Combining Multi-Agent System and Knowledge Graph to Address the Resolution of Decentralized Problems following Digital Twins approach in Open Cyber-Physical System

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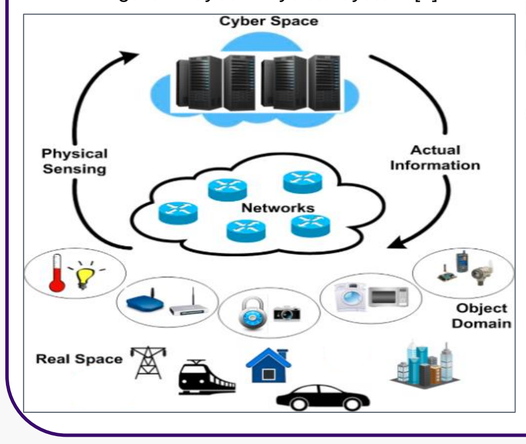
I. Context

Cyber-Physical System (CPS): system in which computing devices work together to control and command physical entities in a feedback loop.

Figure 1. Cyber-Physical System [1]



Use case – **Urban logistics** (Last miles deliveries)

Open CPS allows:

- Optimizing delivery route
- Ensuring ponctual delivery schedule
- Handling unexpected events on-the-fly
- **Decentralising decision-making**
- Involving multiple stakeholders

II. Research Problem

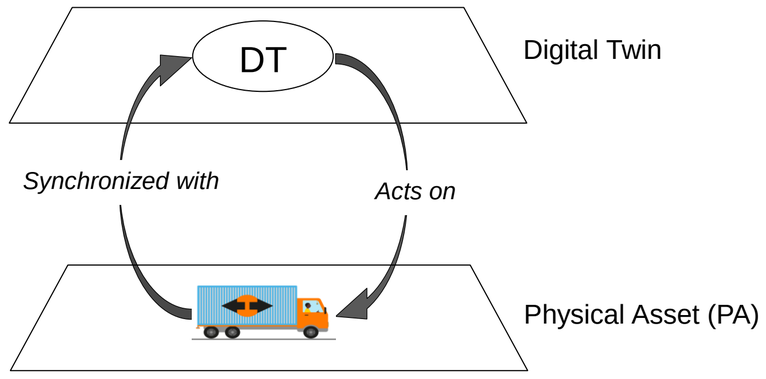
How to address resolution of decentralized problems in open Cyber-Physical System?

Resolving decentralized problems involves multiple independent entities that collaborate to achieve a common goal or address a common issue without central control.

III. State of the art

Multi-Agent System (MAS) simulates the physical assets (PA) and makes decisions (eg. in Healthcare4.0, Smart City, Smart Grids), but physical assets cannot be directly modified by agents.

Digital Twin (DT) connects the physical and digital worlds [2,3]



In [2,3] agents are responsible for achieving the application's goals by using DTs to access and control the physical world.

However, [2,3] fails to consider the autonomy of the physical world and decision are taken at applications layer.

How can DTs coordinate to make autonomous decisions, monitor, control, and act upon their physical counterparts?

IV. Proposed Solution

Hypothesis

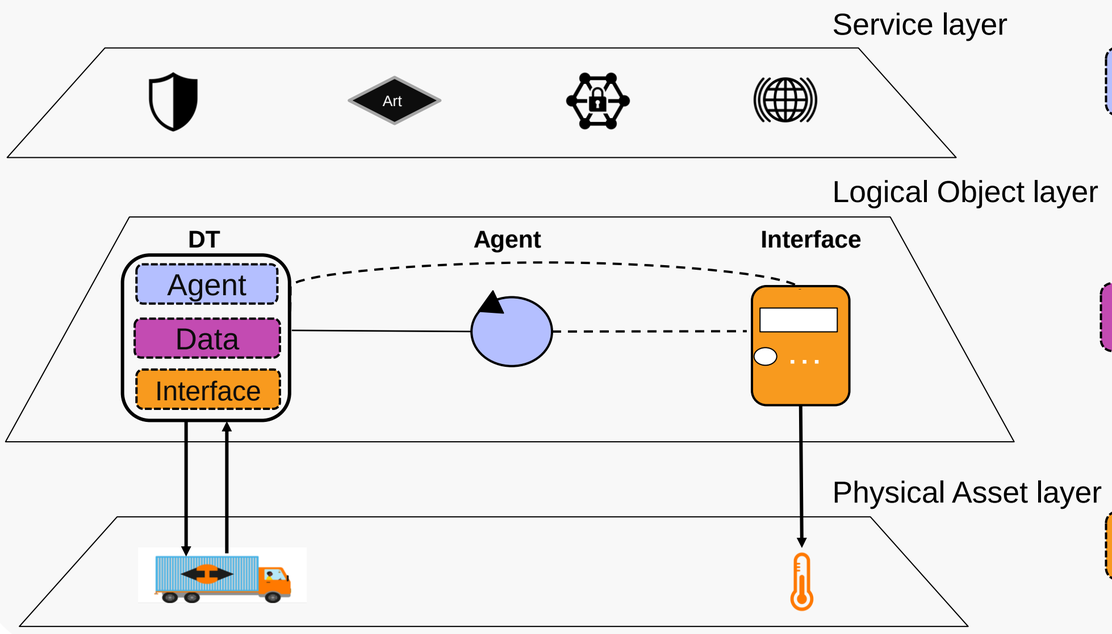
DT is:

- atomic ;
- autonomous ;
- collaborating with other DTs in the system.

Requirements:

- Distributed autonomous decision-making in the Logical Object layer by DTs and agents
- DT takes actions to change physical assets
- Effective communication and coordination among DTs and agents in the Logical Object layer
- Semantic modelling of the physical world

Proposed Architecture



Agent ⇨ Autonomous entity: communication (coordination, negotiation, argumentation), autonomous decision (operational- tactical- strategic planification, simulation, analytics, prediction, control)

Data ⇨ System knowledge with real-time updates: knowledge graph (current state of the PA - representations, PA model, historization), behavior model

Interface ⇨ Interface between the digital twin and its physical counterpart (used to change the state of the physical asset): synchronization, monitoring, operations

References

[1] https://www.researchgate.net/figure/Examples-of-cyber-physical-systems_fig1_346986587
[2] About Digital Twins, agents, and multiagent systems: a cross-fertilisation journey by Stefano Mariani, Marco Picone, Alessandro Ricci (2022)
[3] Web of digital twins. *ACM Transactions on Internet Technology*, Ricci, A., Croatti, A., Mariani, S., Montagna, S., & Picone, M. (2022). *22*(4), 1-30.

V. Conclusion & Perspectives

The proposed architecture enables the digital twins to operate autonomously within the Logical Object layer and modify the state of the corresponding physical assets, thus promoting real-time adaptation and optimization.

Perspectives

- Integration of behavior models in the architecture
- Manage decision conflicts between the digital and physical world

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