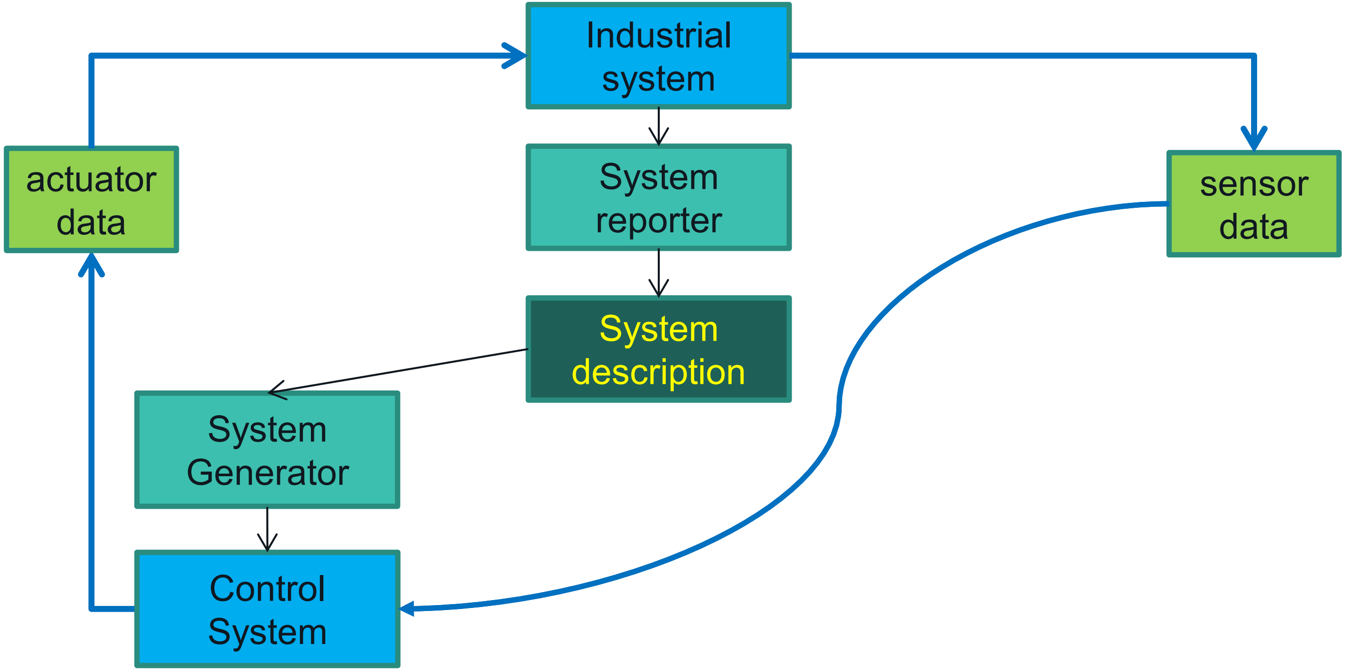

… then we created Digital Simulation

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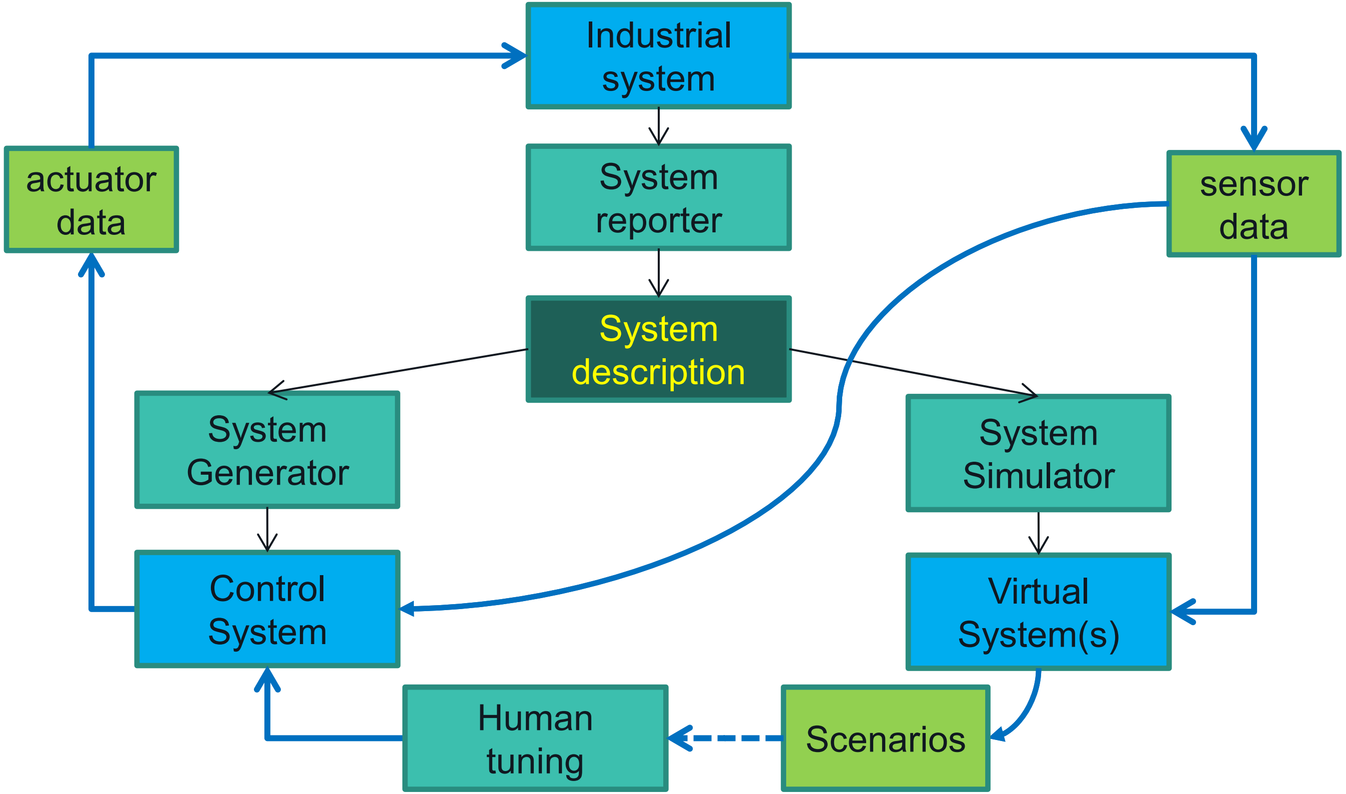

Or the more advanced Digital Twin

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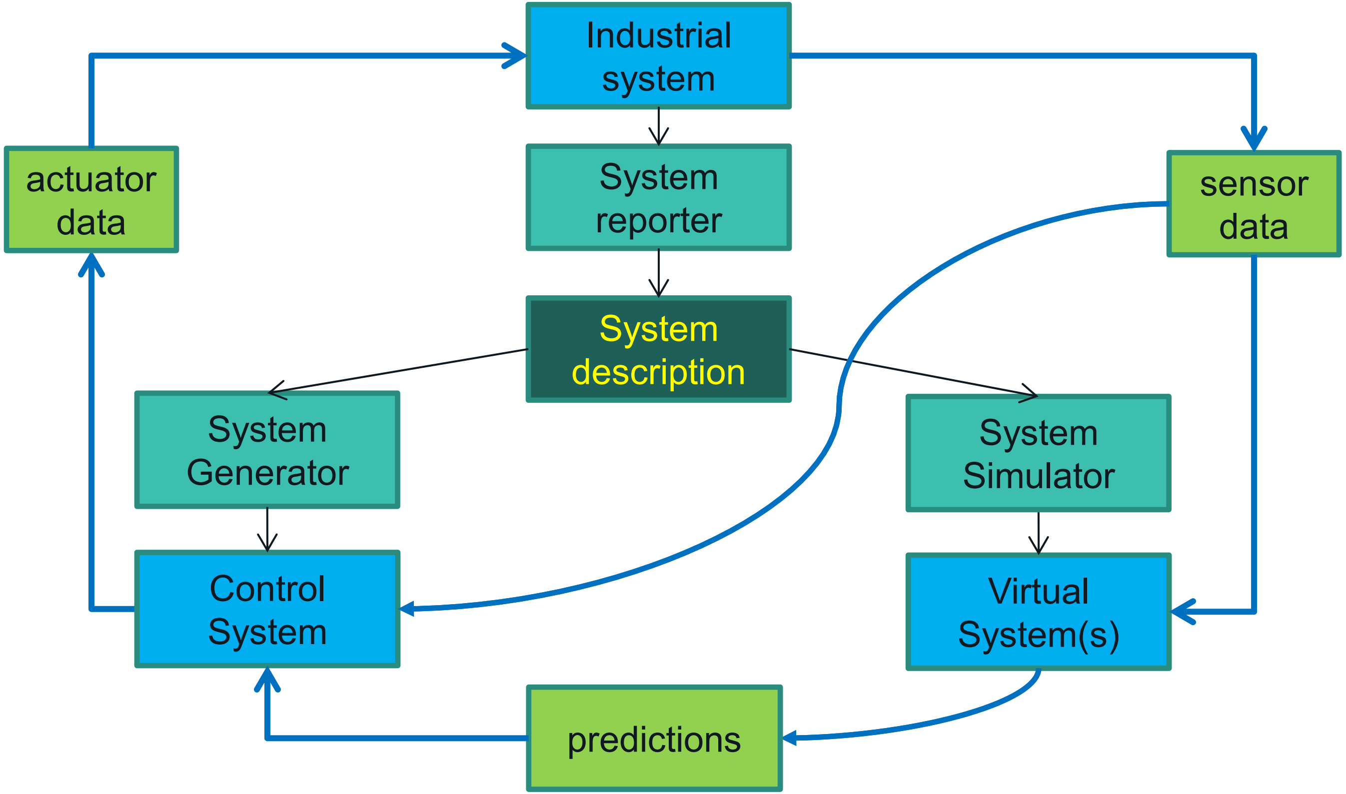
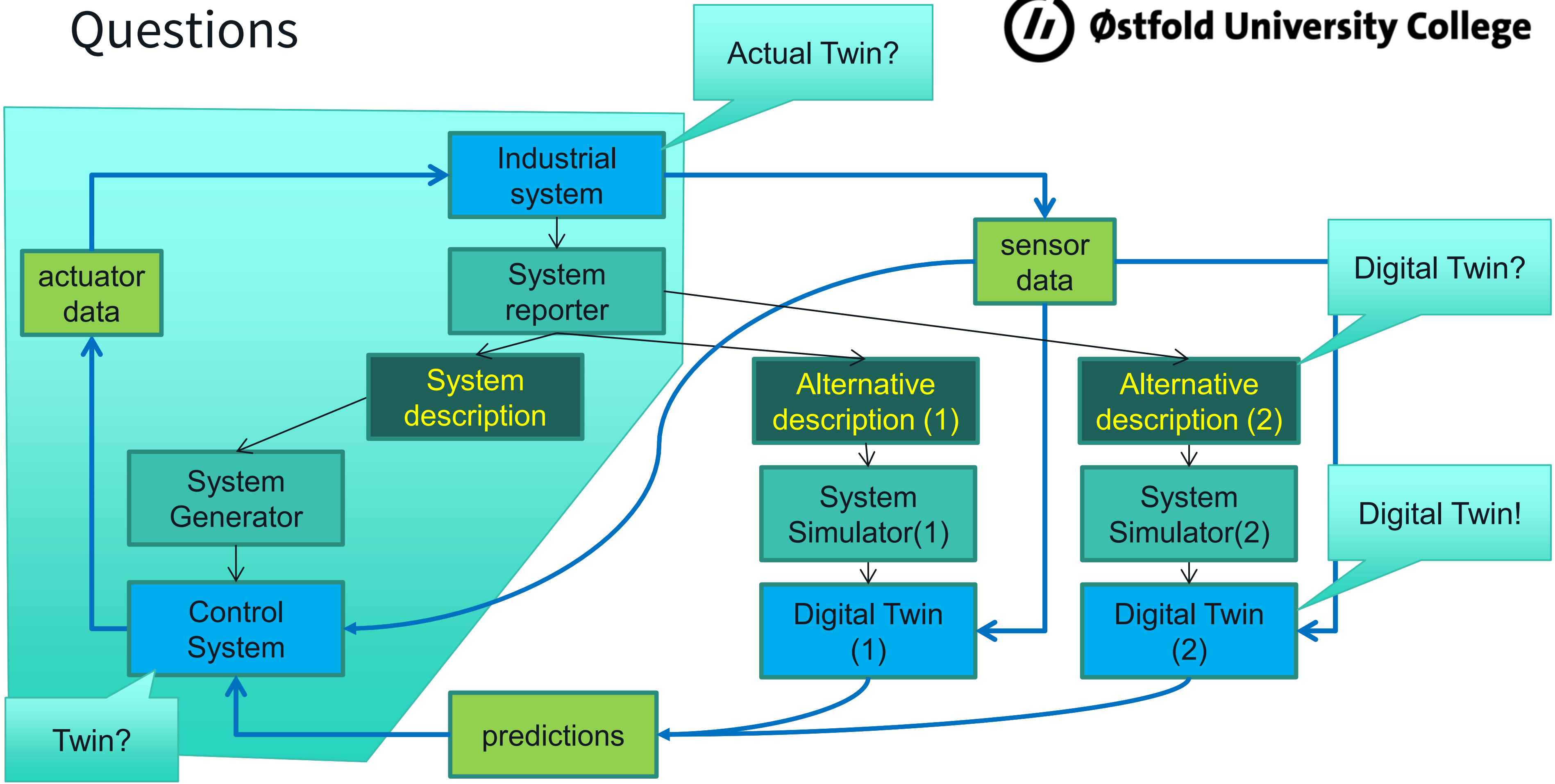


Questions


Actual Twin?
Industrial system
actuator data
System reporter
sensor data
Digital Twin?
System description
Alternative description (1)
Alternative description (2)
System Generator
System Simulator(1)
System Simulator(2)
Digital Twin!
Control System
Digital Twin (1)
Digital Twin (2)
Twin?
predictions

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Definition: Digital Twin and Actual Twin

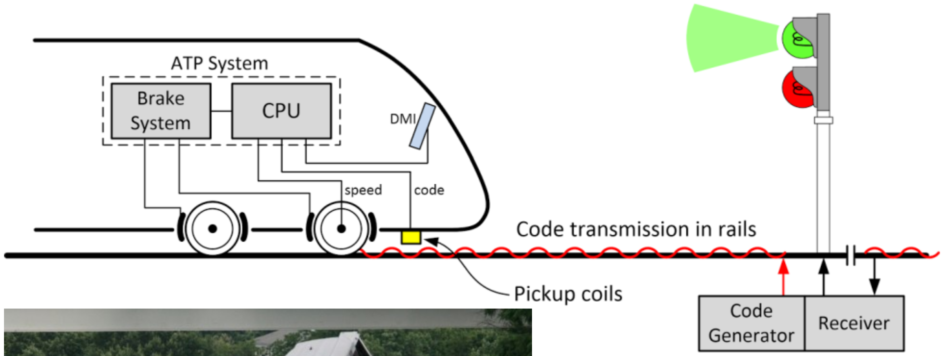
- A Digital Twin (DT) is a digital representation of an actual system, referred to as the actual twin (AT), that is dynamically updated with AT data and that can interact with and influence the AT
  - From SoSyM paper: Continuous Evolution of Digital Twins using the DarTwin Notation
- Digital Twin seems to be a fruitful approach to understanding and manipulating systems with different stakeholders

Why are Digital Twins popular for Industry 4.0?

- Modern systems are dynamic
  - Behavior is important
- Modern systems should work 24/7
  - Adaptivity and evolution are important
  - Simulation is important
- Modern systems are often cyber-physical
  - Concurrency and real-time are important
  - Physical wear and tear are important

The thing with CPS:
“It is physical, stupid!”

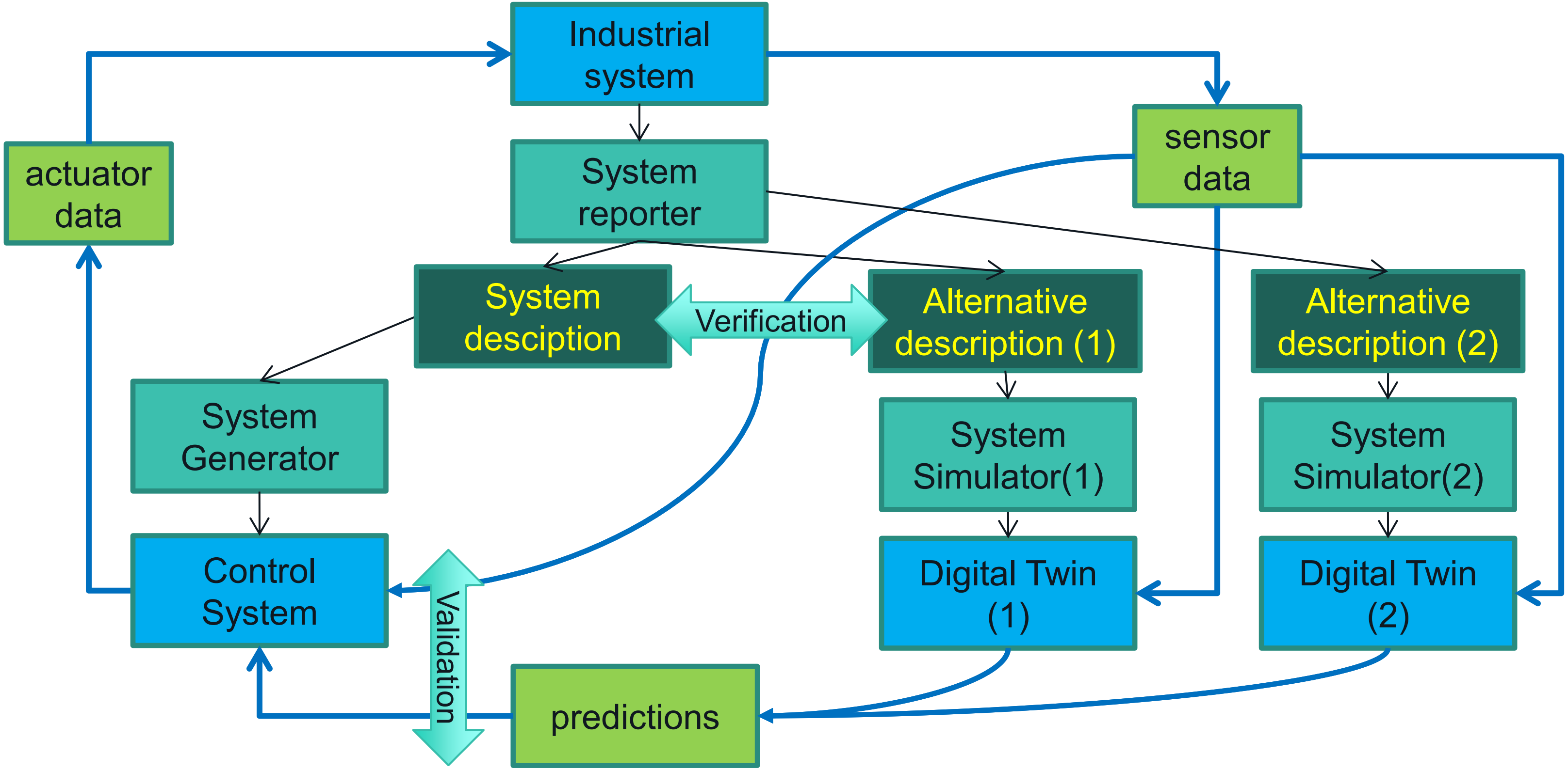
Automatic Train Control (for ABB ca 1990)



(illustration photos from Internet)

- Trains are physical
- Trains are heavy and move fast
  - 400 km/h
  - Braking takes kilometers
- Train Control means full brake if red light is passed
- How would you test this?
- How can you be sure it works the day you need it?
- Necessary technology: simulation
- Related IoT technology:
  - Self-driving cars

Verification and Validation



The room and its simulation

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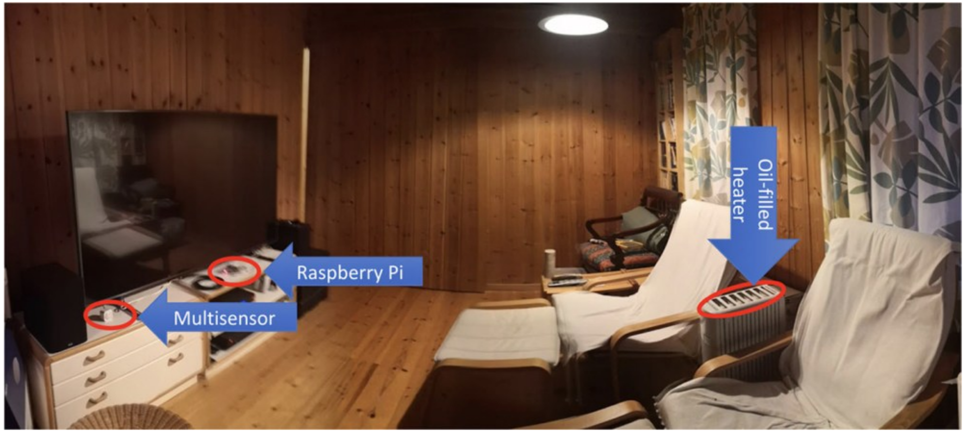
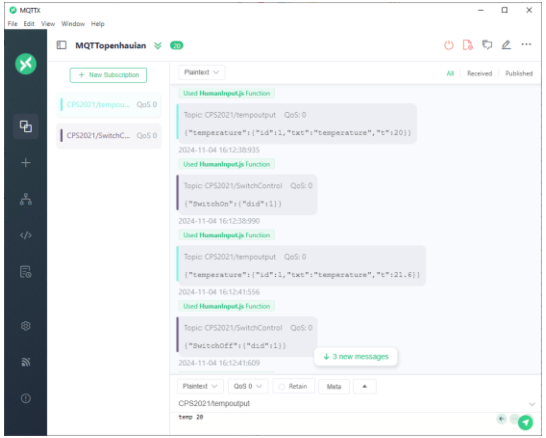
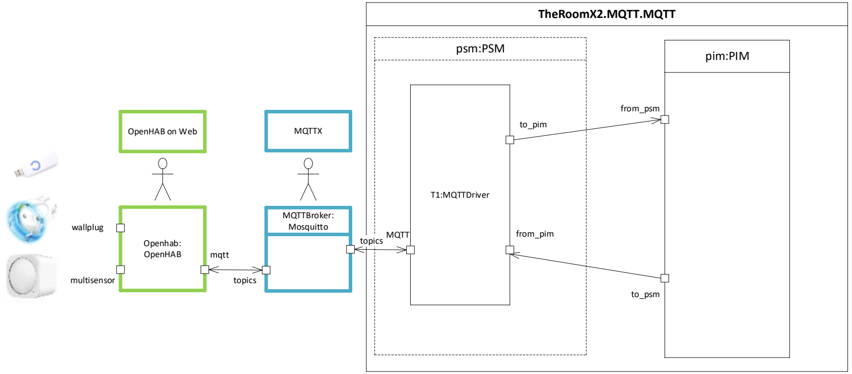
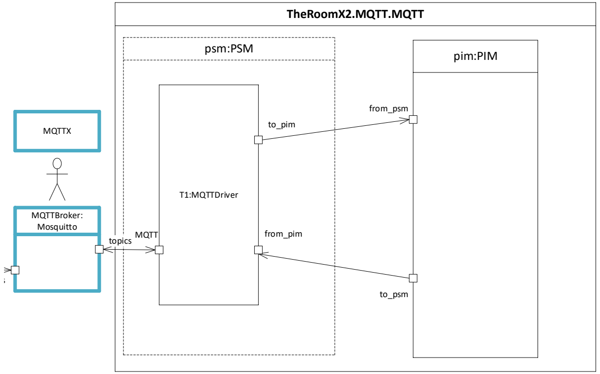
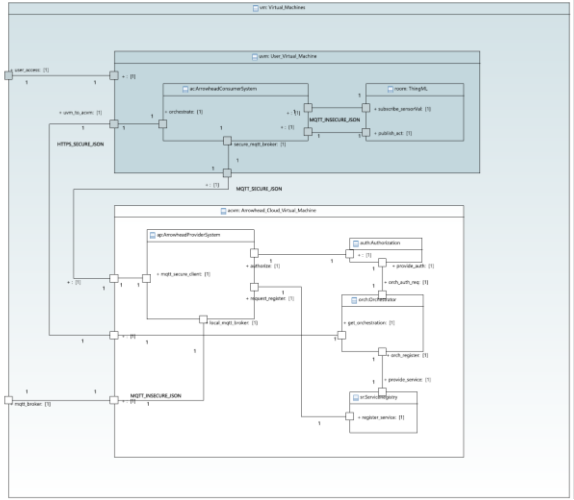


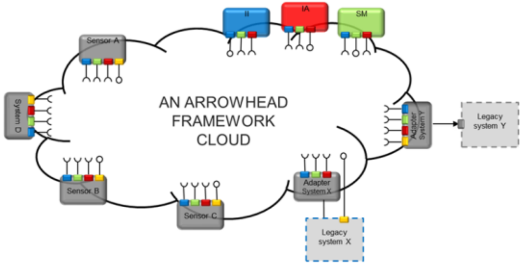


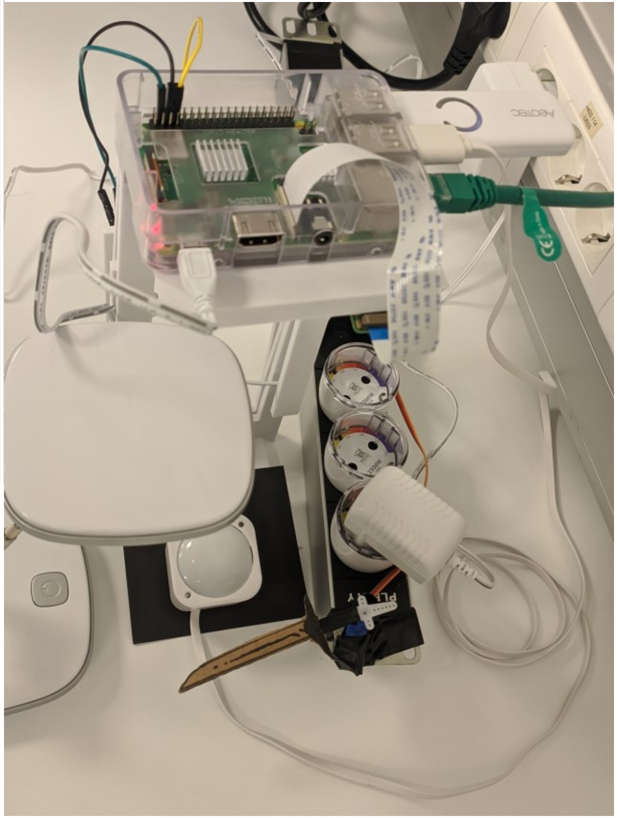


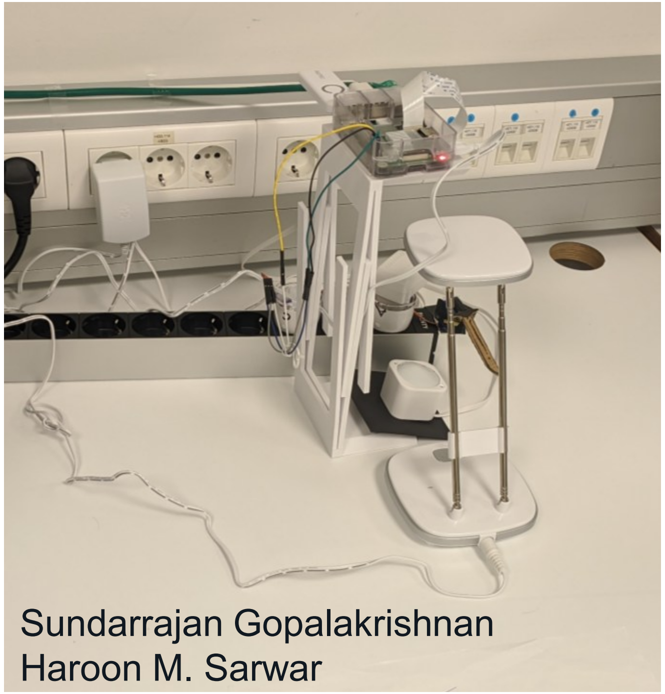


Covid-time: The Arrowhead Remote Virtual Physical Lab



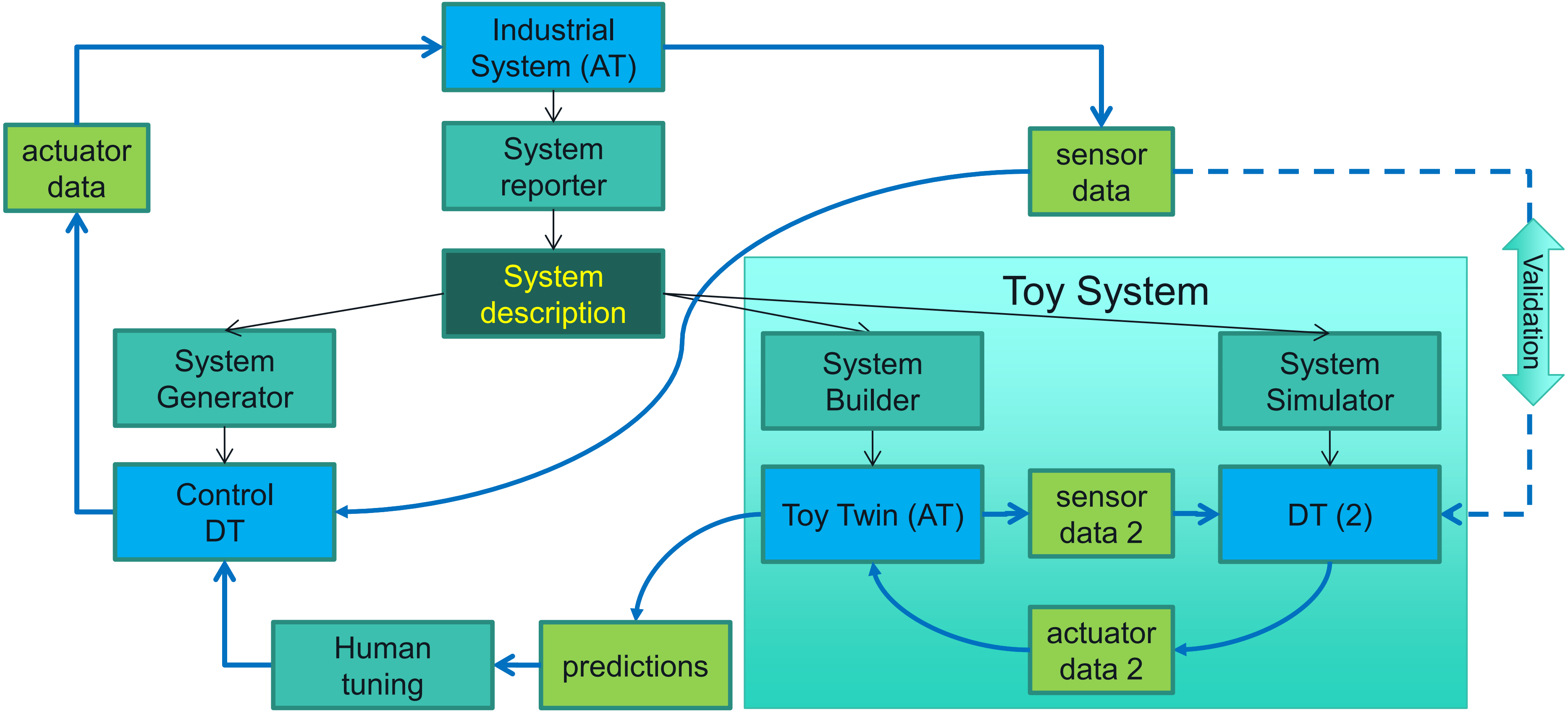




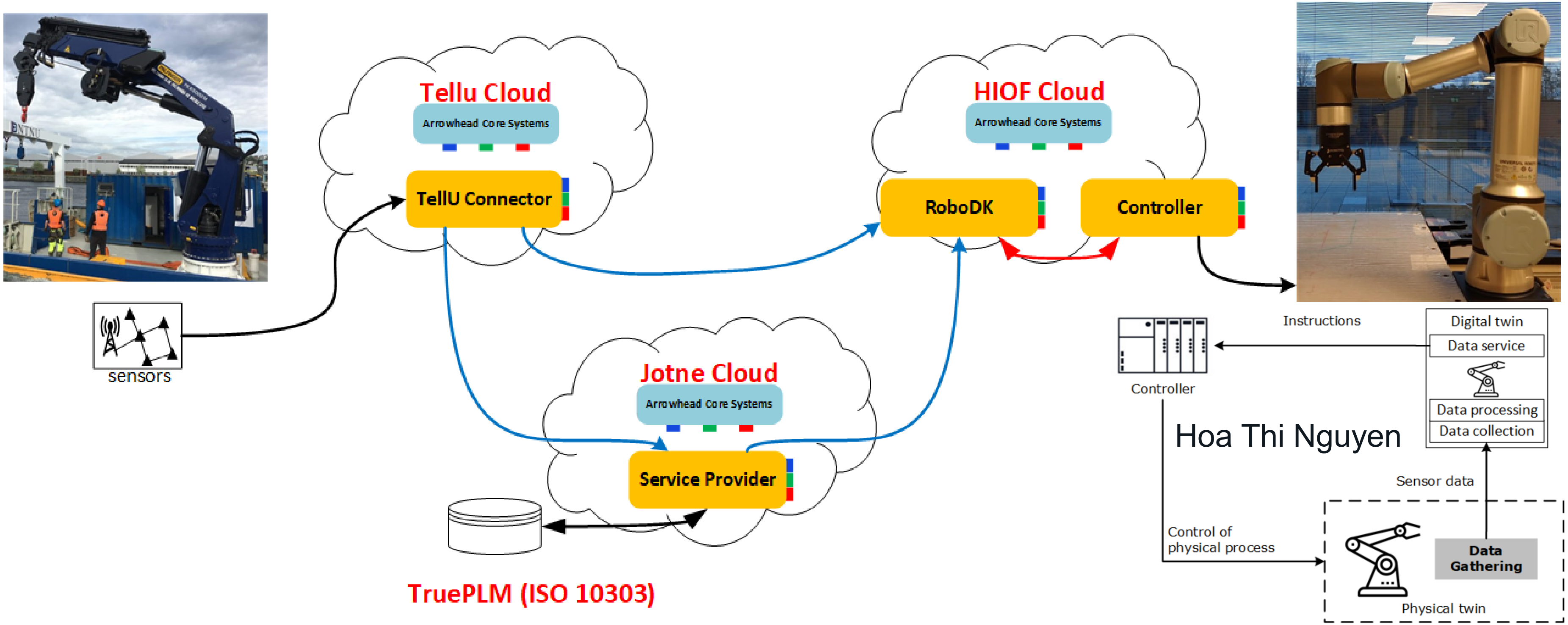


Sundarrajan Gopalakrishnan
Haroon M. Sarwar

Toy Twin

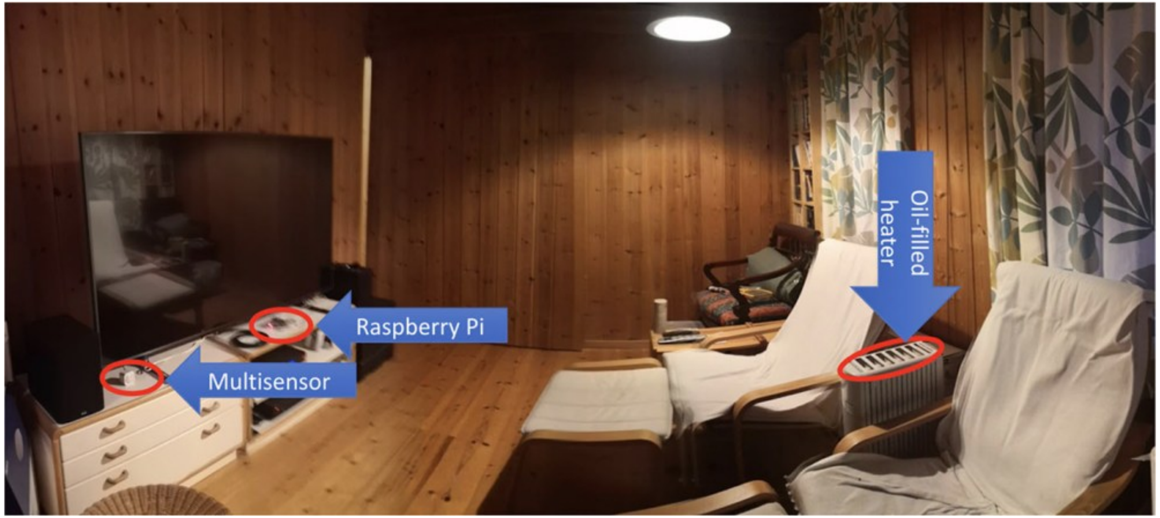

Industrial System (AT)
actuator data
System reporter
sensor data
System description
Toy System
System Generator
System Builder
System Simulator
Validation
Control DT
Toy Twin (AT)
sensor data 2
DT (2)
Human tuning
predictions
actuator data 2

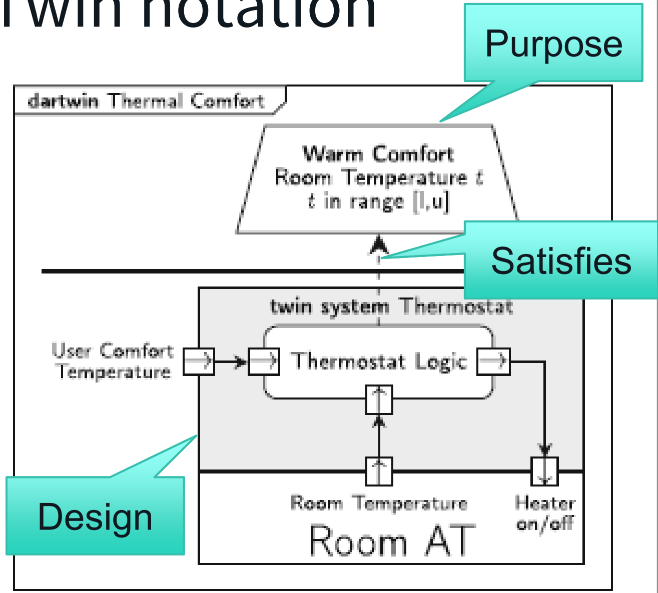
Arrowhead: Physical crane; Lab robot arm; Digital Twin



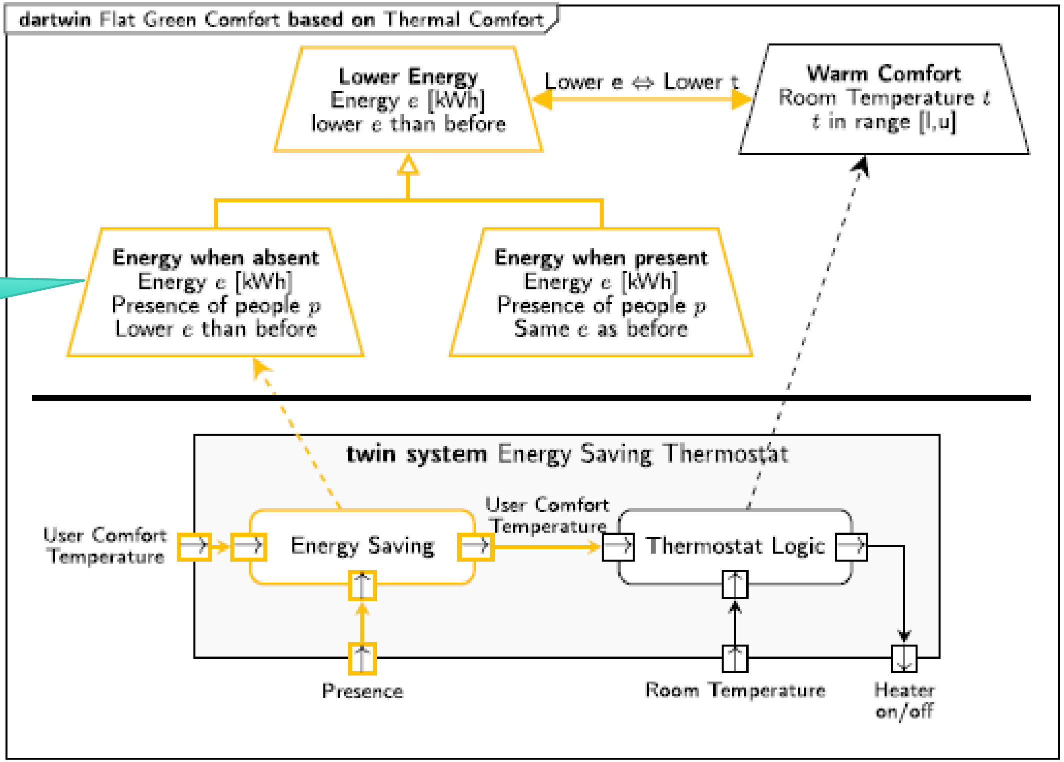
Adapting and Evolving Digital Twins

Evolving my room – a true story – the DarTwin notation

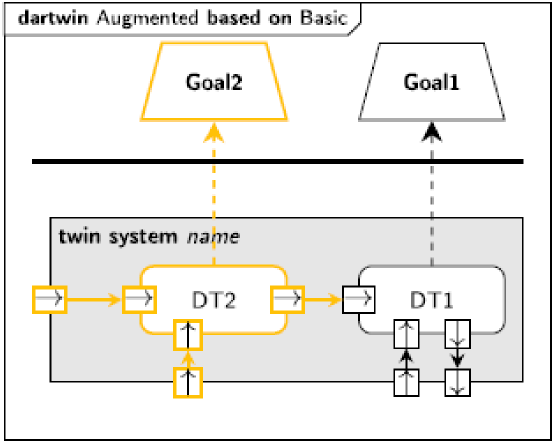




Evolution 1: Green comfort – saving some energy



New changes



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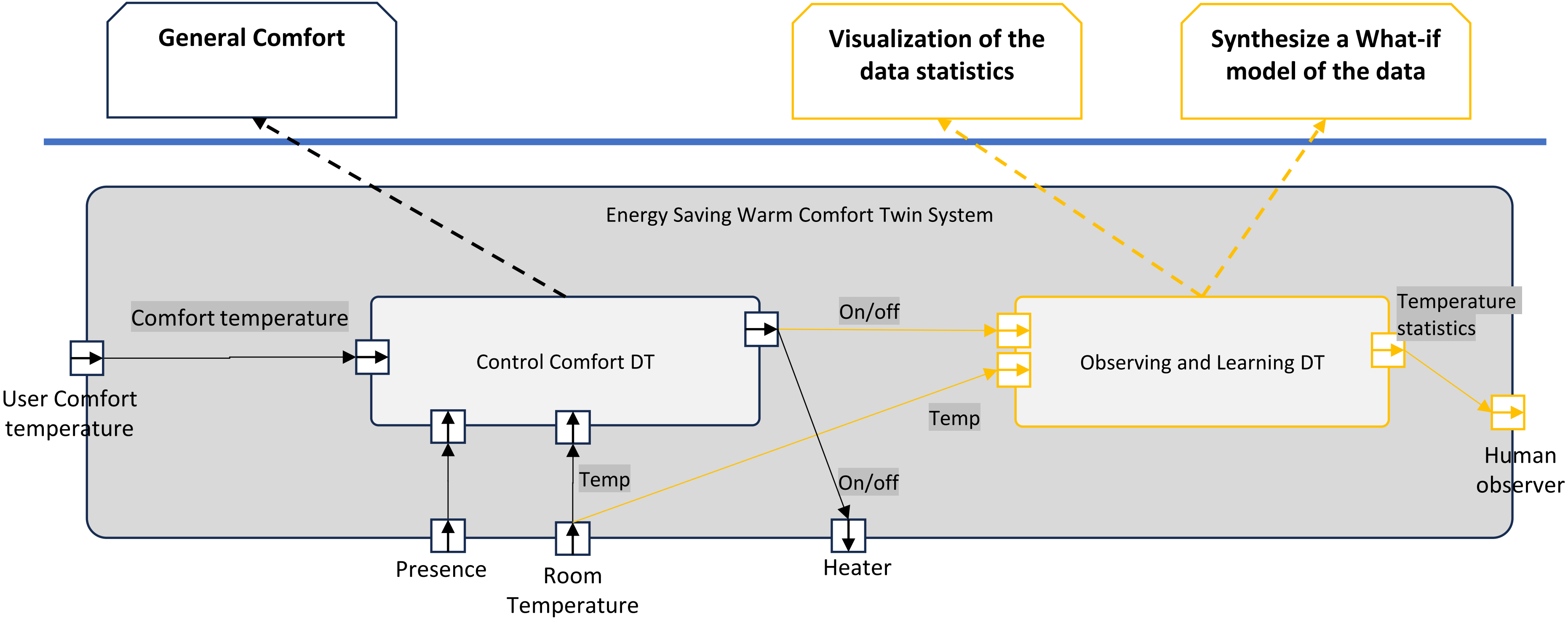
First DT Stage: Dashboard



Observations via OpenHAB

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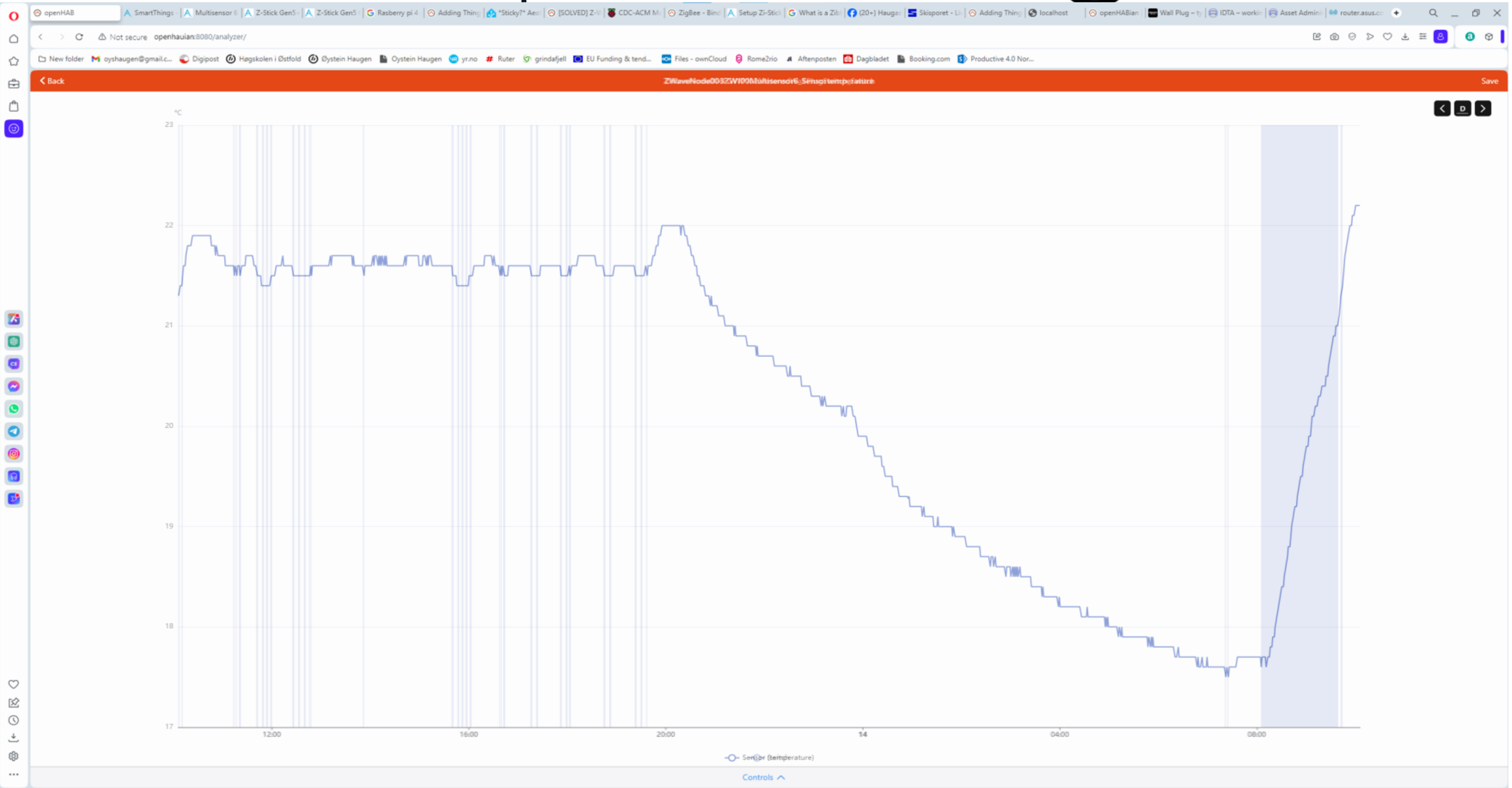
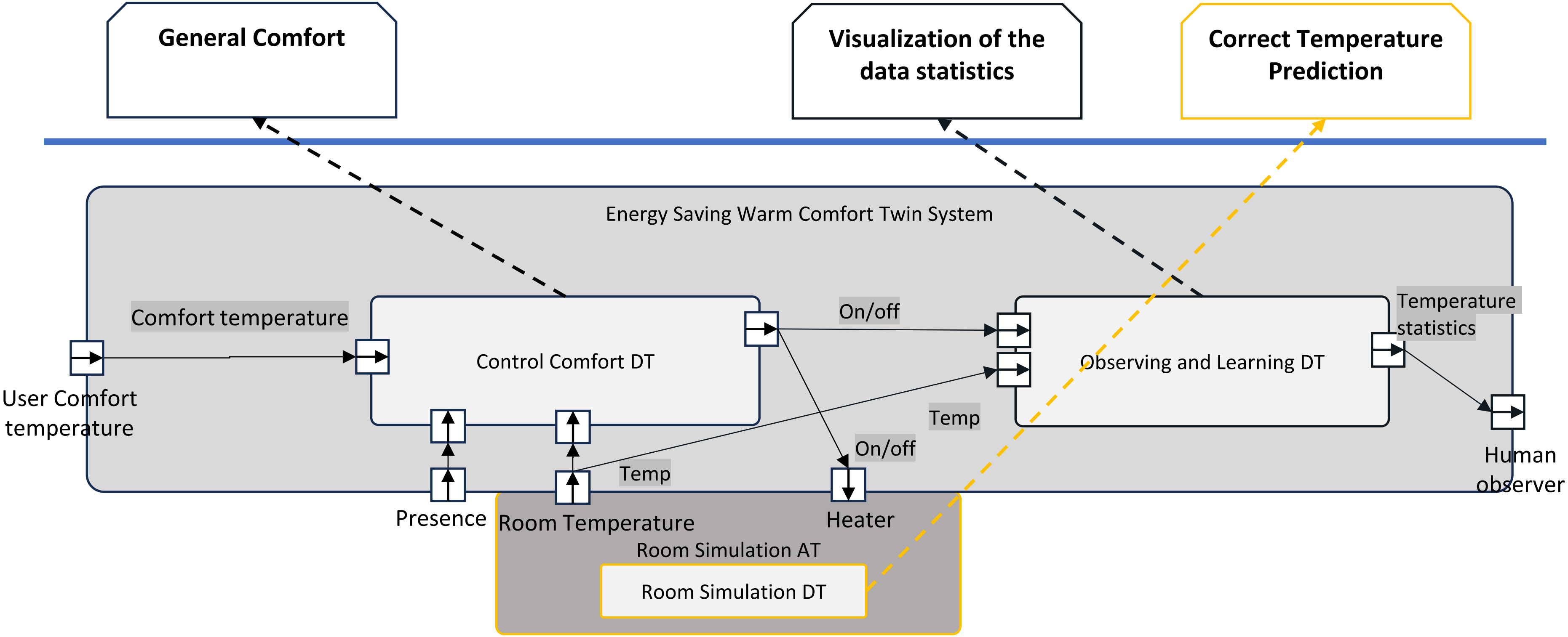


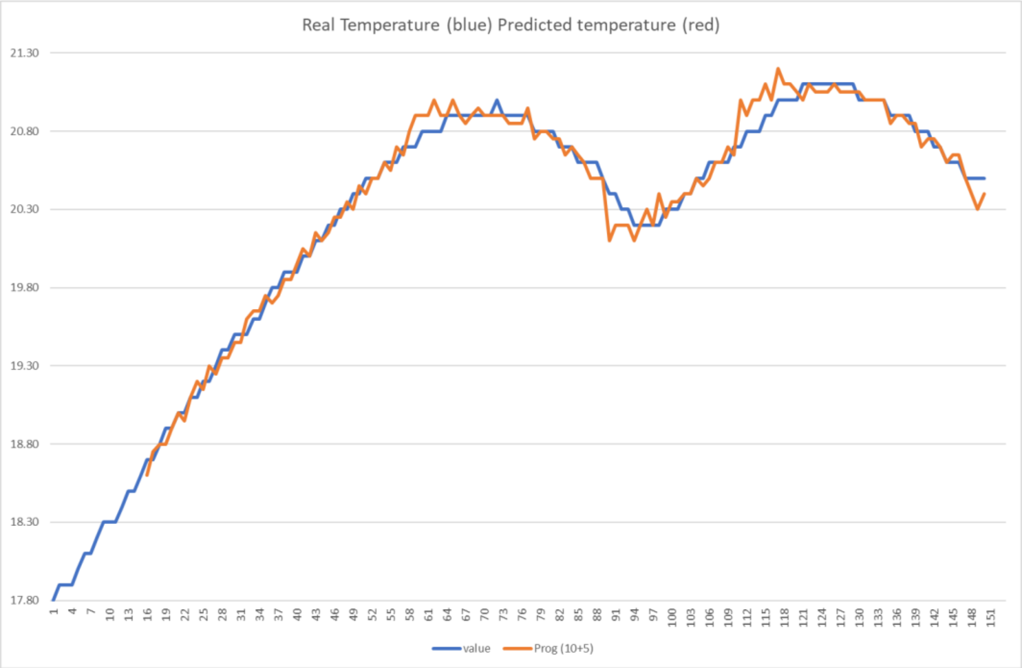
DT for Monitoring

- Prepare for human decisions
- Dashboards for overview
- Augmented reality for combining reality with information

Second DT Stage: What-if Simulation



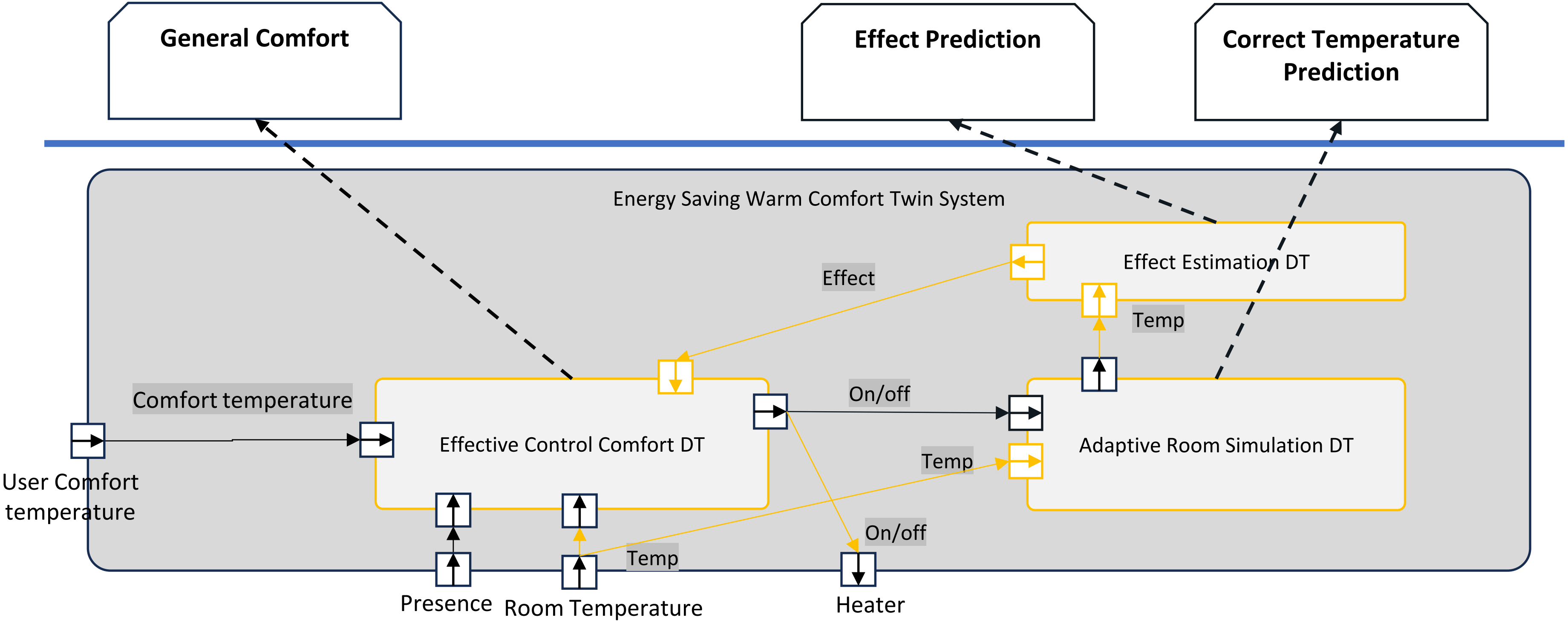
Simulation validation by comparing with historic data



DT for Prediction

- Simulation
- What-if scenarios
- Gamification
- Interdisciplinary exploration and understanding through risk-free execution of DT

Third DT Stage: Prediction-driven control



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DT for Control

- Automation
- Data must be consumed in time
- Updates must preferably be done while executing
- Should apply redundancy
  - Several DTs for the same purpose
  - Federated DTs with different principles
  - Include some human in the loop at least for validation

Digital Twins for collaboration

Boeing: Model Based Engineering (MBE)

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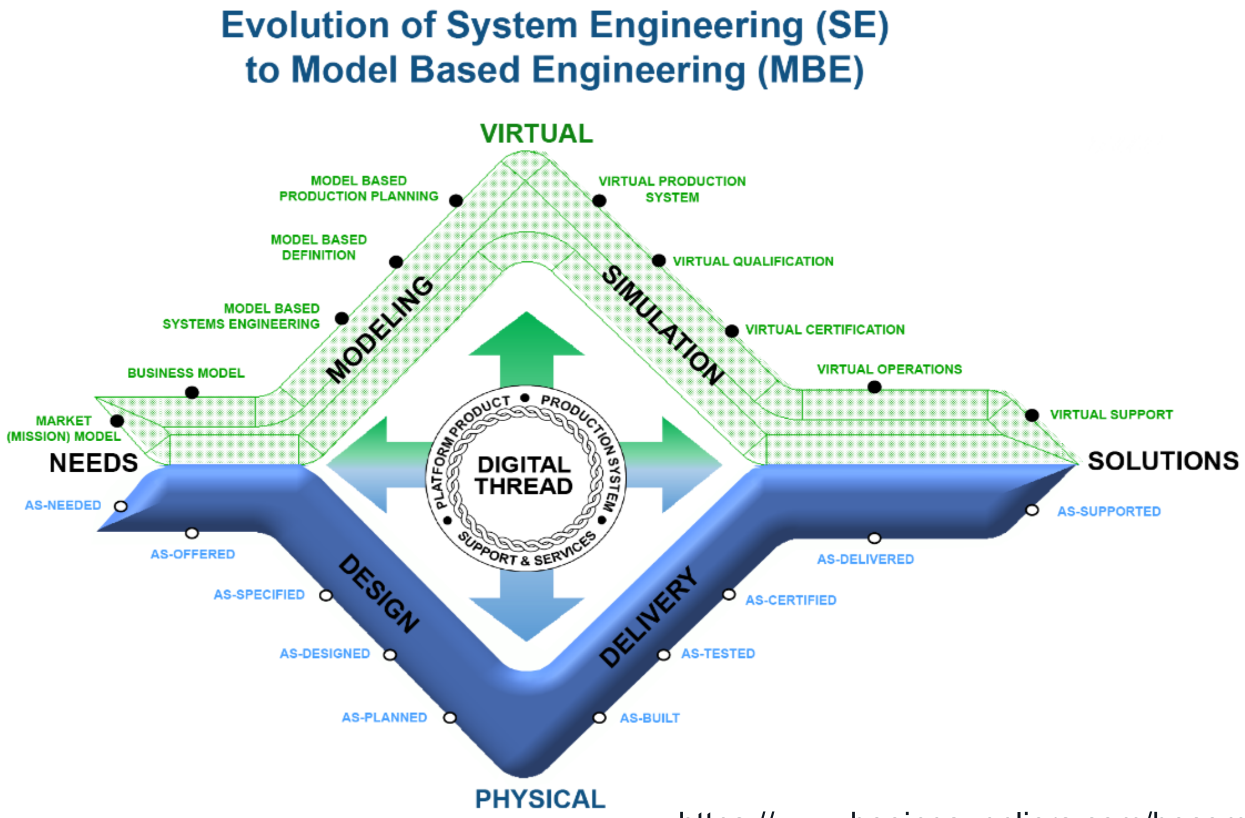

https://www.boeingsuppliers.com/become/modelbasedengineering#what

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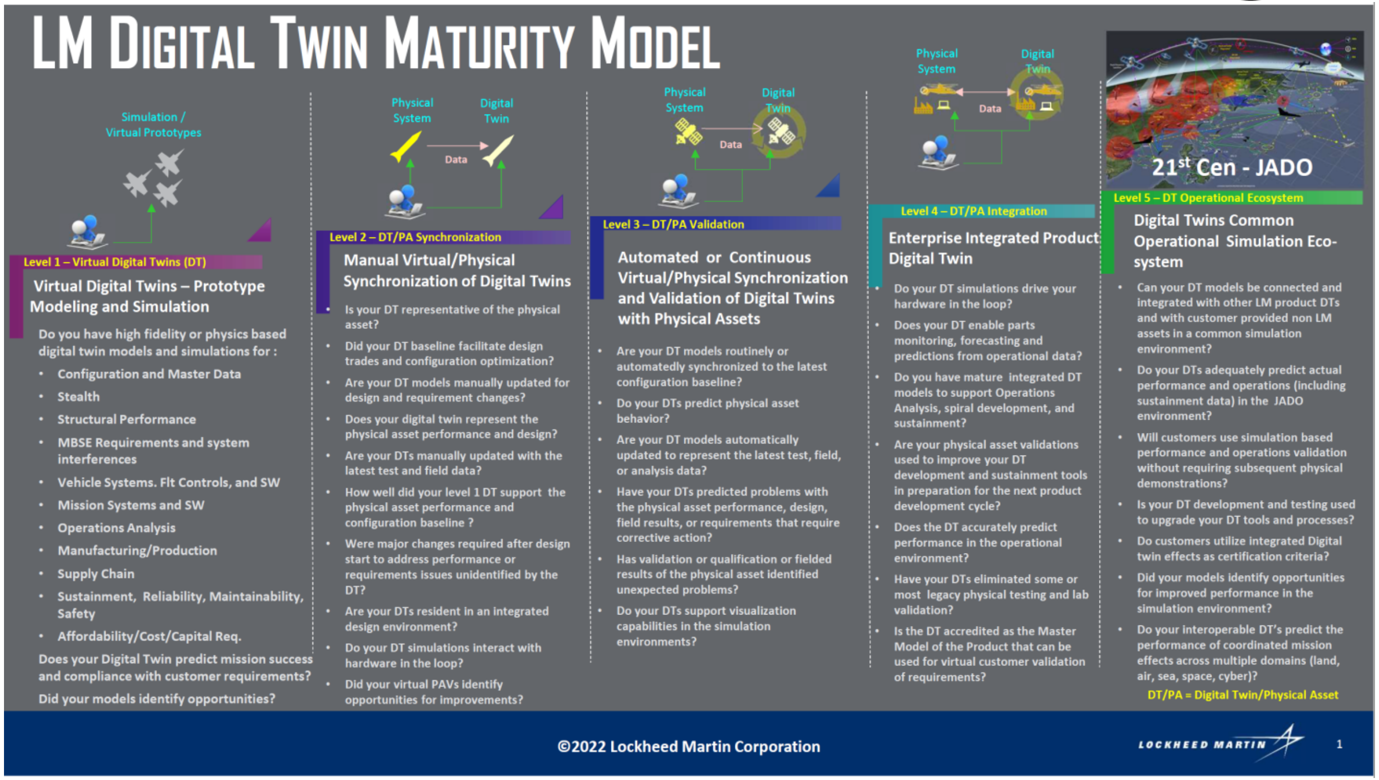

Mirror Image: The Power of Digital Twins at Lockheed Martin

https://www.lockheedmartin.com/content/dam/lockheed-martin/space/documents/digitaltwin/Lockheed%20Martin%20Digital%20Twin%20Maturity%20Model_2021.pdf

CNC production (Mekanisk Service Halden)

- Carving materials to create desired shapes
- Guided by machine programs
- High speed, high precision

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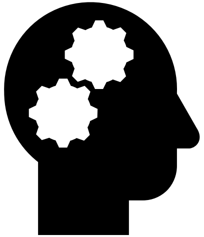
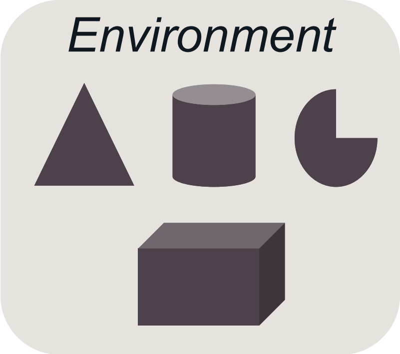
Enhance automation for the operation (Hoa Nguyen)

Imitation learning



Interact



"Imitation"

Using the same information that operators get while monitoring, the AI algorithm can learn the operators' control patterns from historical loggings

the elephAnt In the room

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Digital Twins **with** Artificial Intelligence

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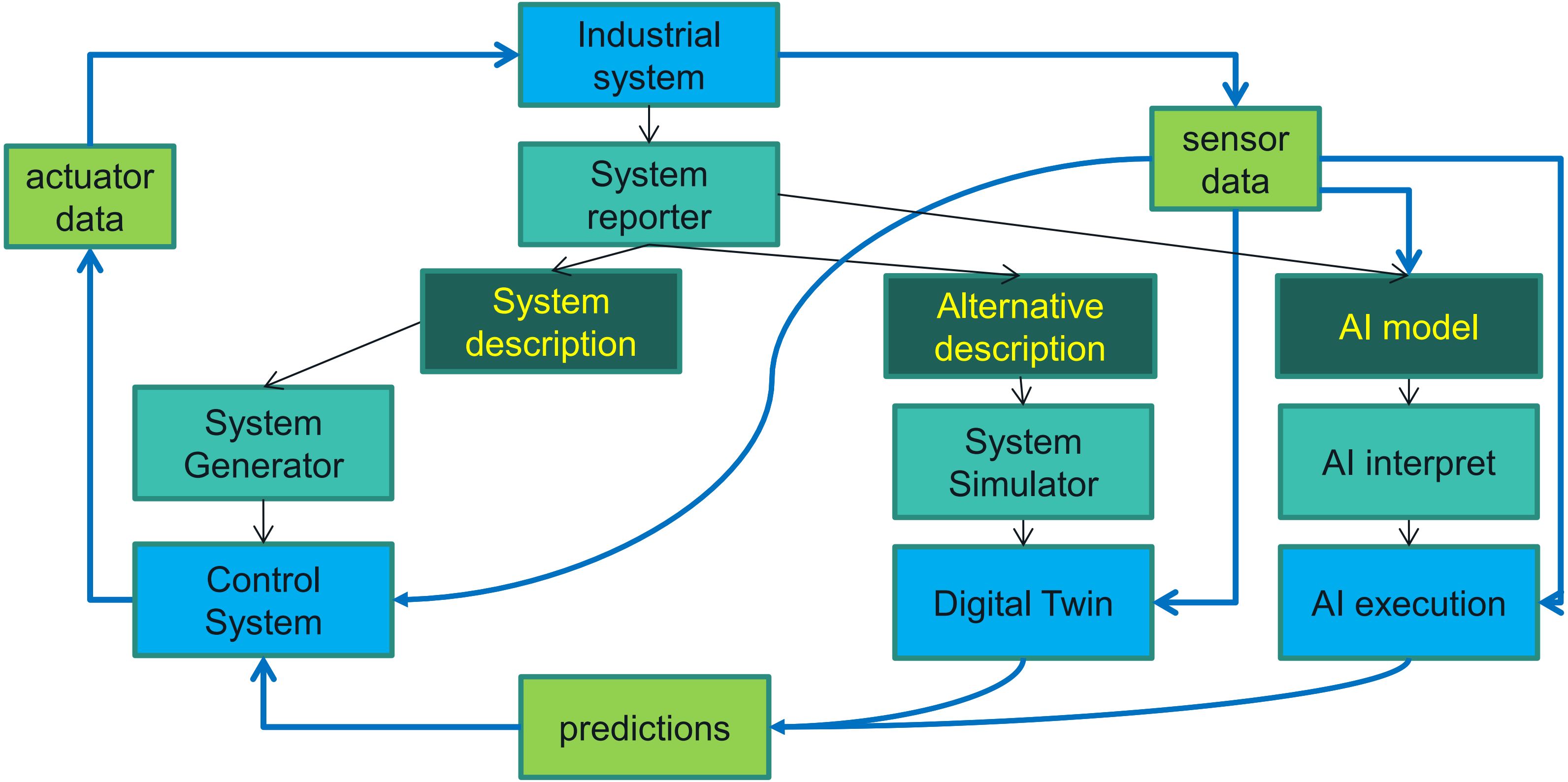

Digital Twins **by** Artificial Intelligence

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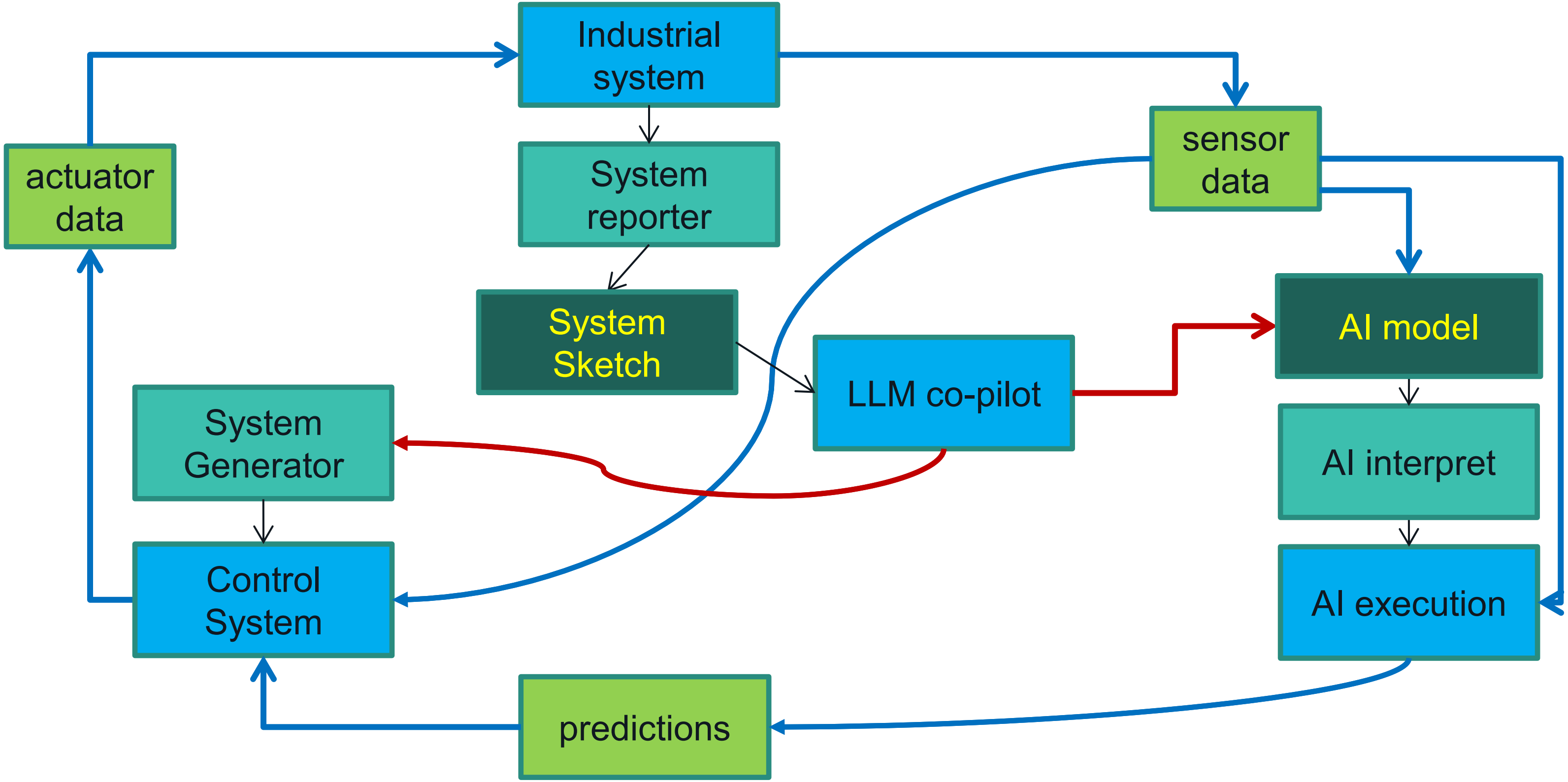
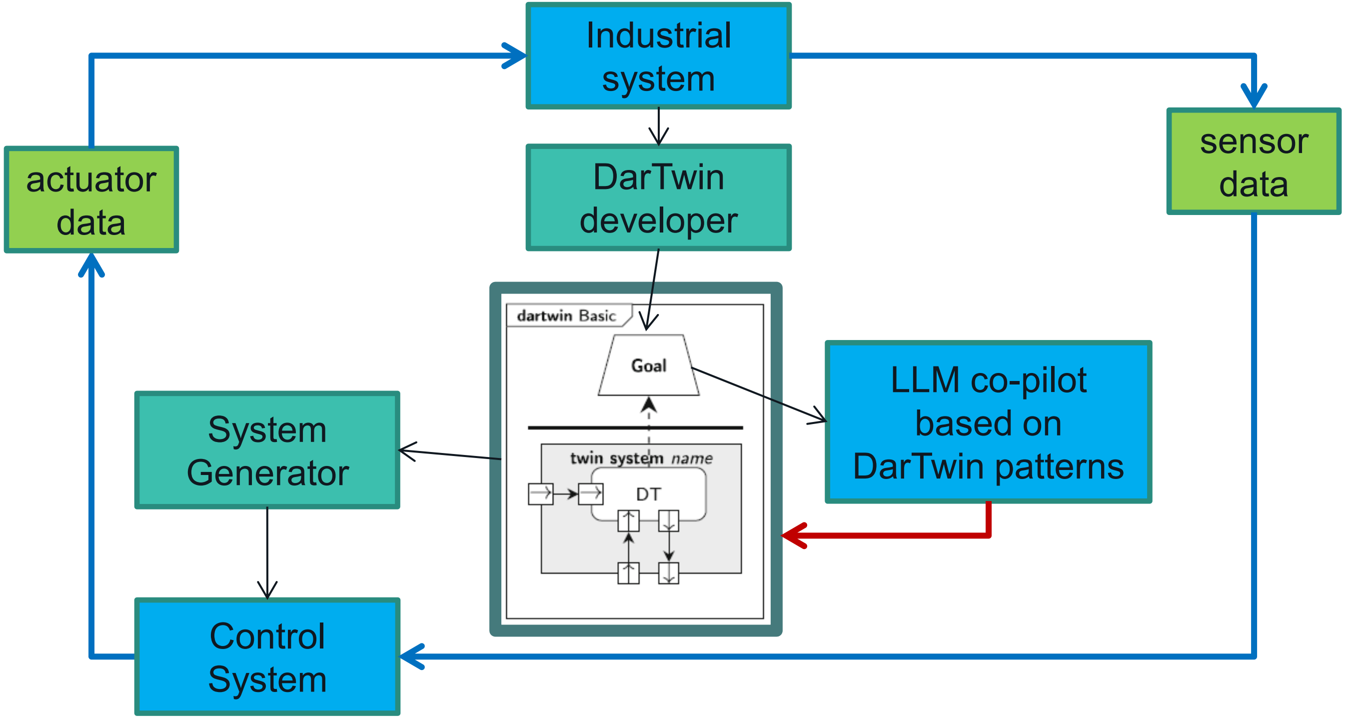


Digital Twins **by** Artificial Intelligence **and** a DarTwin developer



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Formalizing DarTwin in SysML v2

Flat Green Comfort in SysML v2 DarTwin

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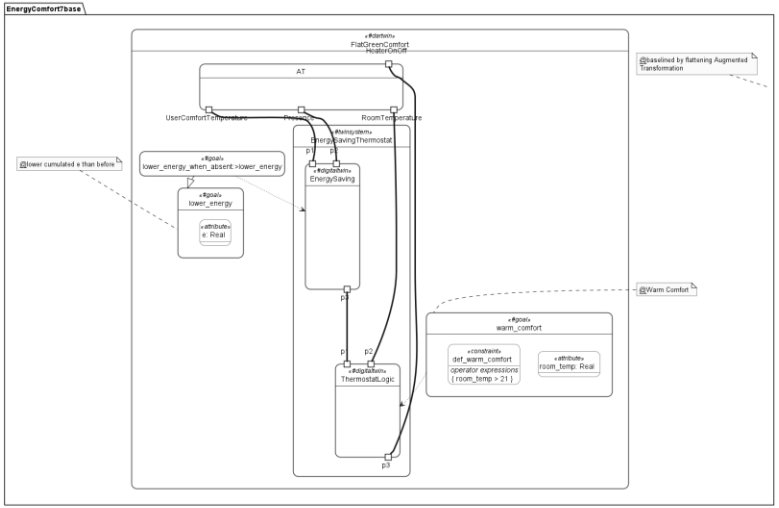

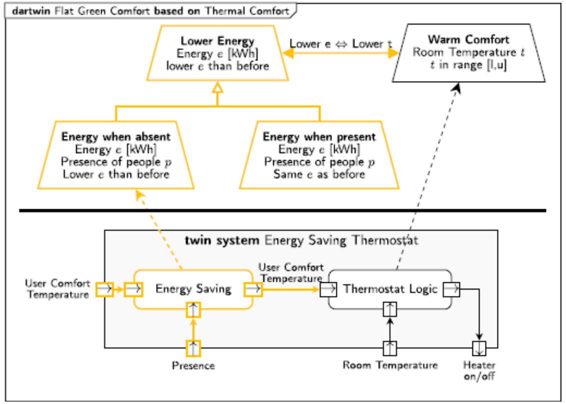


```
#dartwin FlatGreenComfort   {

    #twinsystem EnergySavingThermostat  {

        connect FlatGreenComfort.AT.UserComfortTemperature to EnergySaving.p1;
        connect FlatGreenComfort.AT.RoomTemperature to ThermostatLogic.p2;
        connect ThermostatLogic.p3 to FlatGreenComfort.AT.HeaterOnOff;

        #digitaltwin ThermostatLogic {
            port p1;
            port p2;
            port p3;
        }

        #digitaltwin EnergySaving {
            port p1;
            port p2;
            port p3;
        }

        connect FlatGreenComfort.AT.Presence to EnergySaving.p2;
        connect EnergySaving.p3 to ThermostatLogic.p1;

    } // EnergySavingThermostat


    part AT {
        port UserComfortTemperature;
        port Presence;
        port RoomTemperature;
        port HeaterOnOff;
    }

    #goal warm_comfort {
        doc /* Warm Comfort */
        attribute room_temp:Real;
        constraint def_warm_comfort { room_temp > 21}
    }

    #goal lower_energy {
        attribute e:Real; // Energy kWh
        doc /* lower cumulated e than before */
    }

    #goal lower_energy_when_absent :> lower_energy;

    allocate warm_comfort to EnergySavingThermostat.ThermostatLogic;
    allocate lower_energy_when_absent to EnergySavingThermostat.EnergySaving;

} // FlatGreenComfort
```

Related References

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- SysML v2: the GitHub repository https://github.com/Systems-Modeling/SysML-v2-Release
- Seidewitz., E.: On a metasemantic protocol for modeling language extension. In: Proceedings of the 8th International Conference on Model-Driven Engineering and Software Development - Volume 1: MODELSWARD,. pp. 465{472. INSTICC, SciTePress (2020). https://doi.org/10.5220/0009181604650472

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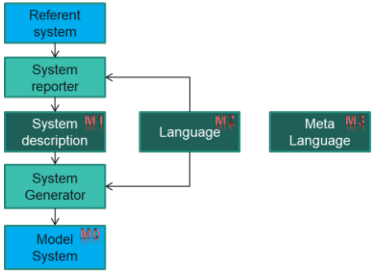

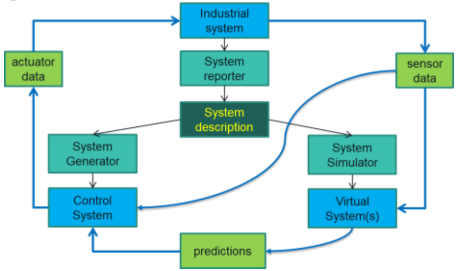

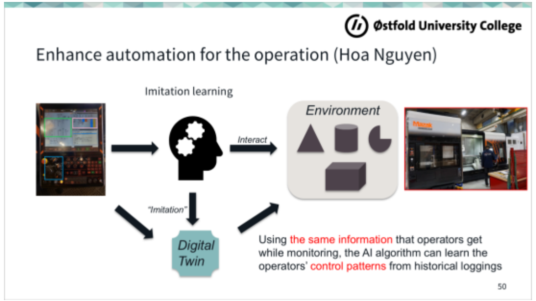


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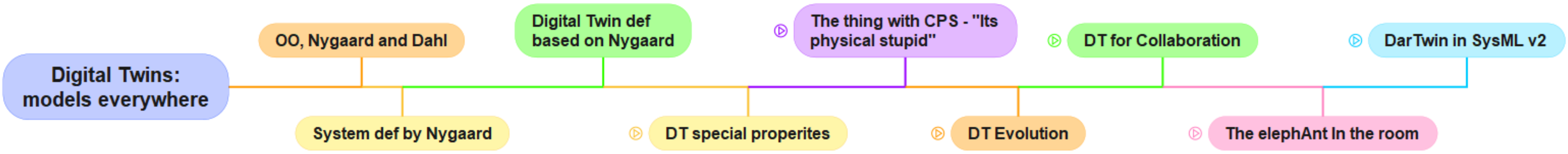
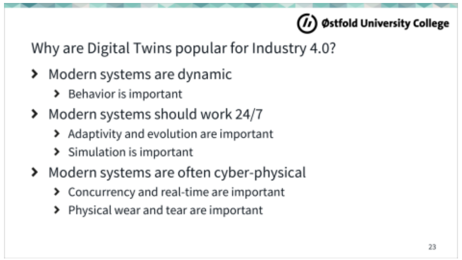
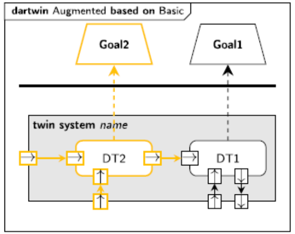
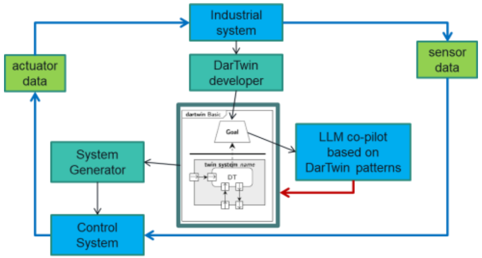


A **system** is a part of the world which *we choose to regard as a whole*, separated from the rest of the world *during some period of* consideration, a whole which we choose to consider as *containing a collection of components*, each characterized by a selected set of associated *data items and patterns*, *and by actions* which may involve itself and other components







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