Digital twin as a Service (DTaaS) Software Platform

Prasad Talasila

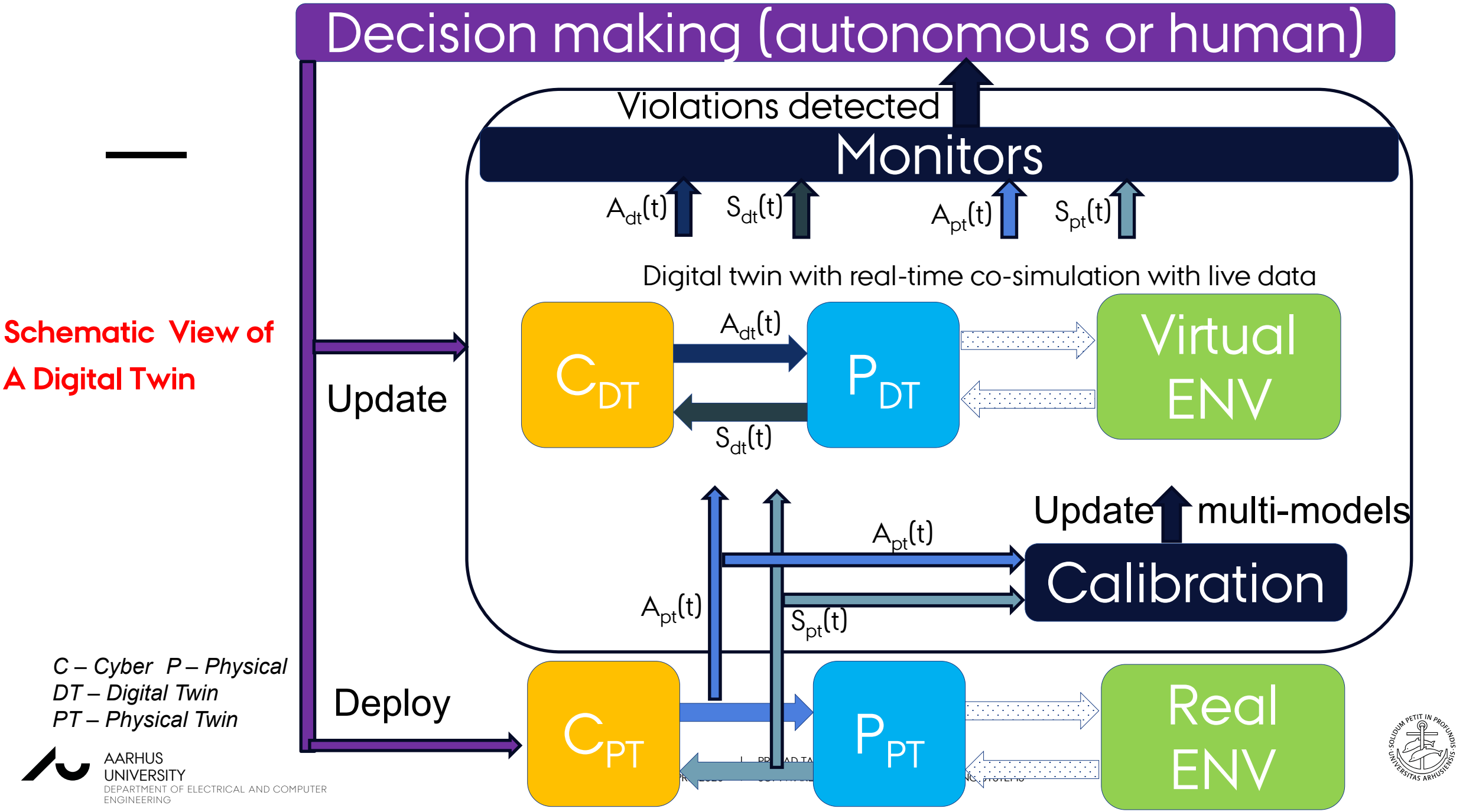
prasad.talasila@ece.au.dk

PRESENTATION OUTLINE

1) Requirements for Digital Twin Platforms
2) A Conceptual Framework
3) DTaaS software platform
4) Implementation Status

PRESENTATION OUTLINE

1) *Requirements for Digital Twin Platforms*
    1) *User Requirements*
    2) Technical Requirements
    3) Example
2) A Conceptual Framework
3) DTaaS software platform
4) Implementation Status

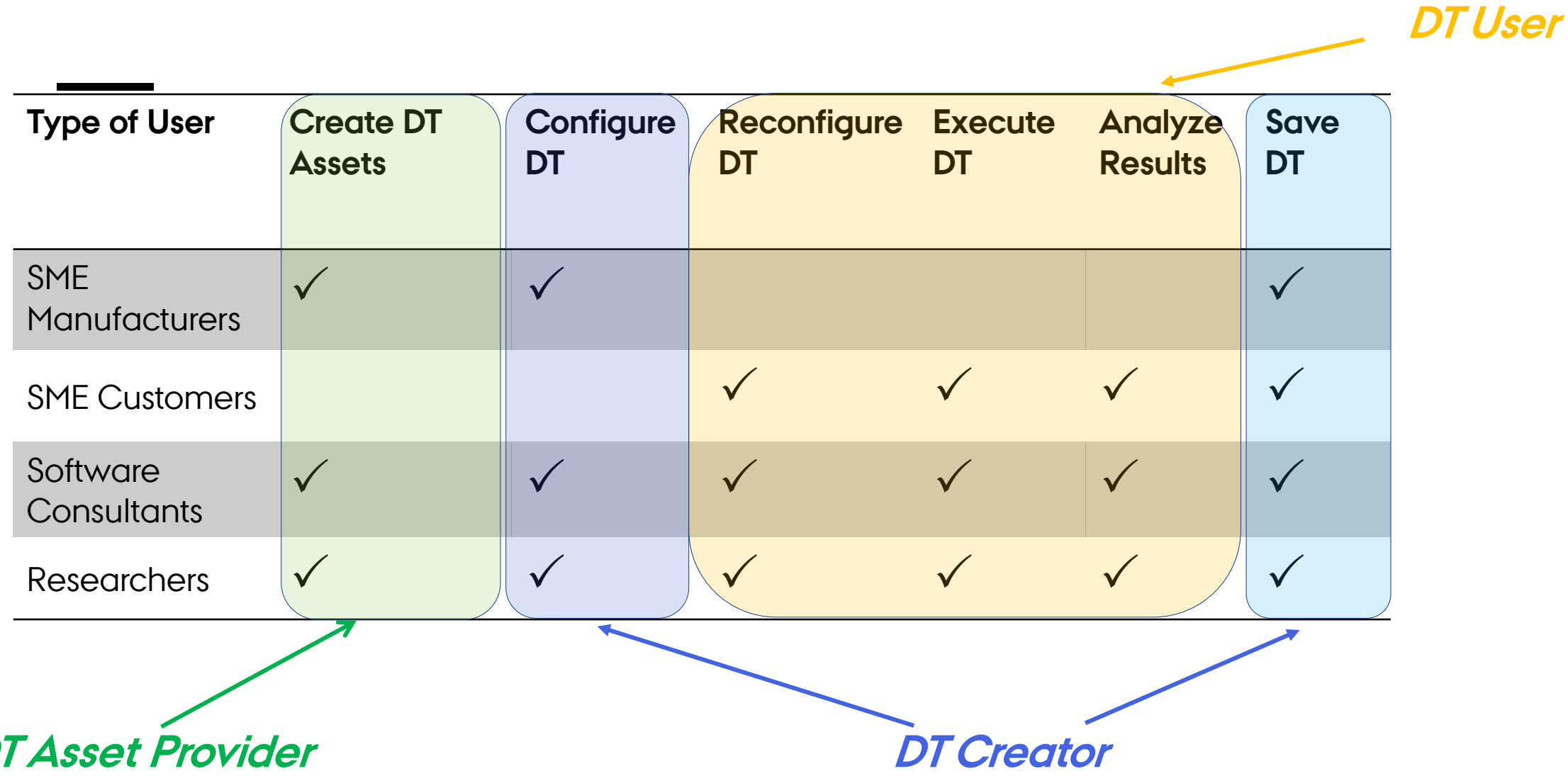


Schematic View of A Digital Twin

C – Cyber P – Physical
DT – Digital Twin
PT – Physical Twin

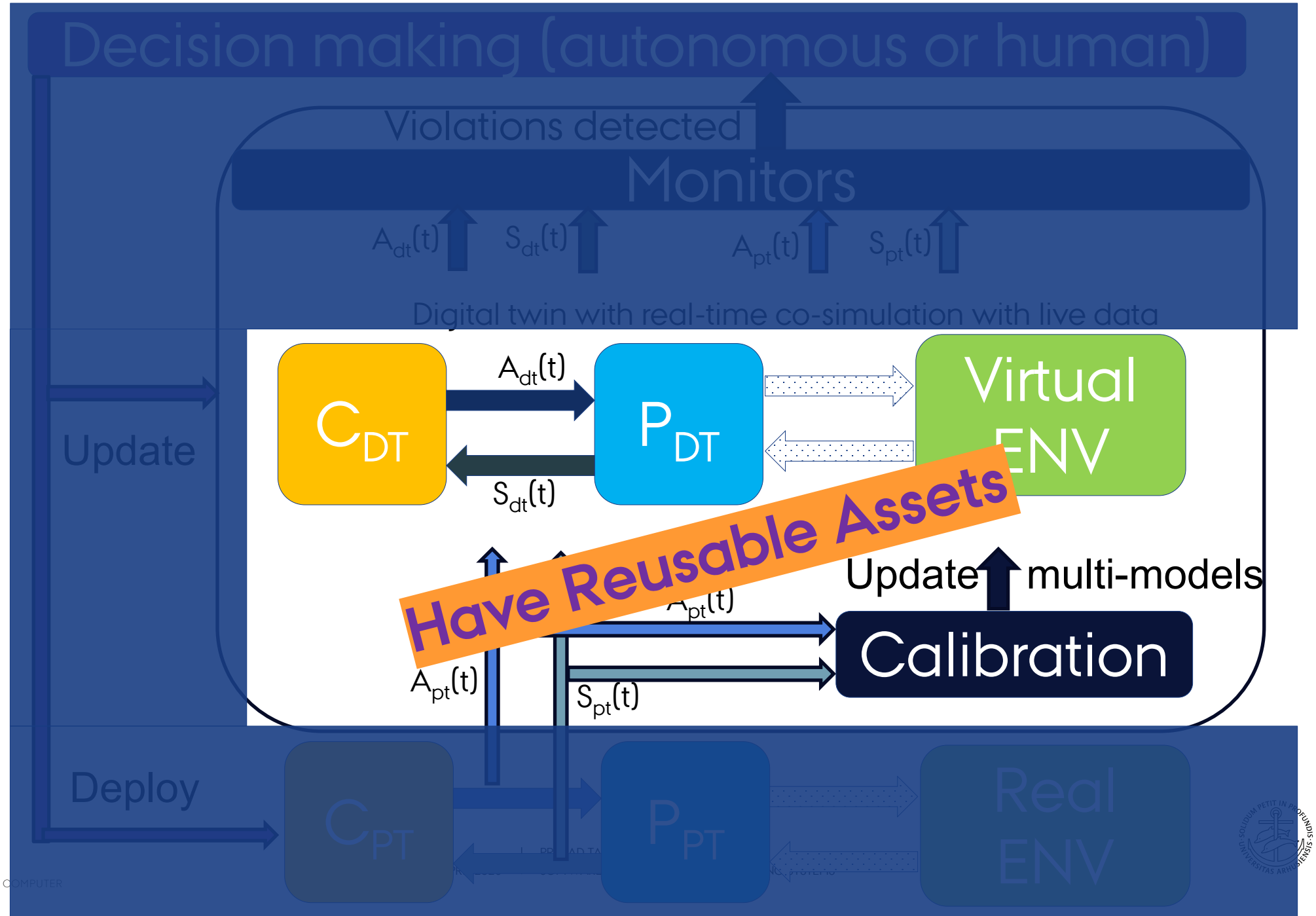
AARHUS UNIVERSITY
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

A PEEK INTO USER ROLES?



PRESENTATION OUTLINE

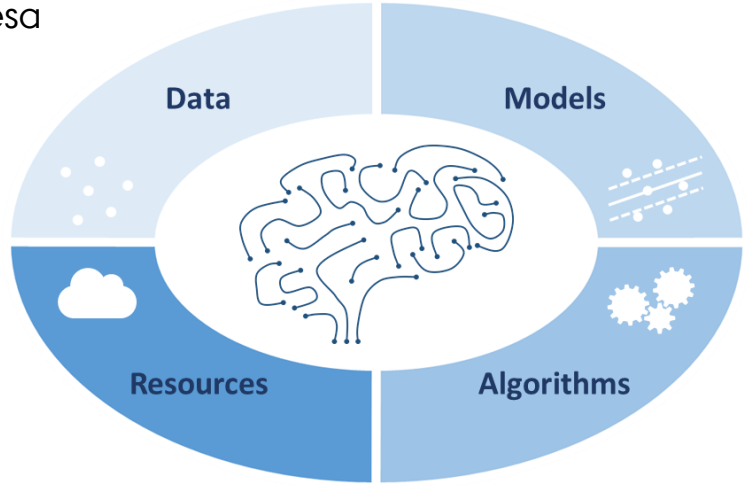
1) *Requirements for Digital Twin Platforms*
    1) User Requirements
    2) *Technical Requirements*
    3) Example
2) A Conceptual Framework
3) DTaaS software platform
4) Implementation Status


Decision making (autonomous or human)
Violations detected
Monitors
$A_{dt}(t)$
$S_{dt}(t)$
$A_{pt}(t)$
$S_{pt}(t)$
Digital twin with real-time co-simulation with live data
Update
C_{DT}
$A_{dt}(t)$
$S_{dt}(t)$
P_{DT}
Virtual ENV
Have Reusable Assets
Update multi-models
$A_{pt}(t)$
$A_{pt}(t)$
$S_{pt}(t)$
Calibration
Deploy
C_{PT}
P_{PT}
Real ENV

Four Categories of Reusable Assets

Data: (users)

Farmers using Agrointelli Robotti
Customers of FabMetrics
Wood drying plants using Prodesa equipment



Models: (manufacturers)

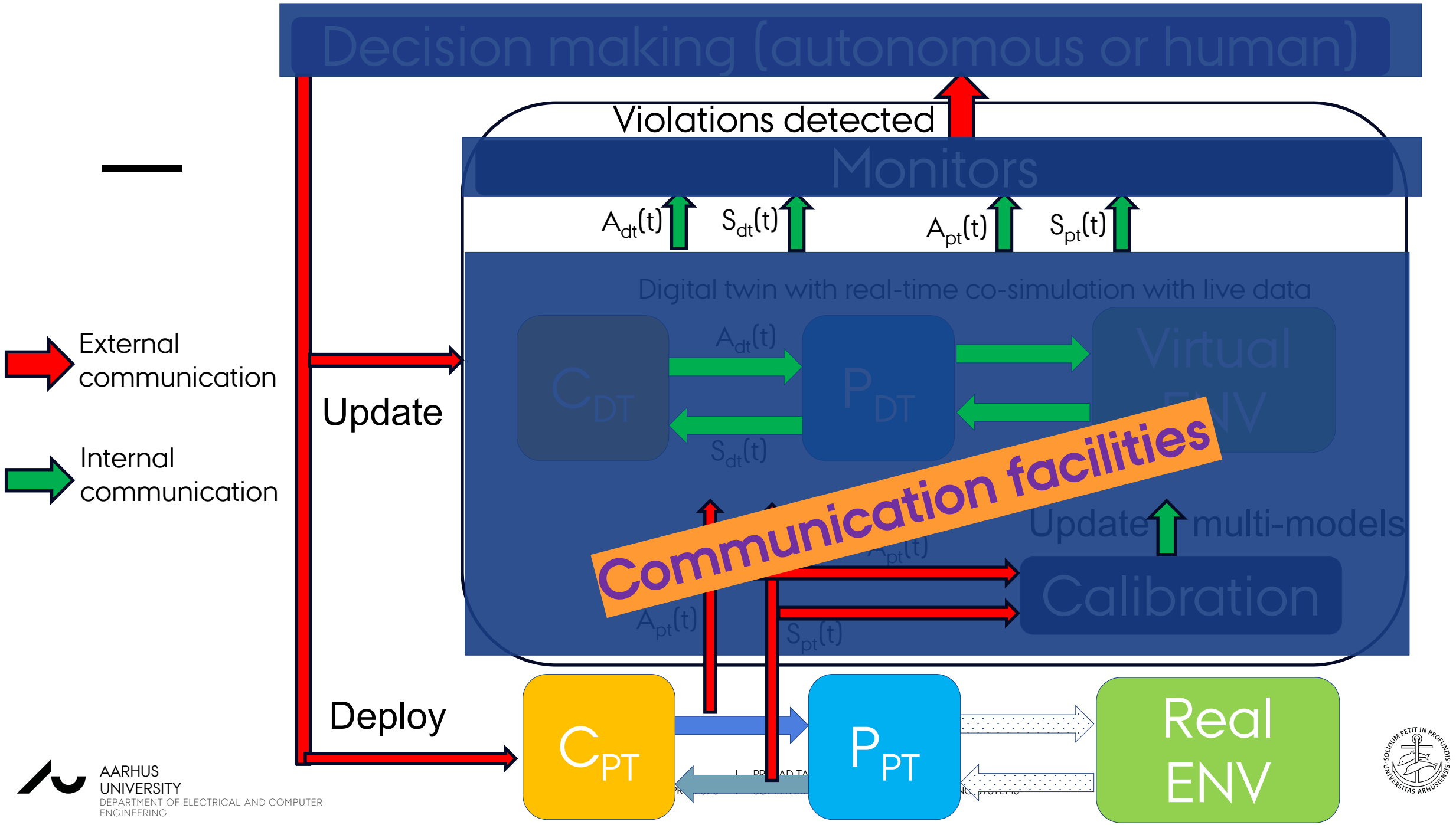
Agrointelli (agricultural robot manufacturing factory and 3D CAD of agricultural robot)
Prodesa (manufacturer of wood pellet dryers)
FabMetrics (manufacturer of glass making equipment)

Execution Platform and Infrastructure:

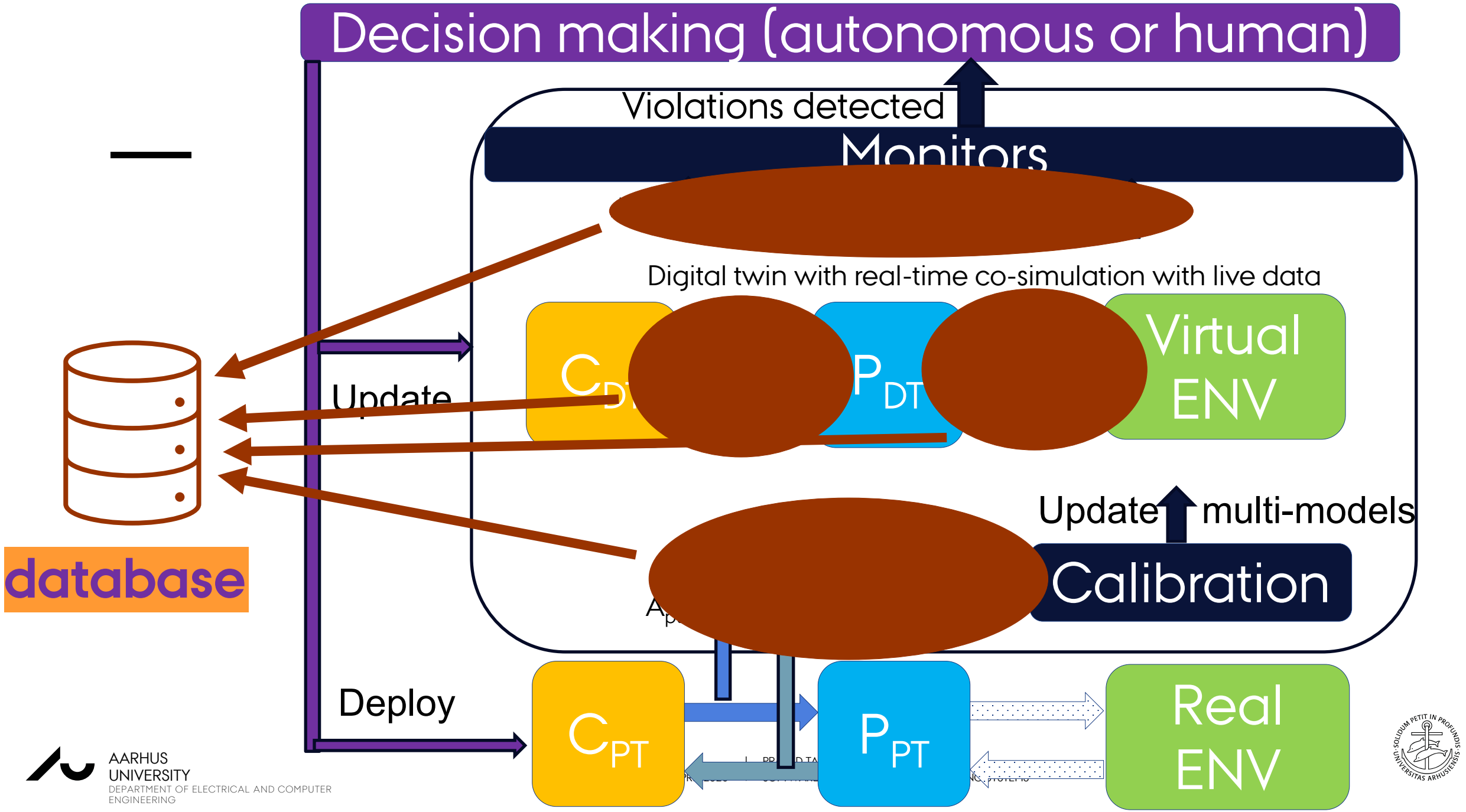
University of Westminister (MiCADO)
SZTAKI (CloudBroker)
EGI (Distributed Cluster Computing Infrastructure)
Public Cloud Services (Azure, AWS)
On-premises (FabMetrics)

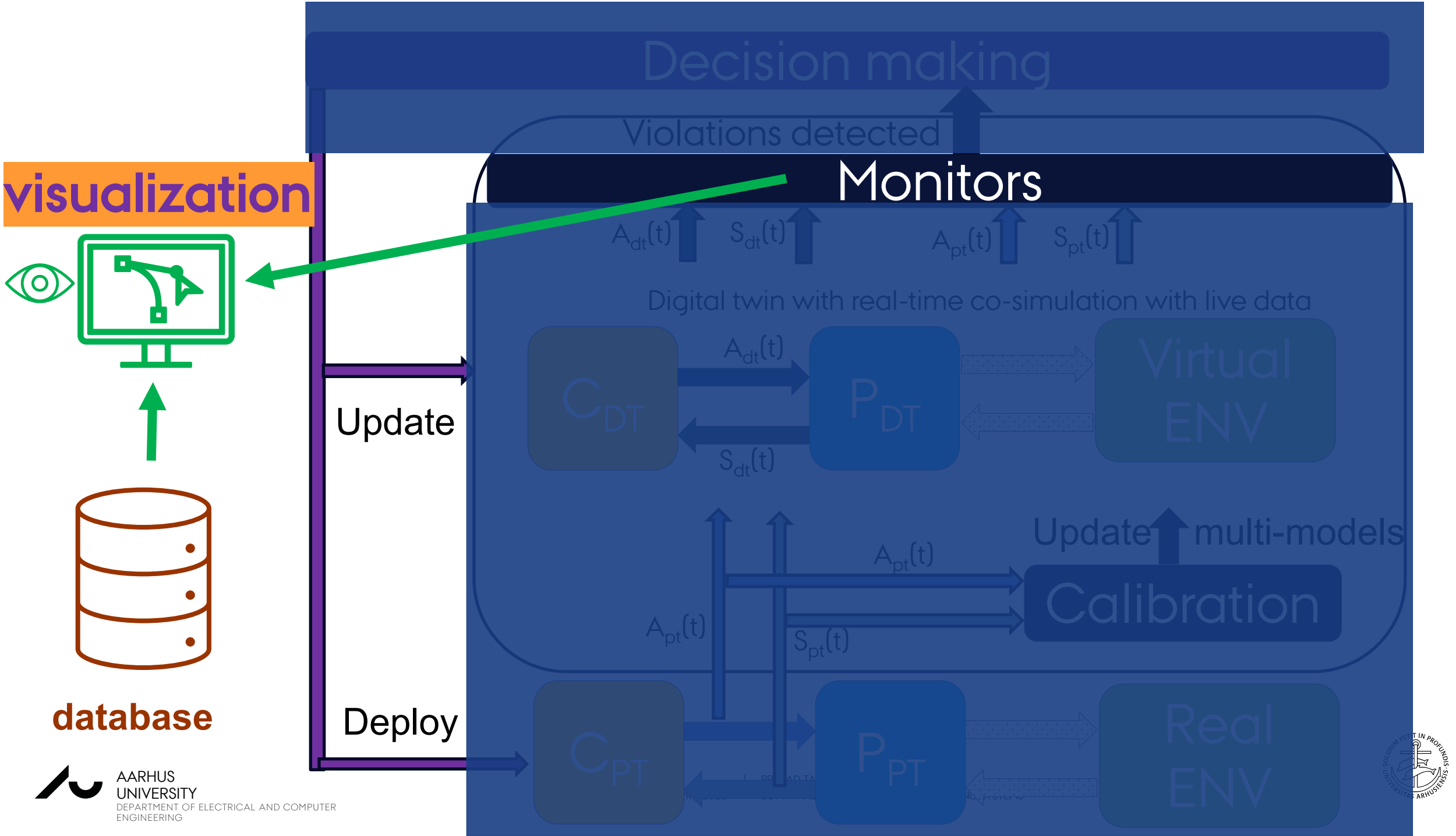
Microservice and Algorithms: (software vendors)

Maestro - co-simulation orchestration engine by Aarhus University
CAELIA –ROM solver and Data Analysis by ITA-INNOVA
DDDSimulator – discrete event simulator and 3D visualizer by TTS
Ristra – Numerical simulator for mechanical structures by IGD, Fraunhofer
SAS a lifecycle assessment tool by SUPSI

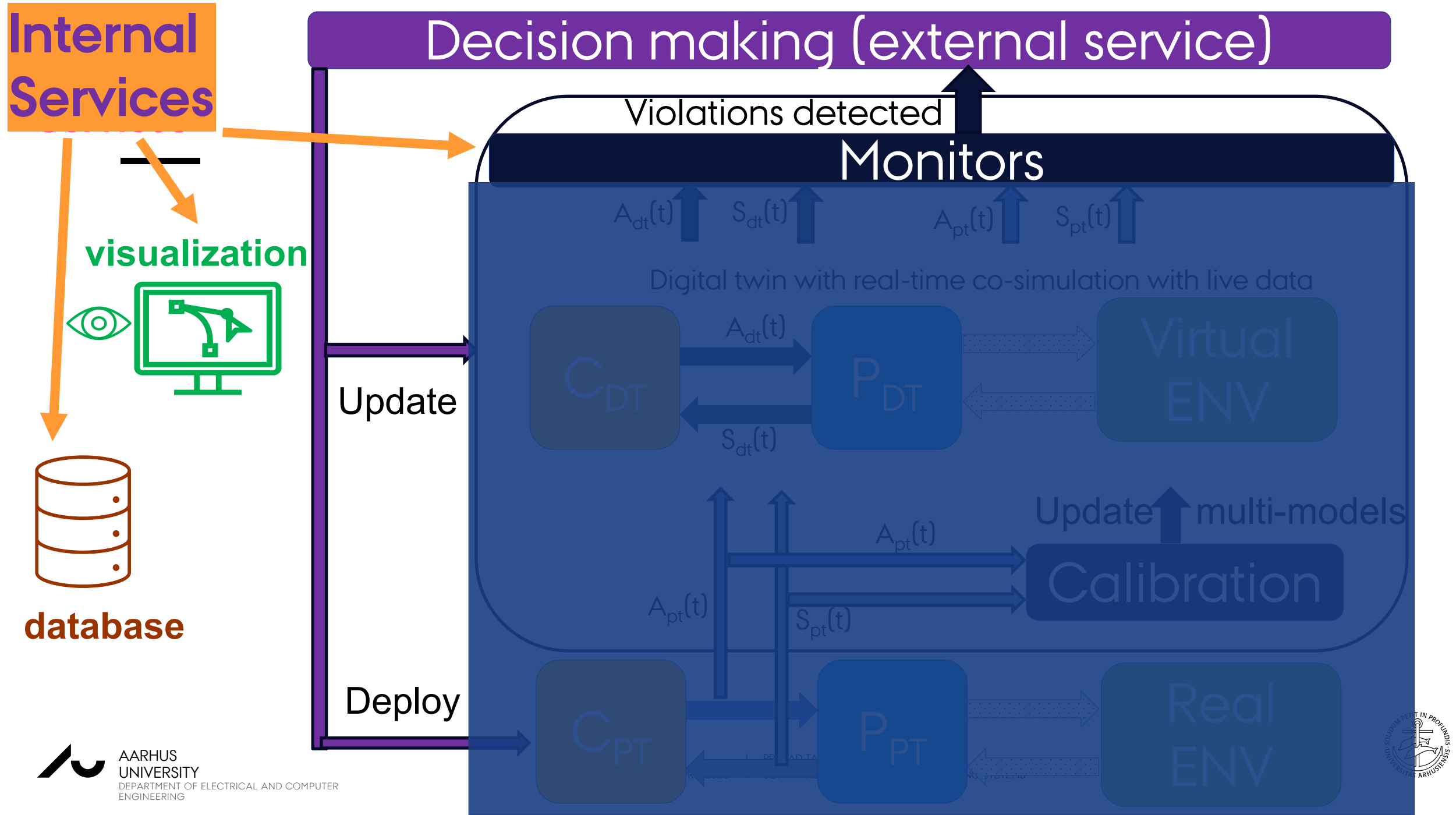


AARHUS UNIVERSITY
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING


Decision making (autonomous or human)
Violations detected
Monitors
Digital twin with real-time co-simulation with live data
Update
C_{DT}
P_{DT}
Virtual ENV
database
Update multi-models
Calibration
Deploy
C_{PT}
P_{PT}
Real ENV



AARHUS UNIVERSITY
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

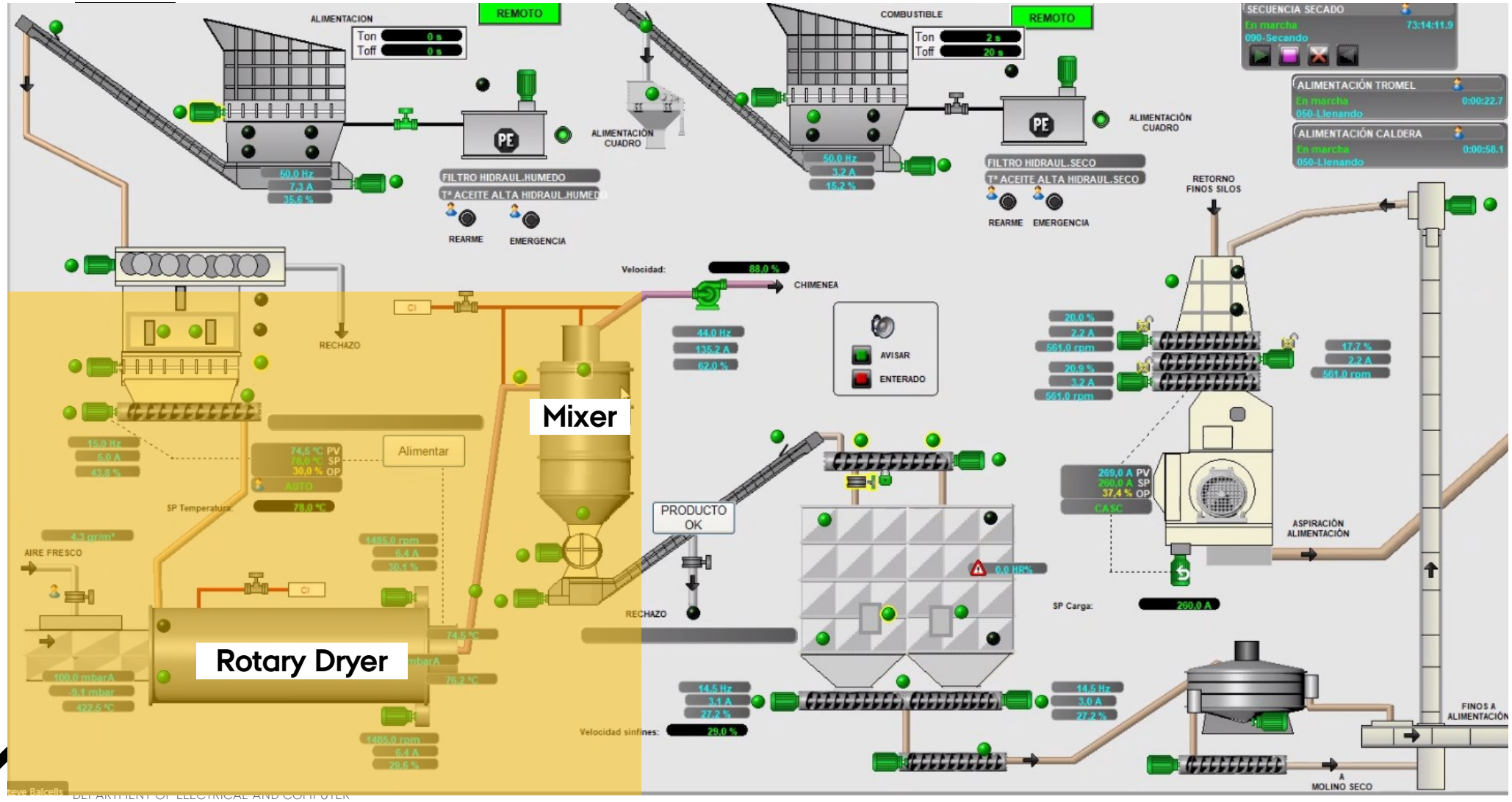


AARHUS UNIVERSITY
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

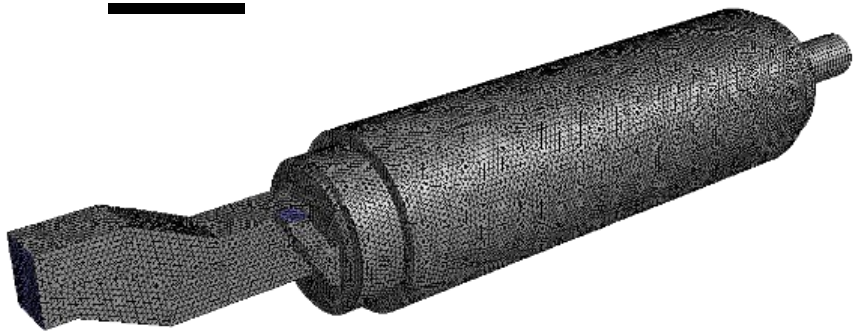
PRESENTATION OUTLINE

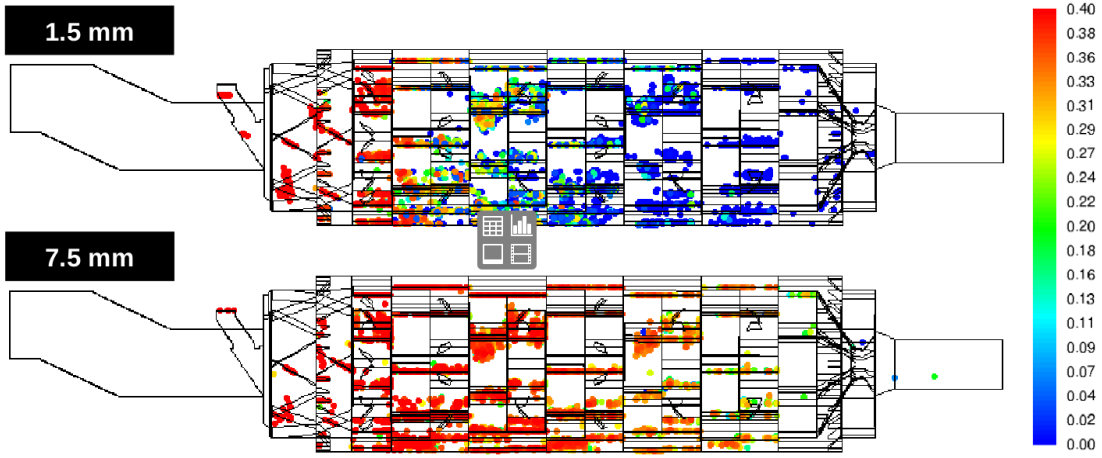
1) *Requirements for Digital Twin Platforms*
    1) User Requirements
    2) Technical Requirements
    3) *Example*
2) A Conceptual Framework
3) DTaaS software platform
4) Implementation Status

WOOD PELLET DRYING PLANT – PRODUCTION OPTIMIZATION



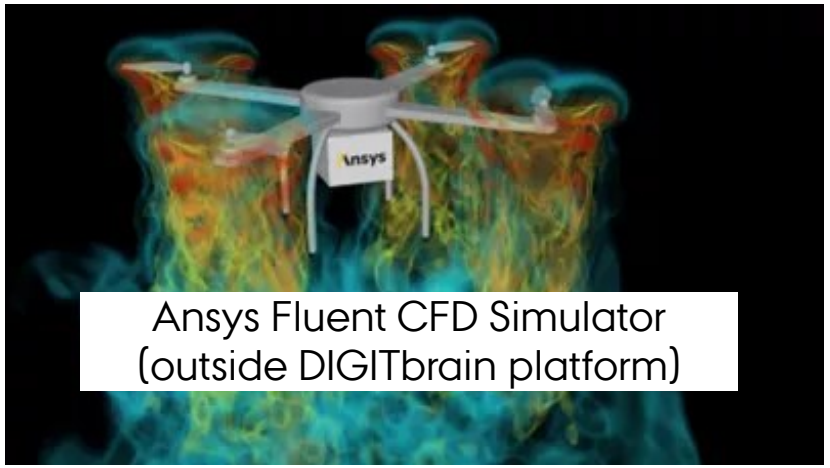
WOOD PELLET DRYING PLANT – COMPETING MODELS: CFD MODEL





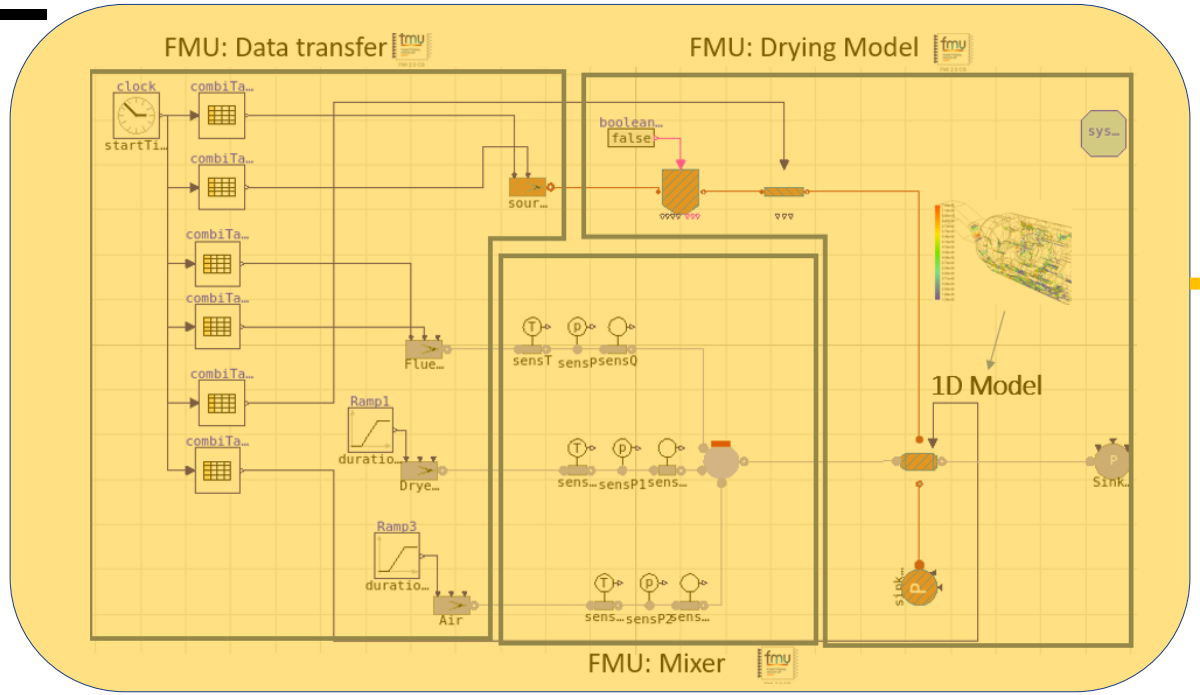
Rotary Dryer CFD Model

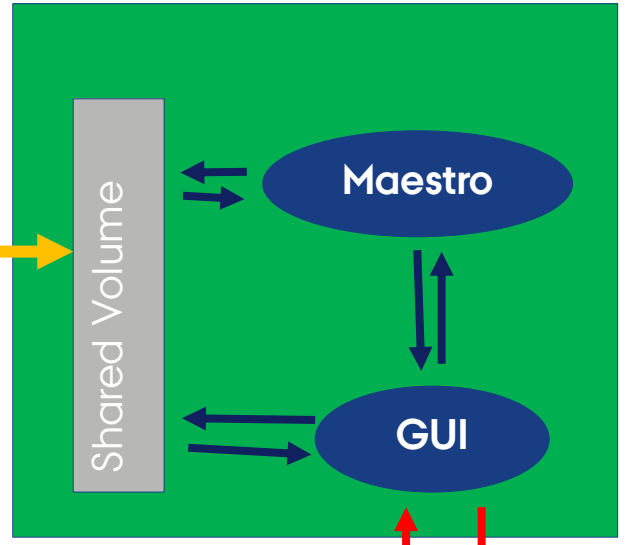
Plant data



Simulation Results

WOOD PELLET DRYING PLANT – COMPETING MODELS: CO-SIMULATION MODELS





Plant data

Optimized production plan

Production Planner

Model Data Microservice Algorithm

PRESENTATION OUTLINE

1) Requirements for Digital Twin Platforms
2) *A Conceptual Framework*
3) DTaaS software platform
4) Implementation Status

DIGITAL TWIN LAYERS: A PROPOSAL

NOTE: This is not a strictly layered architecture

WHAT IS INSIDE THE DIGITAL TWIN LAYERS?

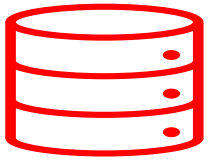
Twin Management

- Configuration of DT
- Analysis/queries capabilities
- Decision support
- Selection of what to visualise

Service Management

- Actual model simulation
- Experimental model simulation
- Monitors
- Calibration
- Reconfiguration
- Trend analysis
- 2D visualisation
- 3D visualisation

Asset Management


Data


Models


Functions


Tools

Data Ingestion & Processing

- Data collection
- Data transmission
- Data storage
- Data processing
- Data fusion
- Data visualization
- Adapters and brokers

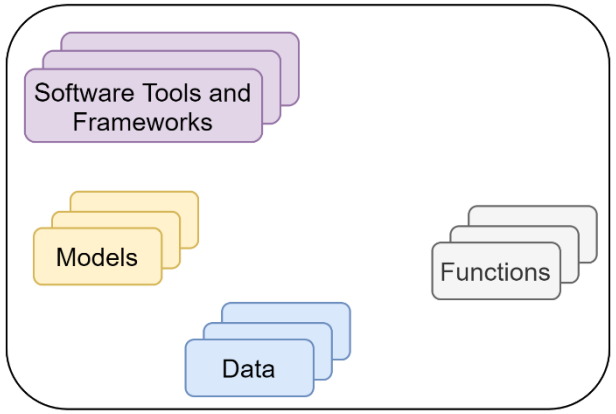
Physical Entities

- System of Systems
- System
- Subsystem
- Component
- Part

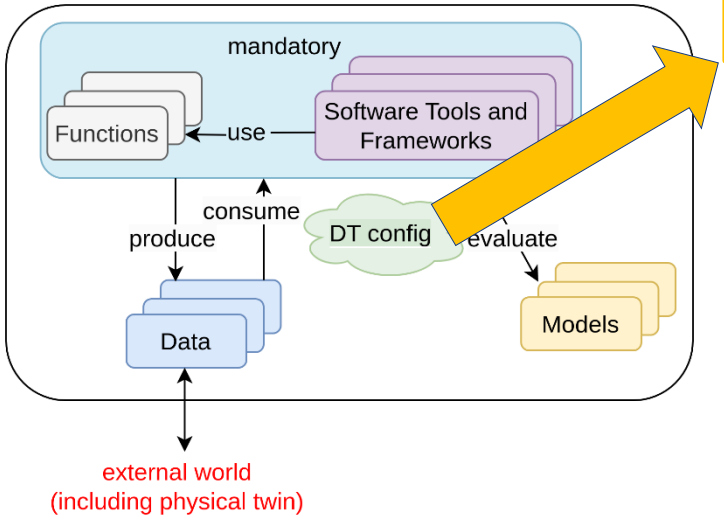
User Interaction

A STEP TOWARDS DEFINING DIGITAL TWINS...

Basic Components



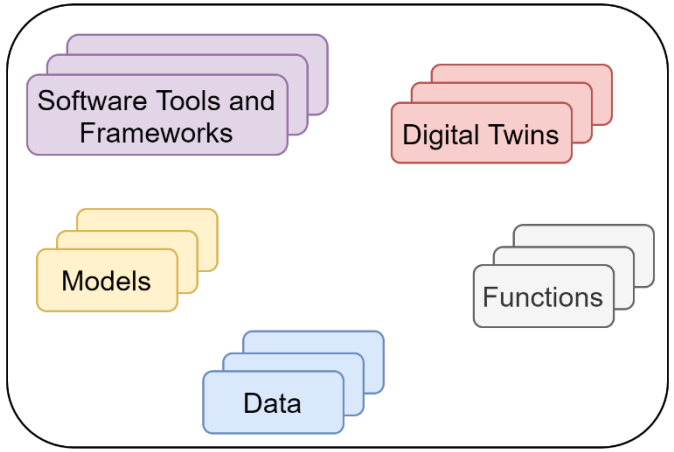
Create DT



DT Config C_{dt}^{l+1}

- Components C_c
- Infrastructure C_i
- Physical twin C_{pt}
- External world C_e
- Internal DTs C_{dt}^{l}
  (flat / hierarchical config)

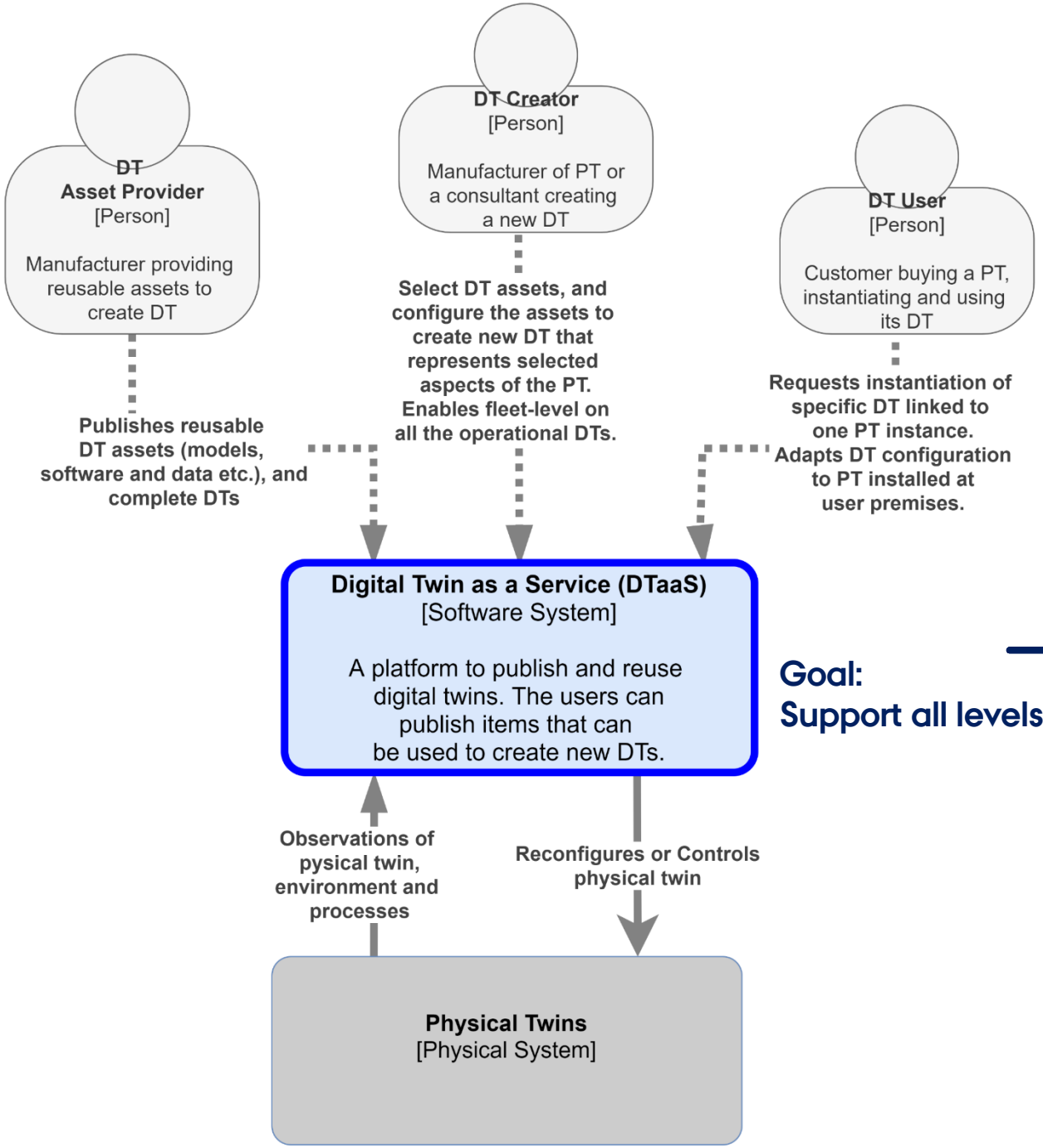
Into the Component Library



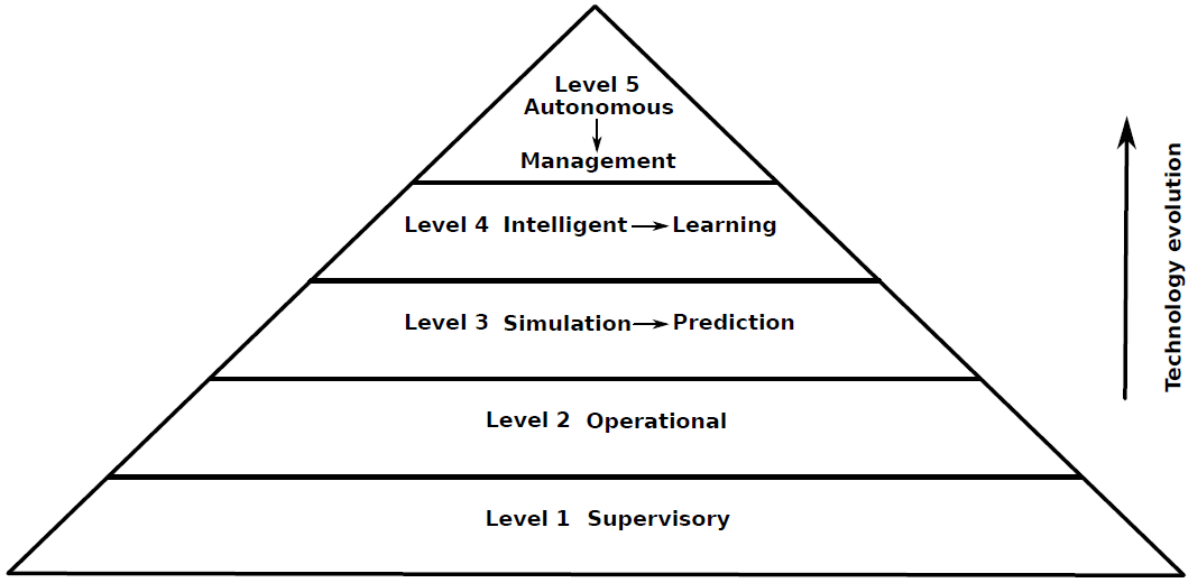
PRESENTATION OUTLINE

1) Requirements for Digital Twin Platforms
2) A Conceptual Framework
3) *DTaaS software platform*
    1) *System Architecture and Design*
    2) Digital Twin Lifecycle Manager
4) Implementation Status

VERY HIGH LEVEL SYSTEM CONTEXT DIAGRAM



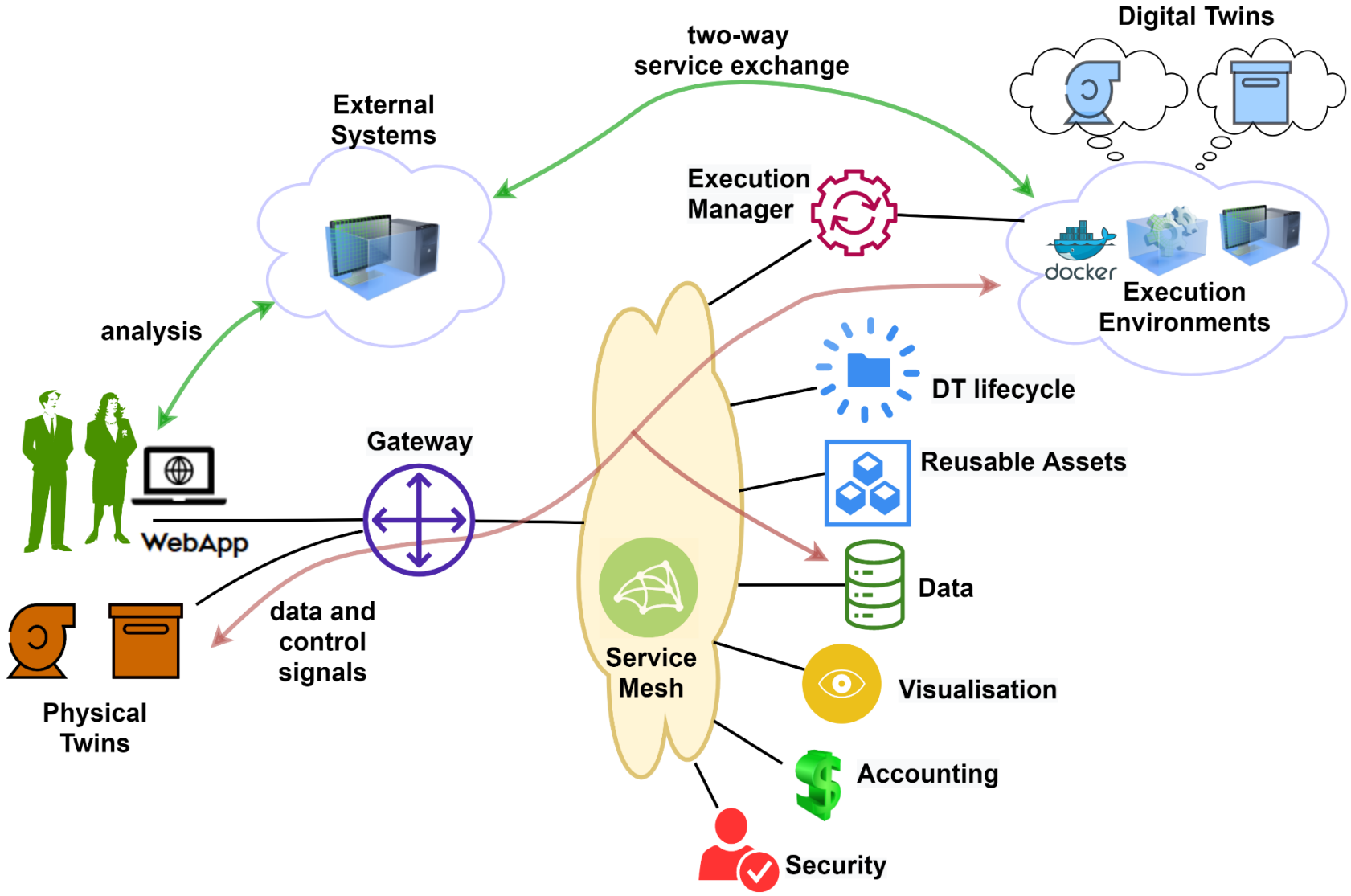
Goal: Support all levels



Hierarchy of DT Capabilities

PRASAD TALASILA
SOFTWARE ENGINEERING AND COMPUTING SYSTEMS

SYSTEM ARCHITECTURE



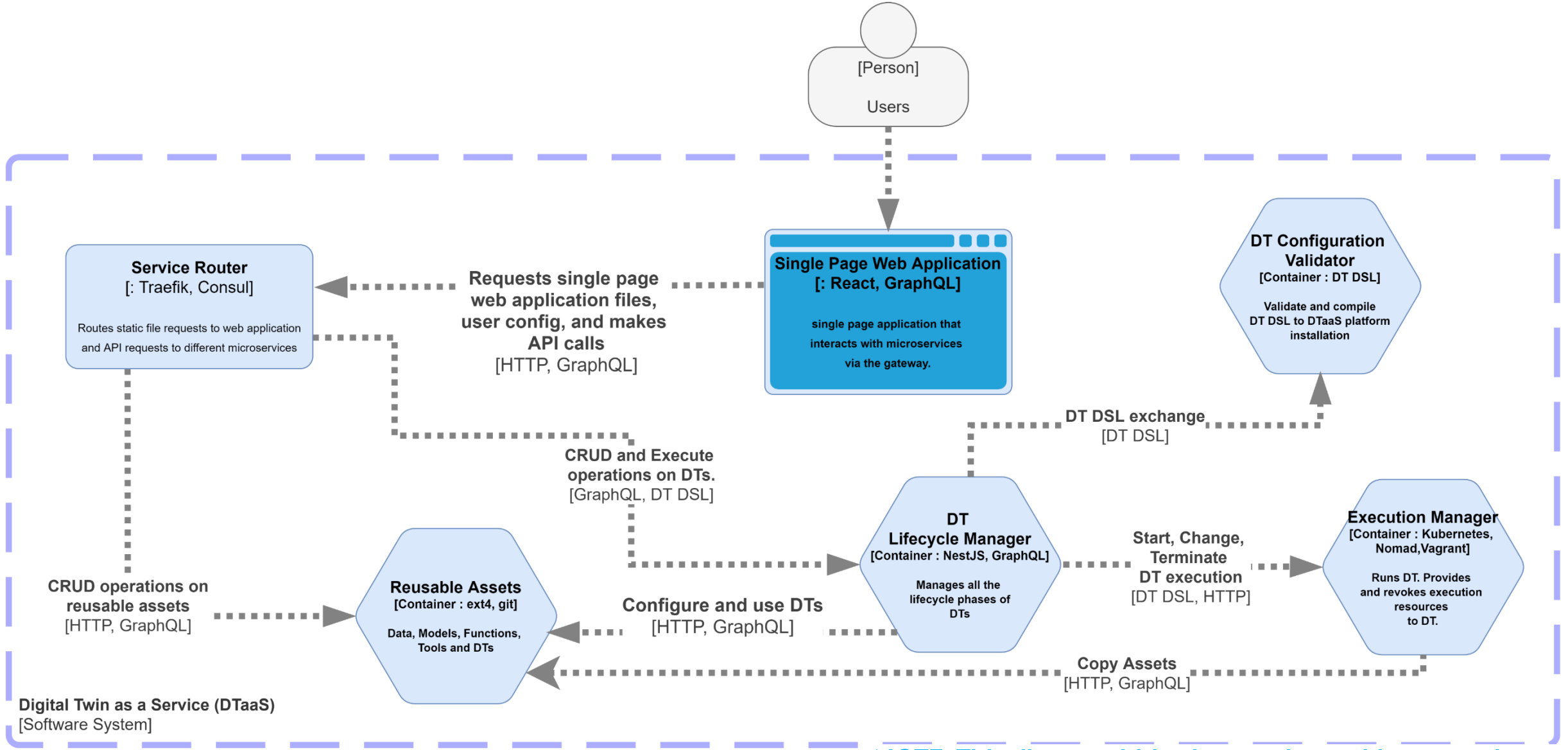
WHAT DO EACH OF THE SYSTEM COMPONENTS DO?

System Component	Responsibilities
security	Authentication and authorization
Accounting	Use of reusable assets and the platform resources
Visualization	Pre-defined or custom visualizations, dashboards etc.
Data	Data archives, Databases etc.
Reusable Assets	Models, Tools, Functions and Digital Twins available for reuse

WHAT DO EACH OF THE SYSTEM COMPONENTS DO? (2)

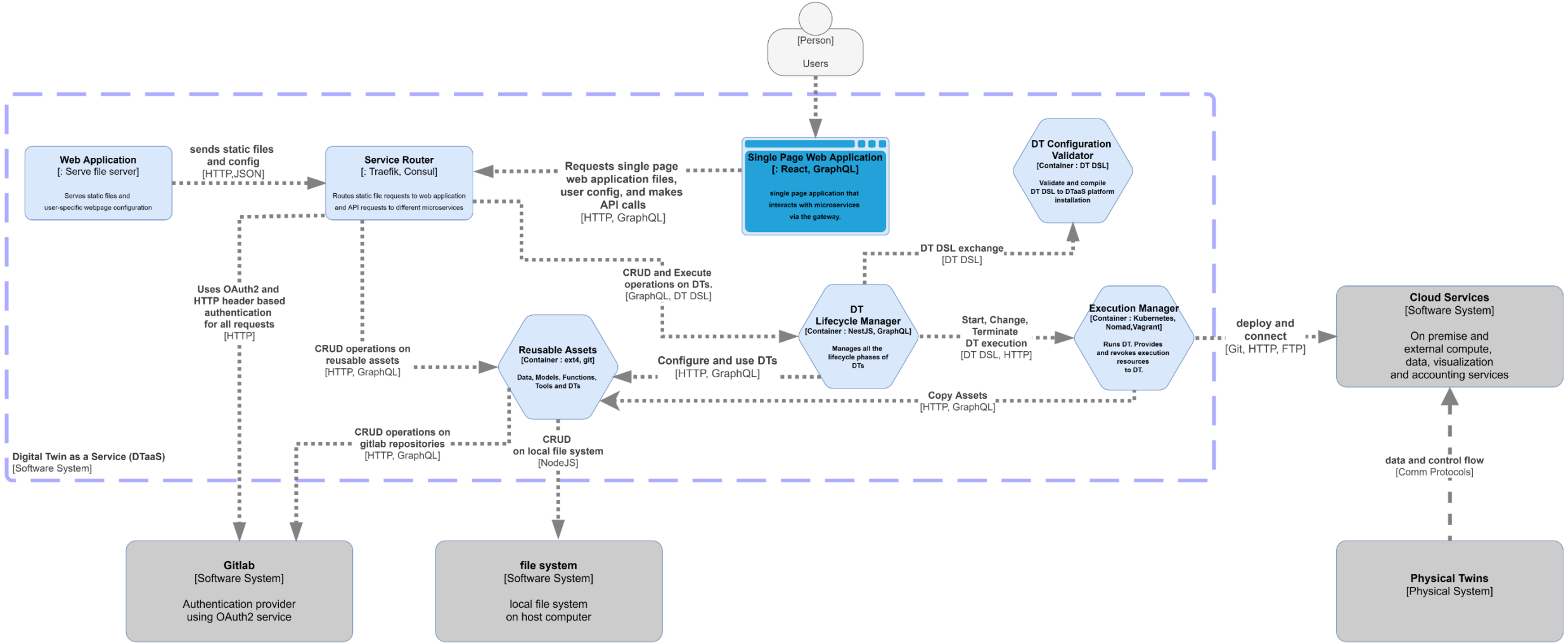
System Component	Responsibilities
DT Lifecycle Manager	Manage digital twins through all their lifecycle stages
Execution Manager	Instantiate and execute digital twins on selected virtualized environments like docker containers, virtual machines, cloud infrastructure.

C4 Level 2 Diagram for Reusable Assets, DT Lifecycle Manager and Execution Manager



NOTE: This diagram hides interactions with external systems

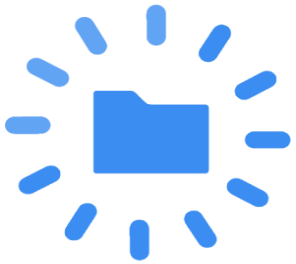
C4 Level 2 Diagram for Reusable Assets, DT Lifecycle Manager and Execution Manager



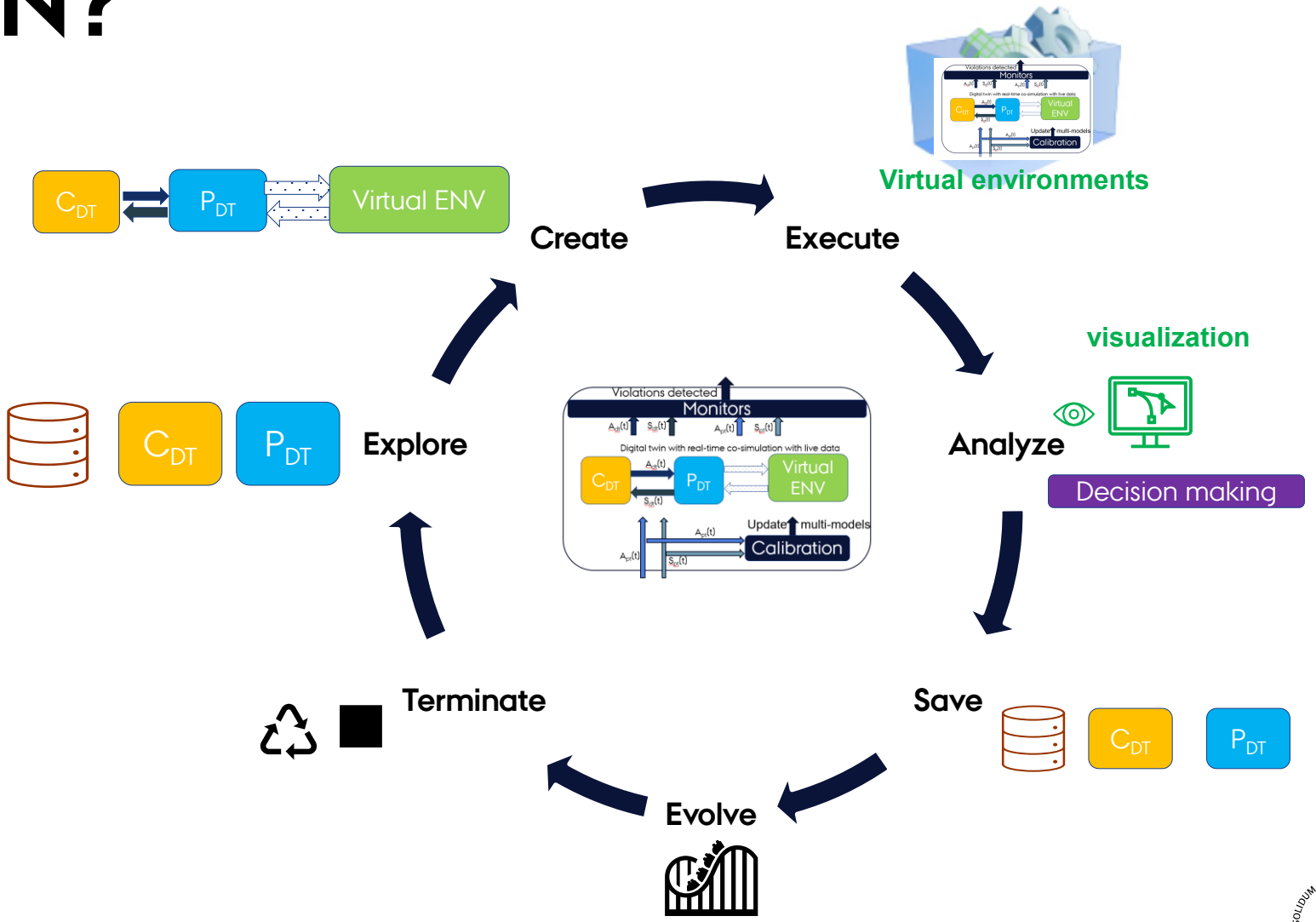
PRESENTATION OUTLINE

1) Requirements for Digital Twin Platforms
2) A Conceptual Framework
3) *DTaaS software platform*
    1) System Architecture and Design
    2) *Digital Twin Lifecycle Manager*
4) Implementation Status

WHAT ARE DIFFERENT LIFECYCLE PHASES A DIGITAL TWIN?



lifecycle manager



IN DEPTH LOOK AT DIGITAL TWIN LIFECYCLE

Author DT Components (on or off platform)

Consolidate and Explore DT Components (like a market place)

Create / Configure new DT (like a Lego playground)

Execute one DT
(with a click)

Scenario Analysis
(execute many DTs with a click)

Analyze (using data science tools)

Save(any of DT components)

Evolve

Terminate

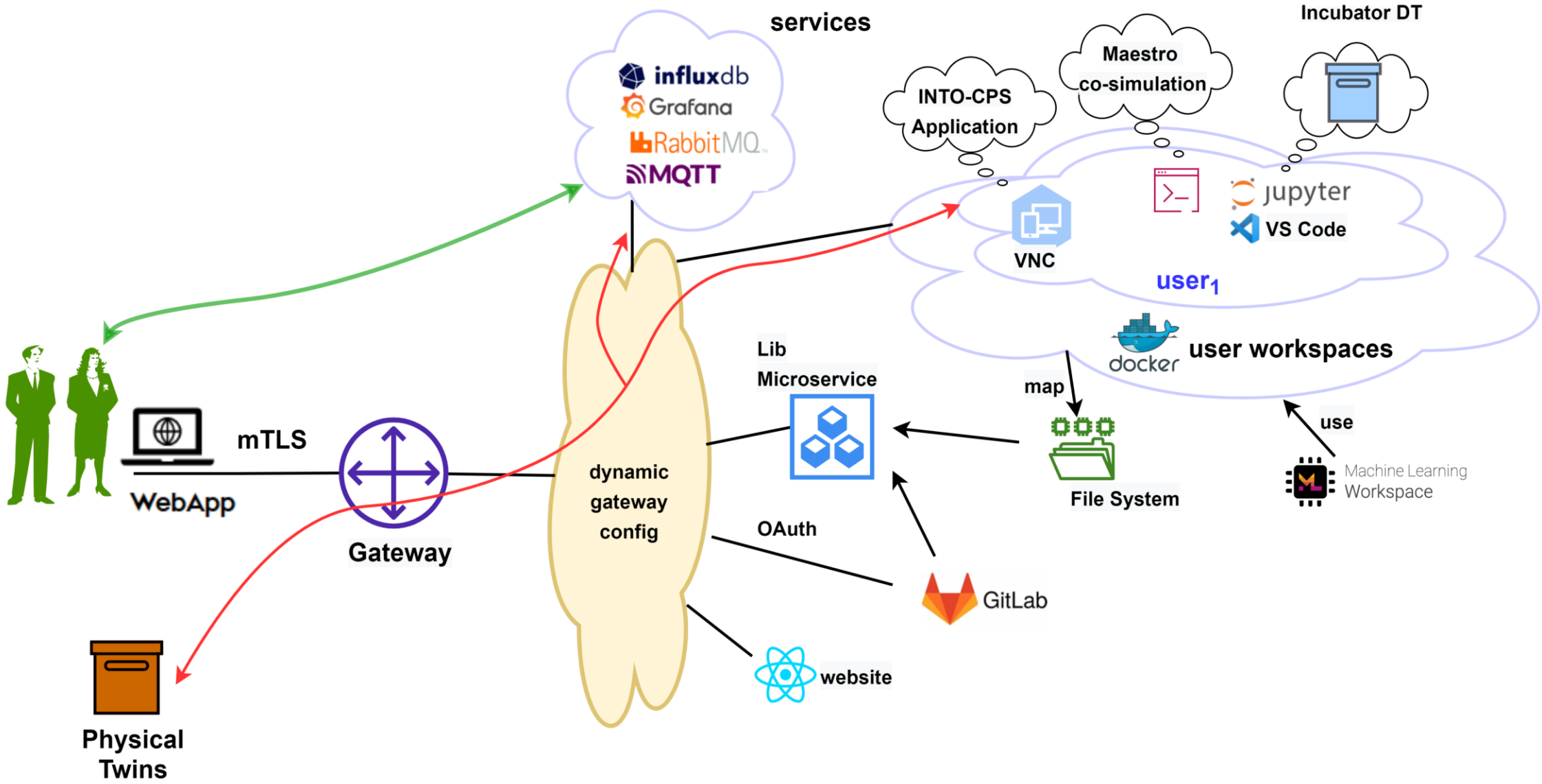
What's the cache?

Not so linear transition

PRESENTATION OUTLINE

1) Requirements for Digital Twin Platforms
2) A Conceptual Framework
3) DTaaS software platform
4) *Implementation Status*

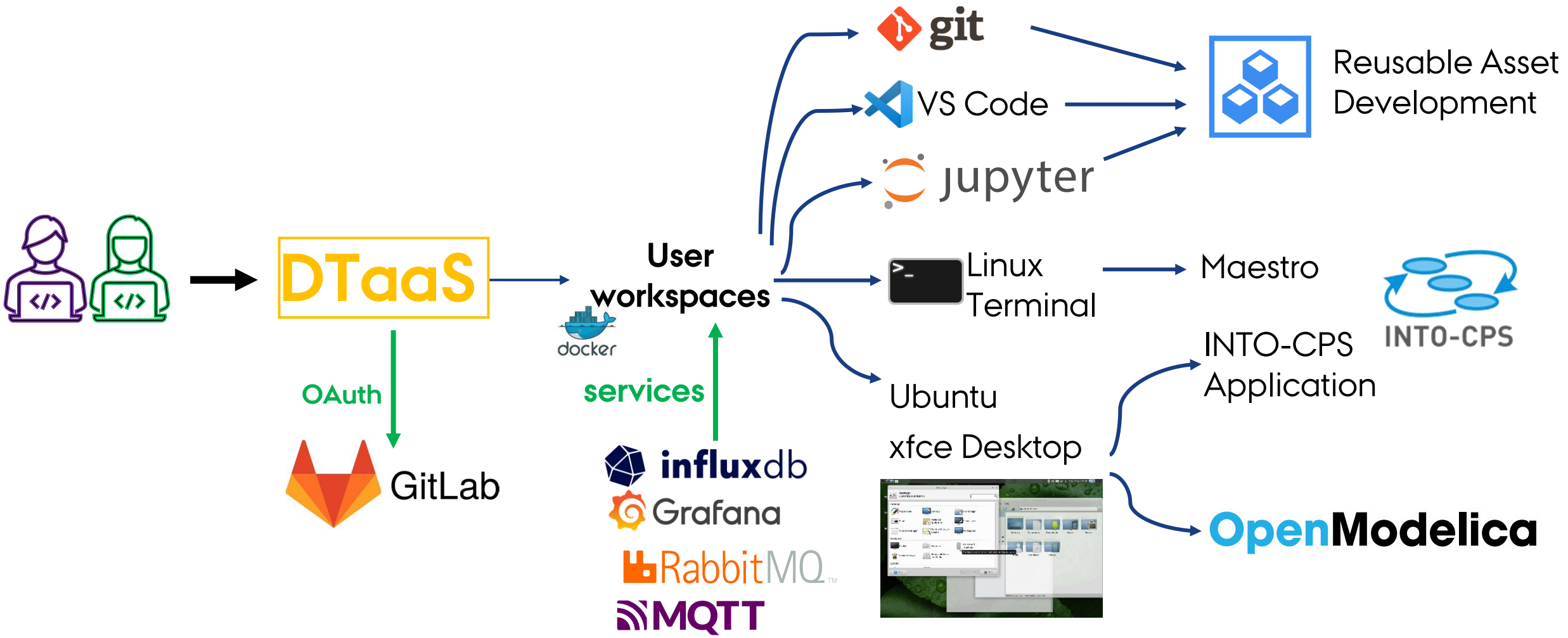
WHAT IS THE CURRENT STATUS?



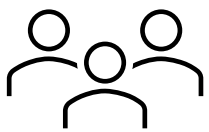
WHAT IS THE CURRENT STATUS?

Component	Current Status of Microservice	Off the Shelf Software	Temporary Replacement
Web Application	Under Development		
Reusable Components	Under Development		local files, gitlab
Security		Gitlab Oauth	
Gateway		Traefik	
Execution Manager	Under Development	MiCADO, Ansible, Vagrant	Static Scripts
Communication Facilities	Integrated into Execution Manager, , Microservice Discovery (Mesh / Consul)	TCP Gateway servicing SSH, RabbitMQ, MQTT	SSH, RabbitMQ, MQTT
Databases	Not Started		InfluxDB
Visualization	Not Started		Grafana
Accounting	Not Started		
DT Lifecycle	Under Development		

EXISTING FEATURES OF DTAAS



DEVELOPMENT PRIORITIES IN IN DTAAS PROJECT



→ **DTaaS** —Active→

- Multi-user and microservice security
- DT Configuration DSL (YAML schema)
- UI for DT creation
- REST Interface to DT
- DT examples

REFERNCES

- Peter Gorm Larsen, Increasing Dependability of Cyber-Physical Systems by using Digital Twins (Presentation), March 2023.
- John Fitzgerald, Claudio Gomes and Peter Gorm Larsen (Editors), The Engineering of Digital Twins (book draft), May 2023
- Wagg, D., Worden, K. orcid.org/0000-0002-1035-238X, Barthorpe, R. et al. (1 more author) (2020) Digital twins: State-of-the-art future directions for modelling and simulation in engineering dynamics applications. ASCE - ASME Journal of Risk and Uncertainty in Engineering Systems, Part B. Mechanical Engineering, 6 (3). 030901. ISSN 2332-9017.
- https://accord-global.com/software_engineering_services.html (system software development processes), accessed: 26-April-2023
- INCOSE Systems Engineering Handbook, 4th Edition, 2015.
- Images: Docker, InfluxDB, Grafana, RabbitMQ, MQTT, VSCode, Jupyter, xfce desktop, Linux Terminal, git, OpenModelica, Matlab, Gitlab
- DIGITbrain deliverables – A EU Horizon 2020 project under grant number 952071.
- Data Ingestion and Processing and platform comparison
  Qi, Q., Tao, F., Hu, T., Anwer, N., Liu, A., Wei, Y., Wang, L., & Nee, A. Y. (2021). Enabling technologies and tools for digital twin. Journal of Manufacturing Systems, 58 (PB), 3–21. https://doi.org/10.1016/j.jmsy.2019.10.001
- Fei Tao, Meng Zhang, Yushan Liu, A.Y.C. Nee, Digital twin driven prognostics and health management for complex equipment, CIRP Annals, Volume 67, Issue 1, 2018, Pages 169-172, ISSN 0007-8506 (5 dimensional digital twin)
- Tekinerdogan, Bedir, and Cor Verdouw. "Systems architecture design pattern catalog for developing digital twins." *Sensors* 20.18 (2020): 5103.

AARHUS
UNIVERSITY