Revisit of COIN with the Advances of the last 4 years: Combining Programmable and Distributed Systems, AI and Digital Twins

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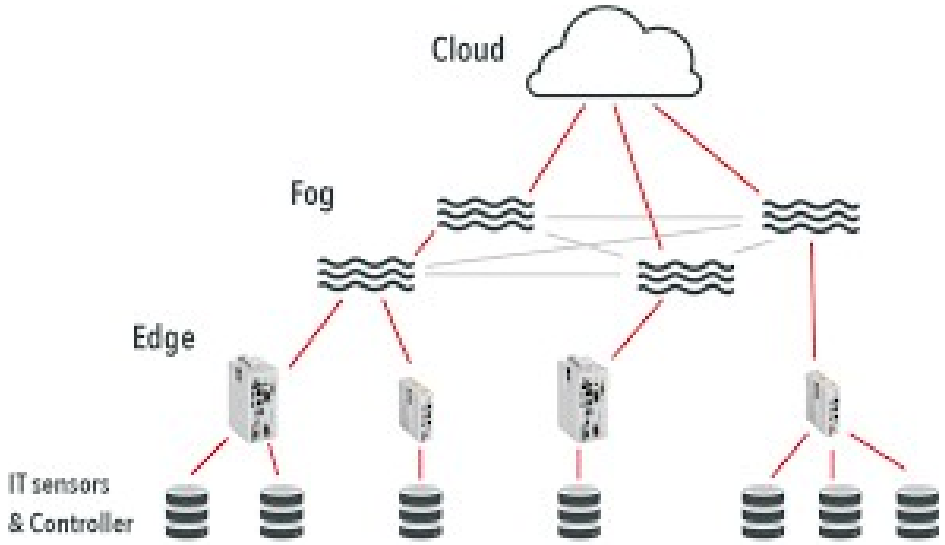
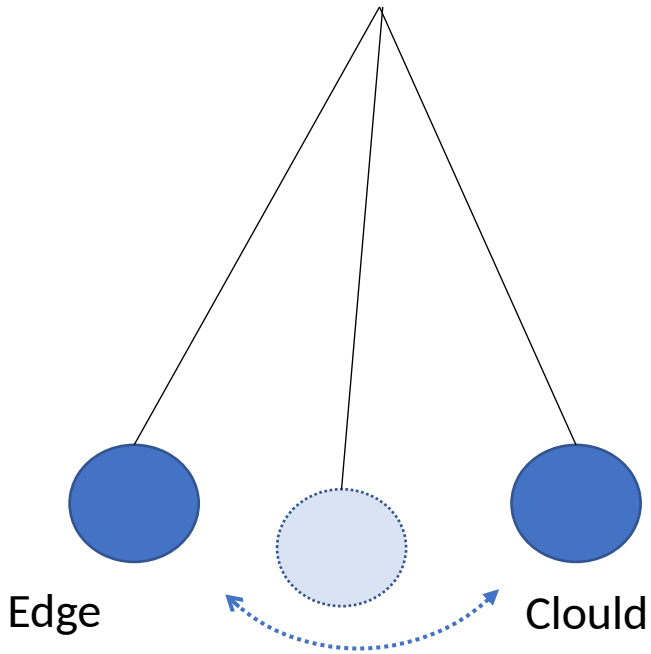
Extending 5G (and 6G)

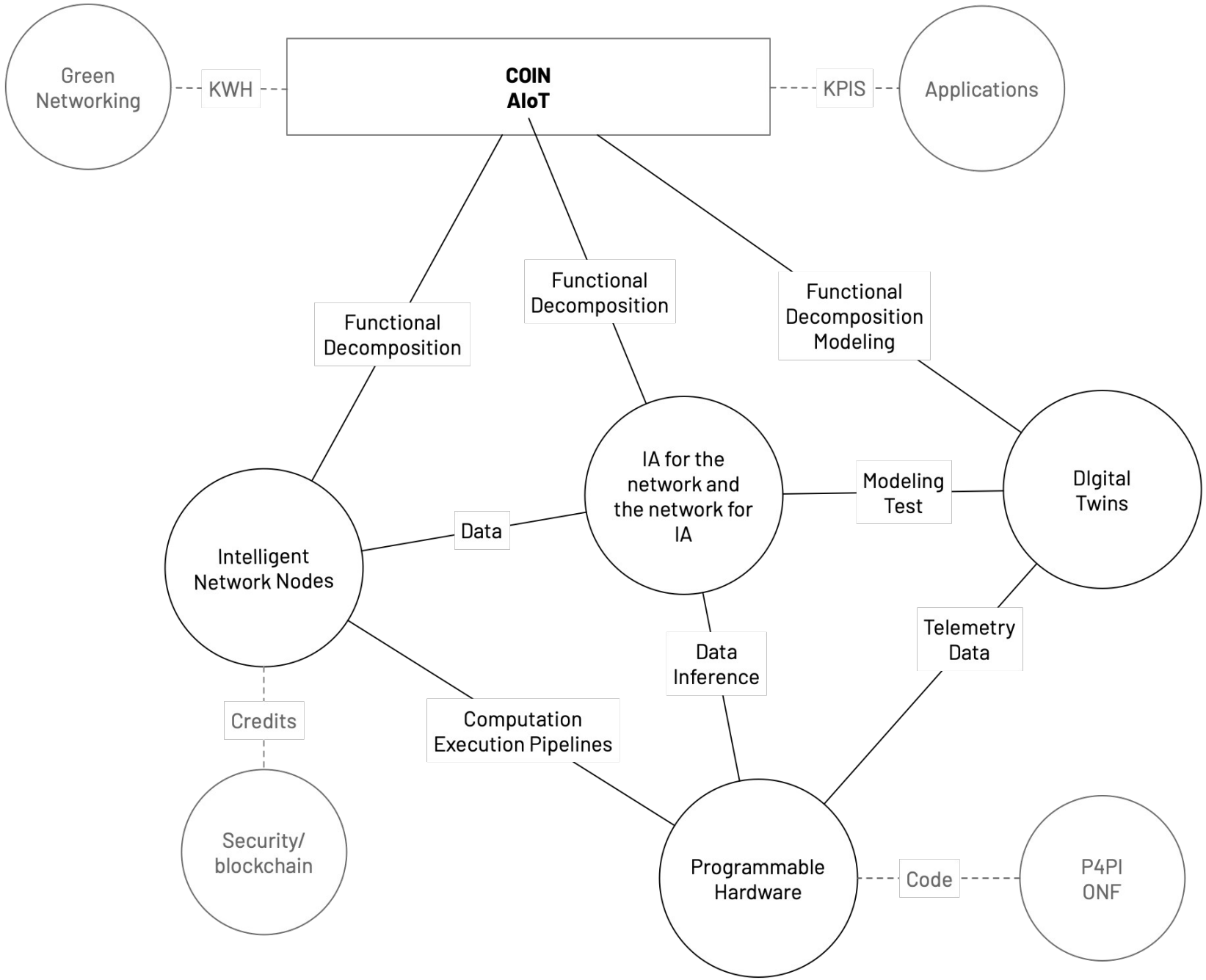


- Edge, fog and cloud applications and devices requires constant connectivity
- High throughput and low delay
- Using Machine Learning and Artificial Intelligence in practical decision making
  - AI for the network and the Network for AI
- Internet of Things (Internet of everything?)

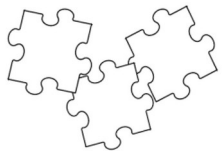
The Next G: network of network/system of systems

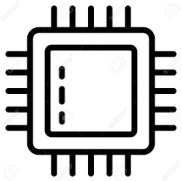
- The pendulum is to return to the concept of "networks of networks" that was at the basis of the Internet
  - Decentralization of the Internet to regional autonomy
  - Autonomous and federated systems
  - Data governance
  - Energy savings
- Distributed systems are more suitable for complex, multidisciplinary applications
  - Functional decomposition and orchestration are critical
- **COIN axes:**
  - AI for the network and the network for AI
  - Modeling and digital twins
  - Programmable networks
  - Intelligent network nodes

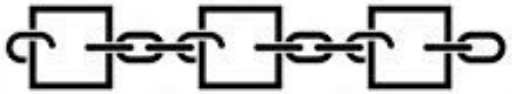



Green Networking
KWH
COIN AIoT
KPIS
Applications
Functional Decomposition
Functional Decomposition
Functional Decomposition Modeling
IA for the network and the network for IA
Modeling Test
DIgital Twins
Intelligent Network Nodes
Data
Telemetry Data
Data Inference
Credits
Computation Execution Pipelines
Security/ blockchain
Programmable Hardware
Code
P4PI ONF

Distributing the Functionality





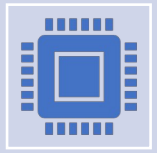


- Functional Decomposition
  - Horizontal: « Life of a Packet »: from the user device to the cloud
  - Vertical: distribute decisions to improve overall efficiency (twins and multi-scale AI/AM)
- IoT with containers and ochestration for local)
  - Resource sharing
- Programmable nodes for enhanced data management tasks (load managemenet, compression, data reduction, etc.)
- Blockchain (or other) for security

The goals

Core goals: lower latency, higher reliability, sustainability

Needs the capture, storage and processing of heterogeneous, multi-source and multi-destination data and the need for localized decision-making (e.g. in IoT) due to delays and connectivity reliability



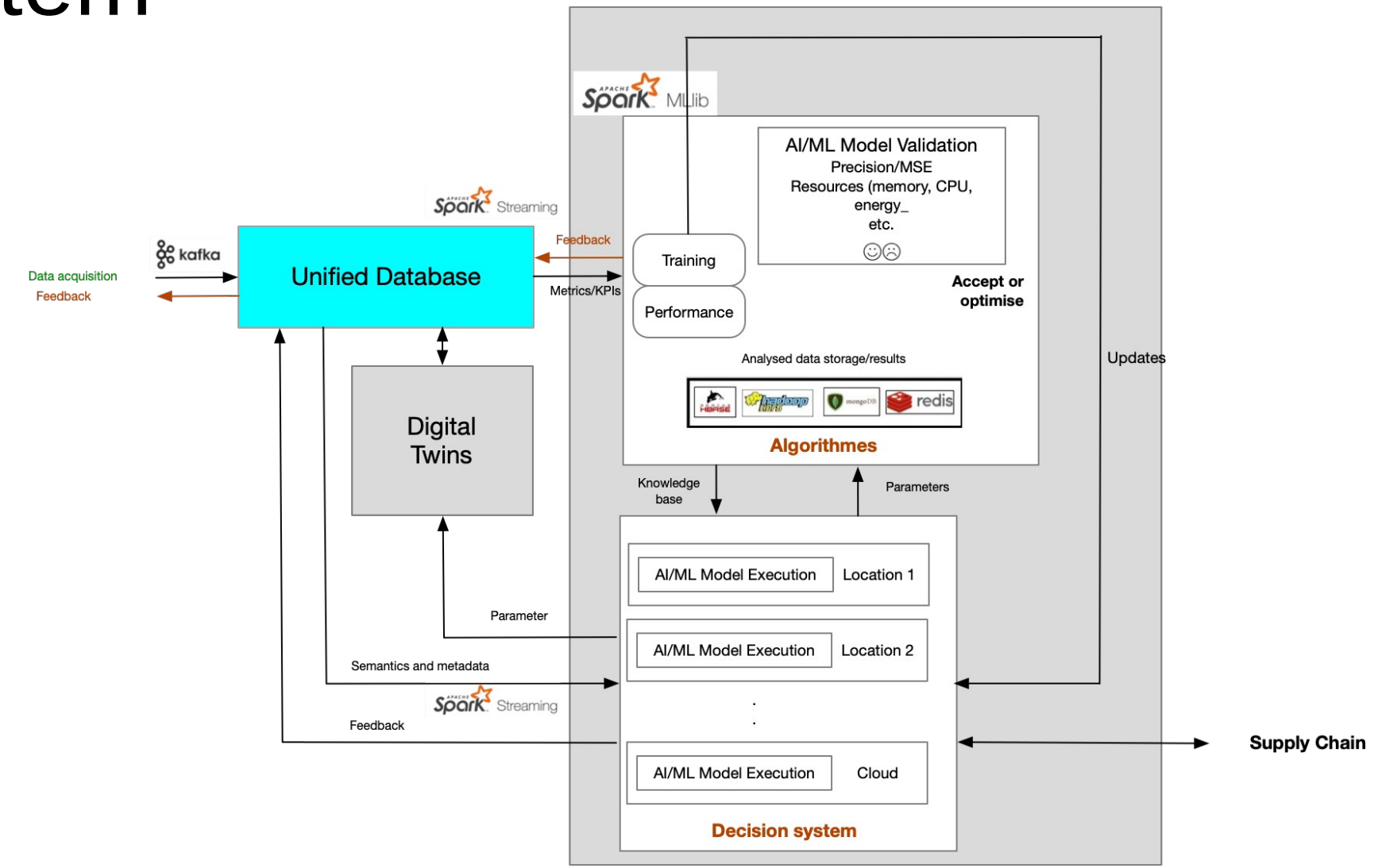
Protocol, sensors, and data orchestration with sustainability (e.g. energy consumption) and security are key

"Data is the fuel of the 21st century"

- The goal: an edge cloud information pipeline *
- The Heterogeneous data systems
  - Standardization and storage
  - No data standards means the data must be "cleansed" and put in common format
    - ETL
      - Extract-Transform-Load
    - Analysis
      - Example: partial correlation via, for example, Lasso penalty models

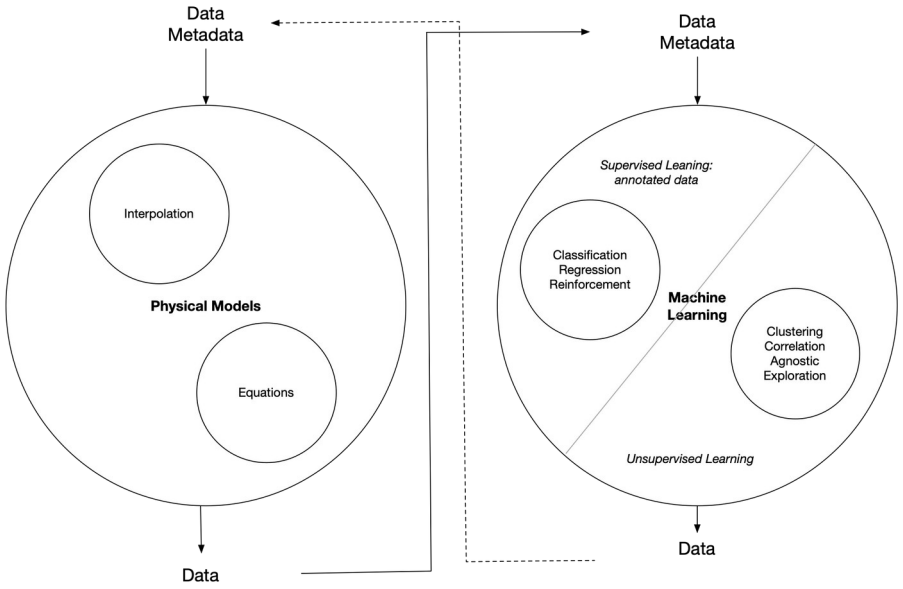
* EU Proposal with avec Ericsson, Telefonica, Orange et U. Linkoping (2018)

Data Driven Decision: Integrated AIoT System



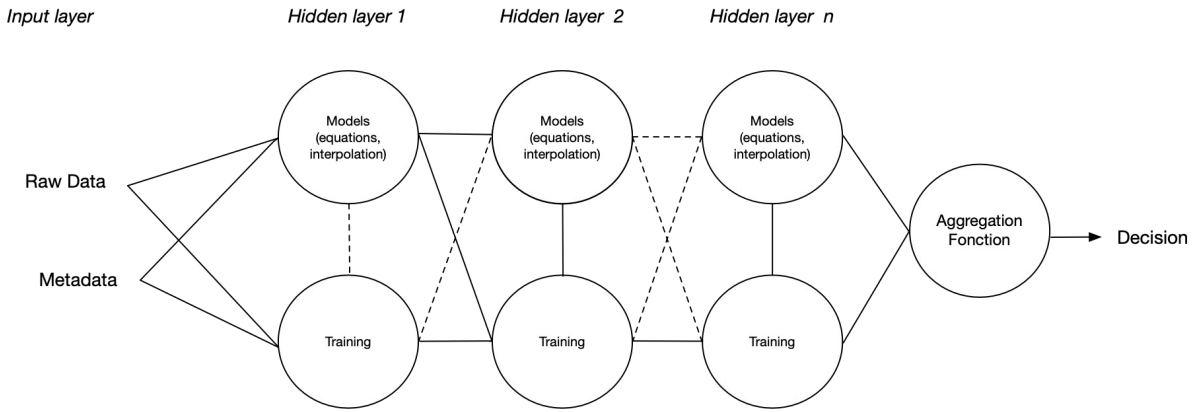
AI for the Network and the Network for AI

- AI: distributed intelligence in the network
  - Data to infer network status and mitigate problems (both are essential and can be done)
  - Beyond traditional emulation and modeling
  - Physical models of transmission Improved management (prediction vs. reaction e.g. NetAI)
  - Automation systems
  - Supervised, unsupervised and reinforcement learning
- The network: collaboration between smart nodes
  - Ref. COIN Use Case Draft
  - Industrial applications
  - Initiatives available in the US for testing and experimentation (e.g. ISU ARA, Colosseum and other PAWR platforms in the US and Europe)
- Issues
  - Efficiency
  - Data vs. physical models
  - Functional distribution

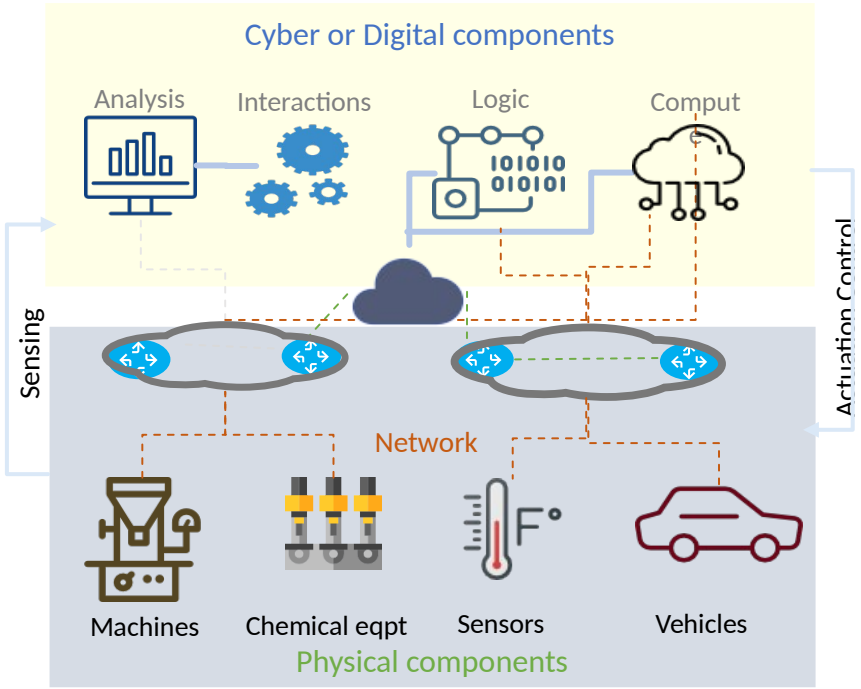


The Networked AI

- Knowledge base
  - Combination of models and operator knowledge (expert system)
- Learning and control
  - Supervised and possibly unsupervised and by reinforcement
  - Physical and statistical models
- Decision
  - Ensemble methods
  - Game theory, genetic algorithms, etc.
- Federated Learning: federating the training between different systems and nodes
  - Keep the data local
  - Enable edge machine learning/decision
  - Distributed systems applied in AI/ML



Digital Twins

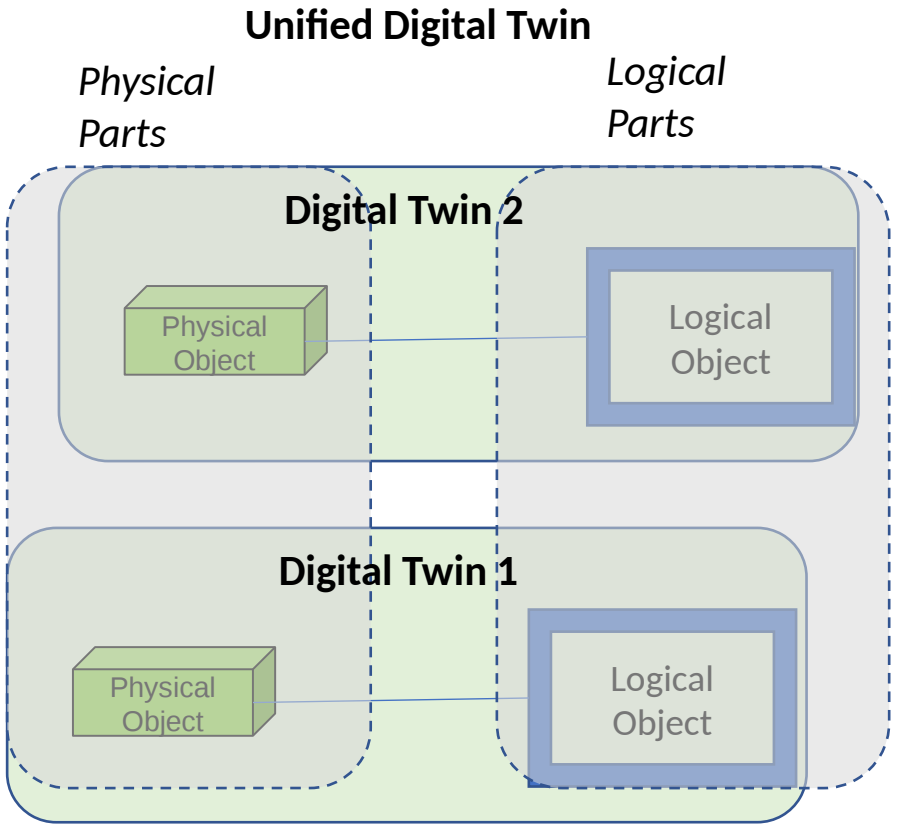


https://www.ibm.com/topics/what-is-a-digital-twin

- Digital version of critical systems beyond traditional simulation
  - Integrated into the measurement and decision-making chain
  - Demands real-time data
- Connected/distributed twins to represent a complex system is a current issue ("system twins")
- Creation
  - Digital shadow
    - Models
  - Twins
    - Simulation/communication
- Usage
  - Decision support
  - Synthetic data
  - Testing artificial intelligence algorithms

Digital Twins in Networking

- Twins of networked systems and nodes
- Extension of existing models in simulation
  - Ex. NTIA O-RAN/Colosseum Project https://arxiv.org/abs/2303.17063
- Application
  - Management
    - Reduce operational risks by allowing to test on the twins not the network
    - Model a complex distributed system
      - Grouping several DTs into a unified one
      - Intelligent nodes
  - Data and telemetry
    - Observe and and control the behavior of the composed DT as well as the individual components
    - Applications can query and control the status of the aggregated DTs as well as the single DT
  - Testing
    - “Hardware” testing – the DTs as hardware representation

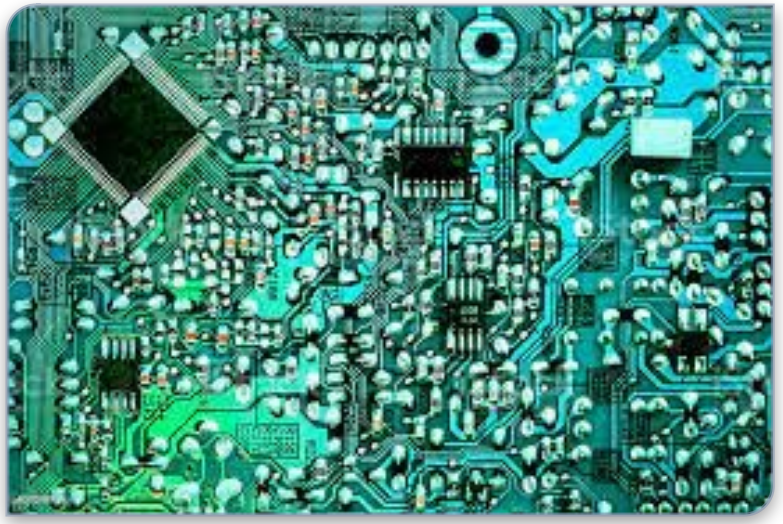


Roberto Minerva, Telecom Paris Sud

* « The Networking Channel » November 2023 on Digital Twinning in Networking

Link to COIN

- The network as a computer board
- The next generation of network softwarization and functional distribution between edge and cloud
- New hardware combining switching, DPU/IPU/smartNIC and computation to perform complex operations on packets in transit
- Intelligence at every layer of the network
  - 6G wireless, O-RAN on going work



Common Requirements

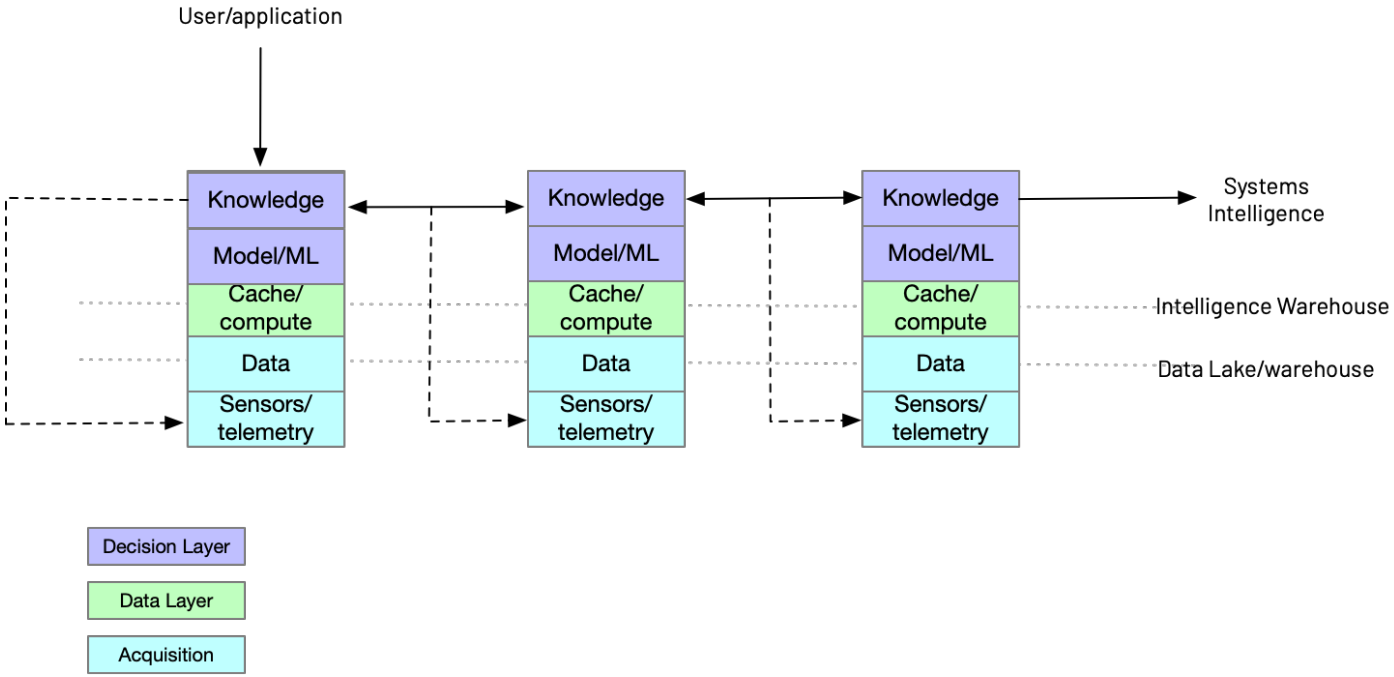
Joint optimization of networking, computing and storage in the fog/edge/cloud

Horizontalization of data plane to **enable cross functional distributed application and cognitive intelligence**

Better integration between applications/service and infrastructure resources

An Example: Programmable Intelligent Network Nodes
(work in progress)

- One goal: "de-cloudization" and distributed network decision making
  - IoT/edge heritage
  - A network version of "containers”
  - Interconnected autonomous smart nodes
  - A ”network” neural network
- Autonomous or combined with other nodes to provide more complex services
  - Distributed in the edge-cloud continuum
  - Analogous to neural network nodes
- Requires message passing and functional distribution
  - "Information Centric Networks" leverage
  - Link to NSF platforms
- Includes important concepts for 6G and IoT
  - "Internet in the small"*



* “Internet in the small” David Clark, MIT 2022

Some Research COIN/IRTF Opportunities

AI/ML, AR and federated learning in networking

Open private and secure datasets in heterogeneous environments and networks

Real-time secure message passing protocols in distributed systems

Function definition, decomposition and orchestration in both the physical and virtual worlds

Twinning of complex cyber-physical systems and of network element

Conclusion and Future Avenues for COIN?

A programmable framework for advanced IoT and data driven network automation

Edge and cloud support for advanced network services and applications based on and enabling AI/ML

Data combined with digital twinning and AR provide targeted services and advanced testing and deployment and facilitate application development

Questions

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Backup

Data, AI, Digital Twins, Computation