IoT Data Fabric for Industrial Metaverse

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6G Flagship

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Timeline of industrial revolutions

First Industrial Revolution, 1760

Transition from human- or animal-powered labor to steam (power looms, spinning machines, steam ships, locomotives)

Second Industrial Revolution, 1880

Transition to electrification and mechanization (assembly line, electric railroad, and telegraph)

The transition to computing, automation, and digitalization, thanks to transistor, ICs

Third Industrial Revolution, 1947

Transition to immersive and embedded uses of tech., thanks to internet, data, and AI, and digital-physical connections via IoT and digital twins

Fourth Industrial Revolution, 2000

The emergent industrial metaverse, *MIT Technology Review Insights*, 2023

Cyberspace VS. Metaverse

(RW)(P)(CC)(S)/ Experience-Duality (ED)		The under-explored cyberspace (Opportunities of entering the Metaverse)								
(RW)(P)(CC)/ Social as Community (S)	Twitter	Instagram	Clubhouse	TikTok	Animal Crossing	Second Life	VR Chat	XSight	Pokémon Go	University
(RW)(P)/ Content Creation (CC)	Medium	Pixlr	Adobe Audition	YouTube	Super Mario Maker	Roblox	Quill	Adobe Aero	BIM	Soft Clay
(RW)/ Personalisation (P)	Xanga	Meitu	Spotify	Netflix	Diablo	Fortnite	VR Commerce	IKEA Place	Google Map AR	Shopping
Read & Write (RW)	SMS	Camera App	MMS	Zoom	S. Mario Bros	Simcity	Beat Saber	Skype	AR Translator	Mah Jong
	Text	Image	Audio	Video	Gaming	Virtual 3D	VR	MR	AR	Physical

Lee, Lik-Hang, et al. "All one needs to know about metaverse: A complete survey on technological singularity, virtual ecosystem, and research agenda." *arXiv preprint arXiv:2110.05352* (2021).

Metaverse Technology and Ecosystem

A. Technologies	
Artificial Intelligence	Automatic Digital Twin, Computer Agent, Autonomy of Avatar.
Blockchain	Data storage, Data Interoperability, Data sharing.
Computer Vision	Localization & mapping, Body & gaze tracking, Scene understanding, Image processing.
Network	5G/6G, QoS/Congestion control, QoE, Network slicing, Network-aware applications.
Edge Computing	Edge Cloud, Distributed/ Federated learning, Fairness- and Privacy- preserved user presence.
User Interactivity	Mobile input techniques, Mobile headsets, User feedback cues, Haptic devices, Telepresence.
Extended Reality	Projection and Hologram, Augmented reality, Mixed reality, Virtual reality.
IoT & Robotics	IoT, Connected vehicles, human-robot interaction.
B. Ecosystems	
Avatar	Appearance and Design, User perceptions, Human-avatar interaction, Avatars in-the-wild.
Content Creation	Authoring, Multi-user collaboration, Creator culture, Censorship.
Virtual Economy	Metaverse commerce, Virtual Objects Trading, Oligopoly, Economic governance, Ownership.
Social Acceptability	Privacy threats, User diversity, Fairness, User addiction, Cyberbullying, Devices, Cultural diversity.
Security & Privacy	Deep-fakes, Alternate representations, Ethical design, Protection of digital twins, Biometric data
Trust & Accountability	Fairness and bias, Power and control, Opacity and transparency, Auditing, Governance.

After its ascension as one of the major technologies of 2022, the metaverse has taken a major backseat to generative AI and ChatGPT since 2023.

Lee, Lik-Hang, et al. "All one needs to know about metaverse: A complete survey on technological singularity, virtual ecosystem, and research agenda." *arXiv preprint arXiv:2110.05352* (2021).

“All of these technologies (to build a viable Metaverse) exist—the tricky part is actually bringing them all together and connecting them.”

- Annika Hauptvogel, Head of Technology and Innovation Management, Siemens

Key Technical Challenges

- Push towards hardware disaggregation
- No common data standard agreed among IoT device manufacturers
- Push towards green mobile networks
- Push towards local computation / data staying at source, or with owners

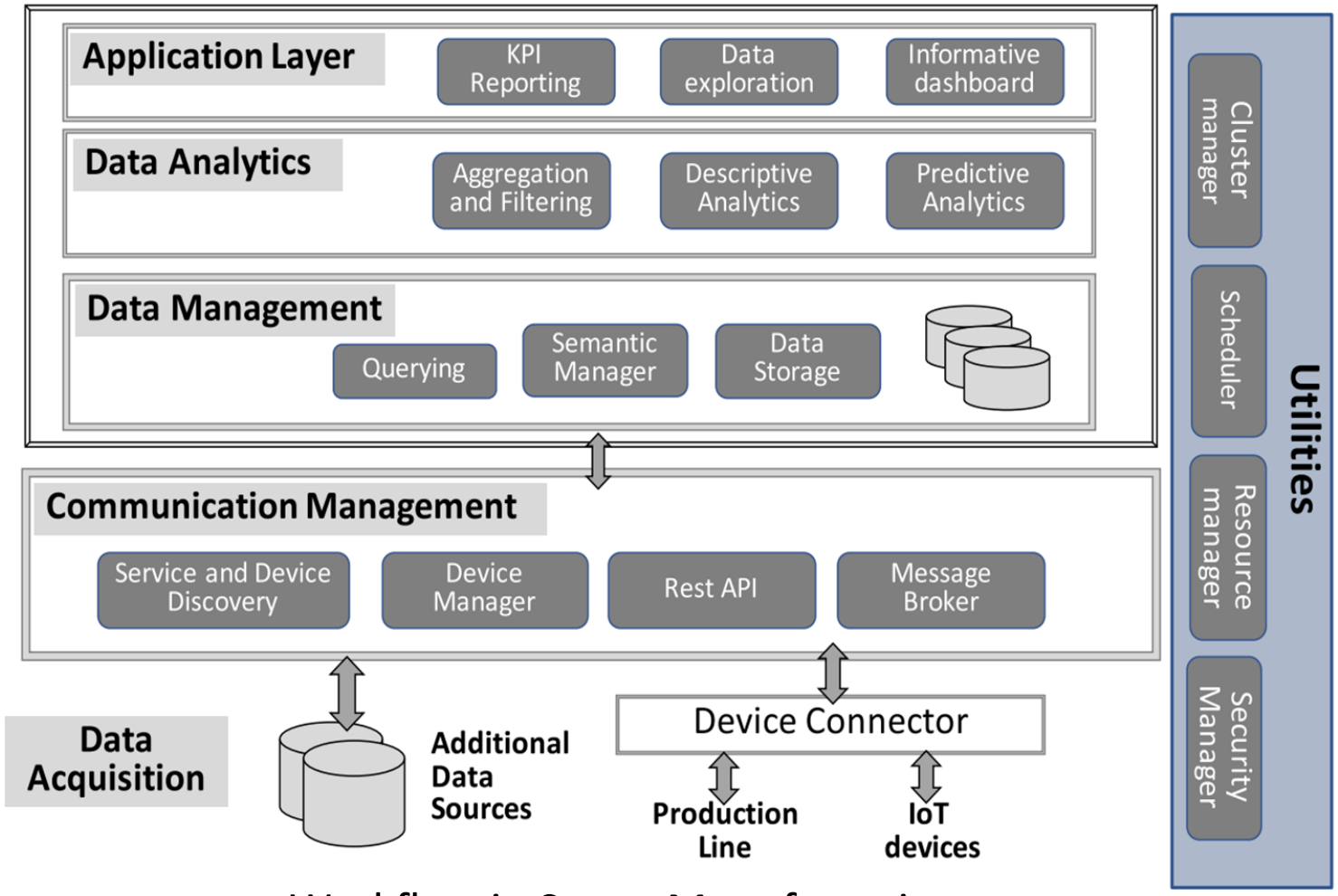
IoT vs. IoT Data Fabric

> *IoT:* Network of things embedded with sensing and communication for the purpose of connecting and exchanging data with other devices over the Internet.

> *IoT data fabric:* Architectural framework that integrates data from diverse sources, including cloud, hybrid, and on-premise, using tools and technology. *Gives* ***unified view of the data***.

Example: Smart Manufacturing

"Adoption of industrial metaverse in smart manufacturing is expected to upgrade the industry for more visible, intelligent and efficient production in the future."



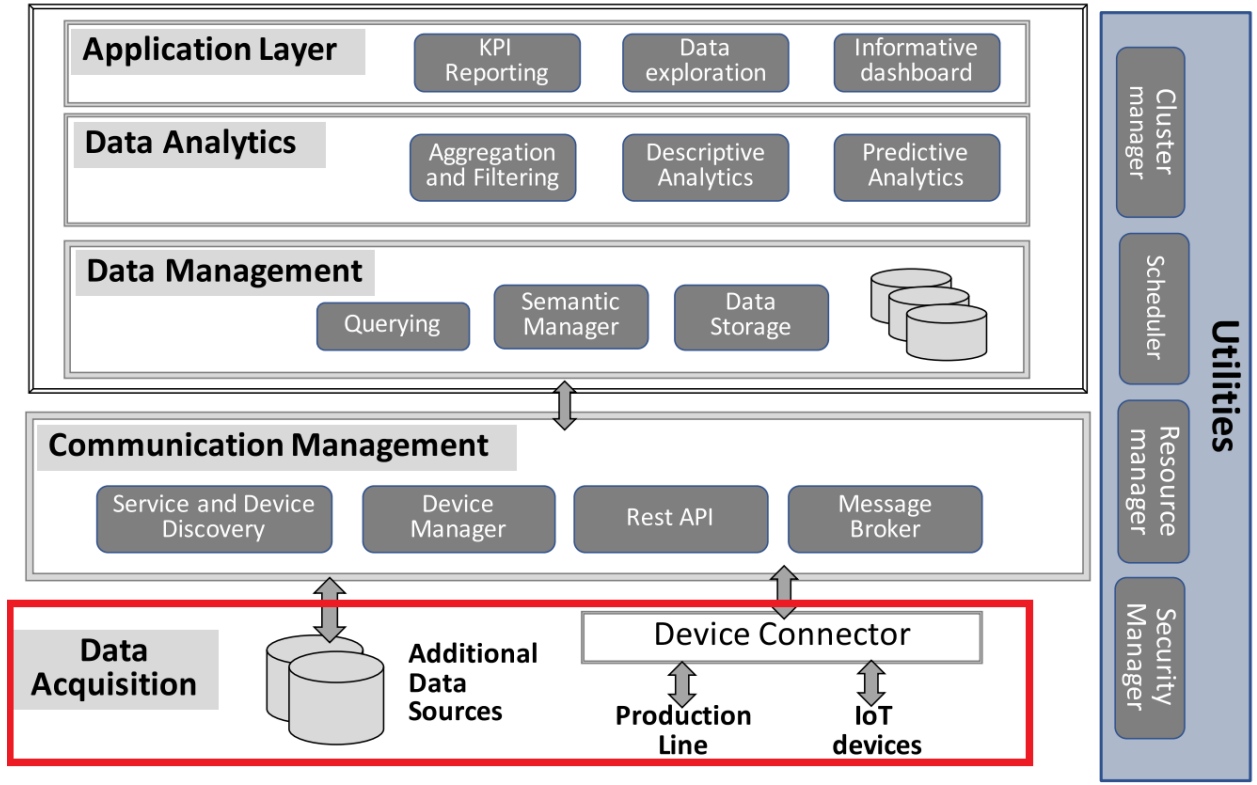
Workflow in Smart Manufacturing

Cerquitelli, Tania, et al. "Manufacturing as a data-driven practice: methodologies, technologies, and tools." *Proceedings of the IEEE* 109.4 (2021): 399-422.

Smart Manufacturing: Data Layer

> *Data Layer:* Existing data (data acquired in past, or from other business partners) and data coming directly from production lines.

> *Key challenge:* How to ensure interoperability among heterogeneous interconnected devices by abstracting the different underlying low-level technologies?

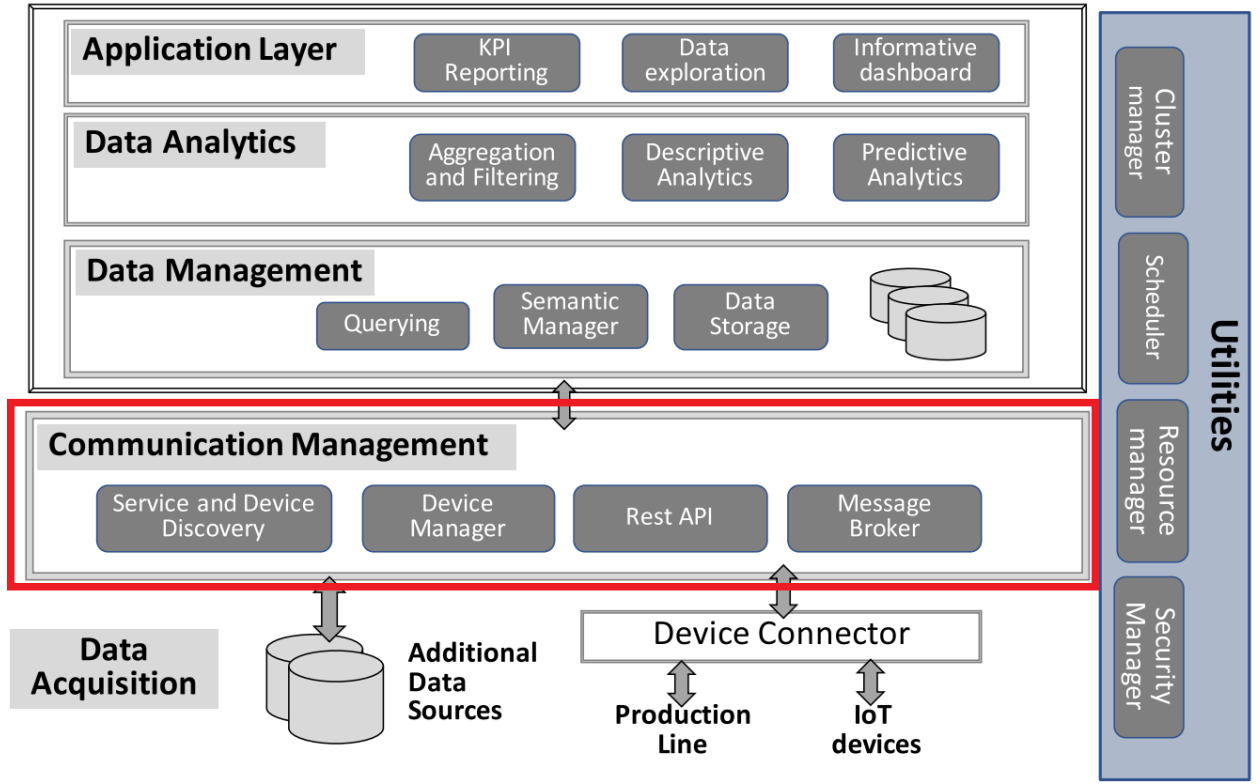


Cerquitelli, Tania, et al. "Manufacturing as a data-driven practice: methodologies, technologies, and tools." *Proceedings of the IEEE* 109.4 (2021): 399-422.

Smart Manufacturing: Communication Layer

> *Communication Layer:* Enables bidirectional communication among all entities in the fact.

> *Key challenge:* How to ensure only the ***right data*** is exchanged between ***right entities*** in a ***timely*** and ***reliably*** manner?



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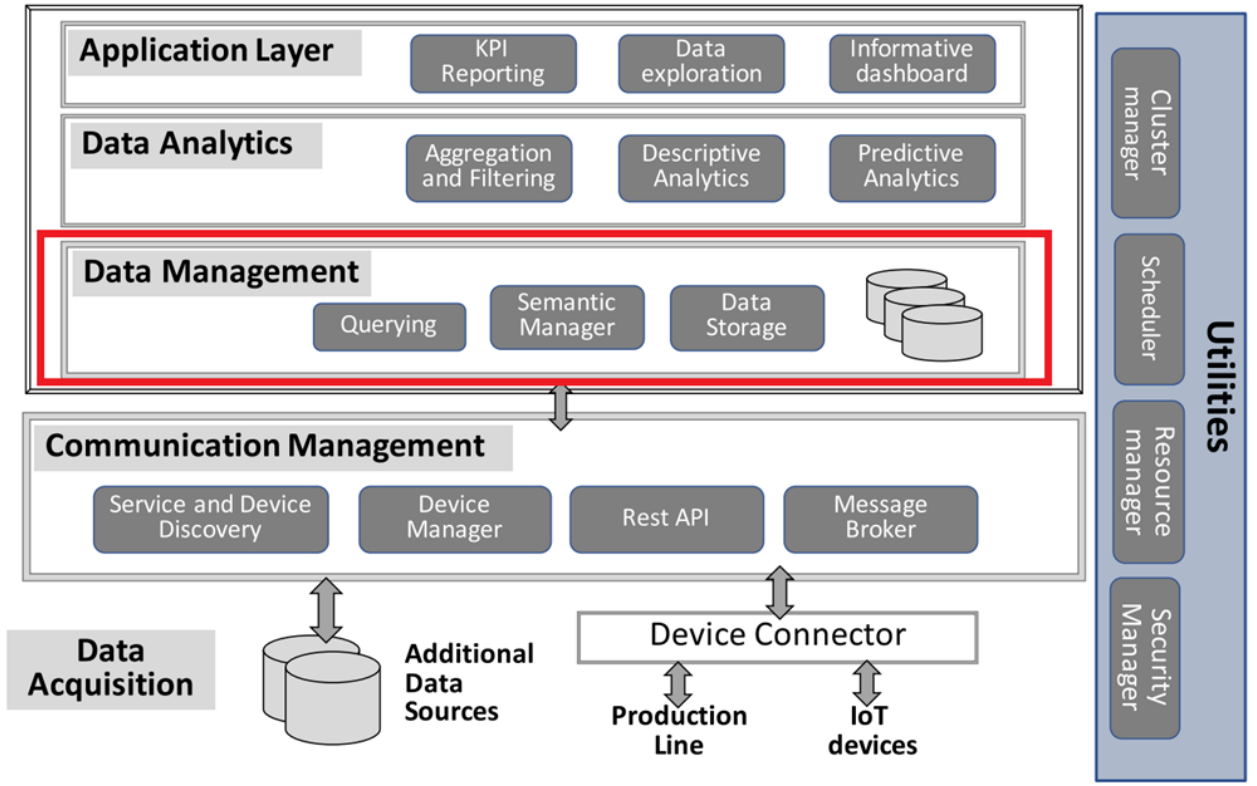
Smart Manufacturing: Data Management Layer

> *Data Management Layer:* Ensures persistence of data, primarily built using existing database system technologies.

> *Key challenge:* How to ensure 1) semantic knowledge allowing interoperability across heterogeneous devices? 2) quick response to queries.



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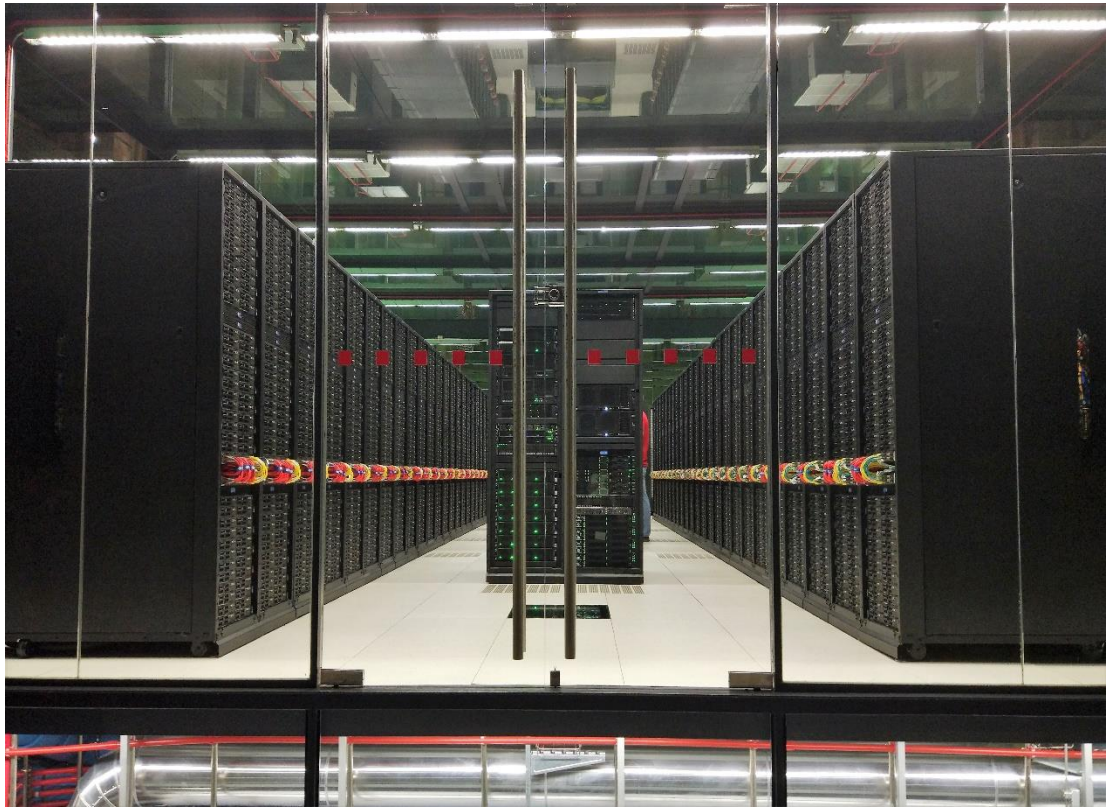
Towards Industrial Metaverse: Sustainability

> What about sustainability goals? Can we even build sustainable industrial metaverse in next 5-10 years? Every single bit to be transferred across the network has associated carbon cost.

> Can we learn from Supercomputers, which are essentially a large-scale distributed system (like a metaverse)?

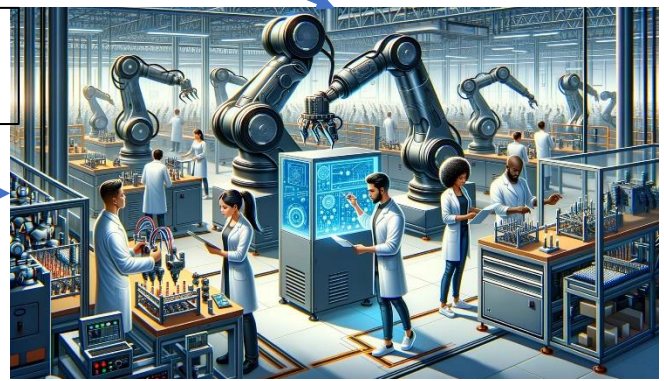
> We already know that performance in supercomputer is communication



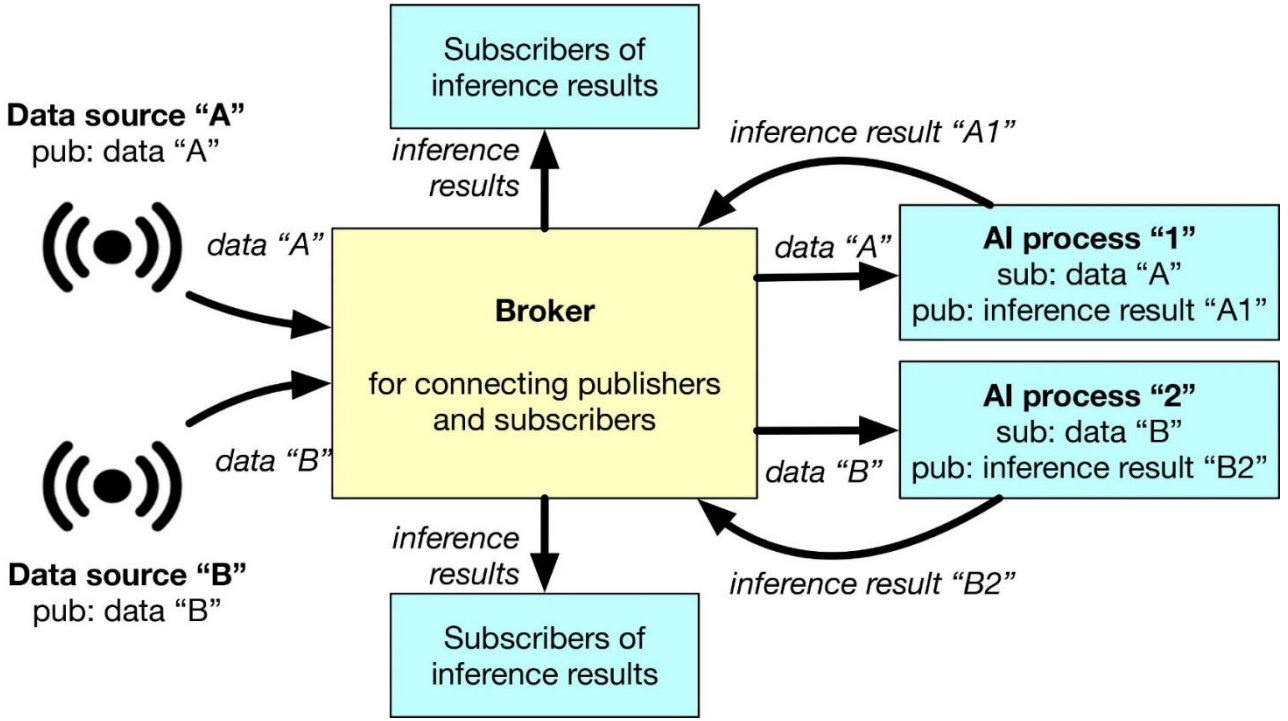
MareNostrum 4 supercomputer at Barcelona Supercomputing Center

*We need a **high-performant interconnect** for the **continuum of entities** (both hardware and software services) which solves **interoperability** problem, **heterogeneity** problem, as well as **efficiency** problem.*

Connecting Industrial Multiverses



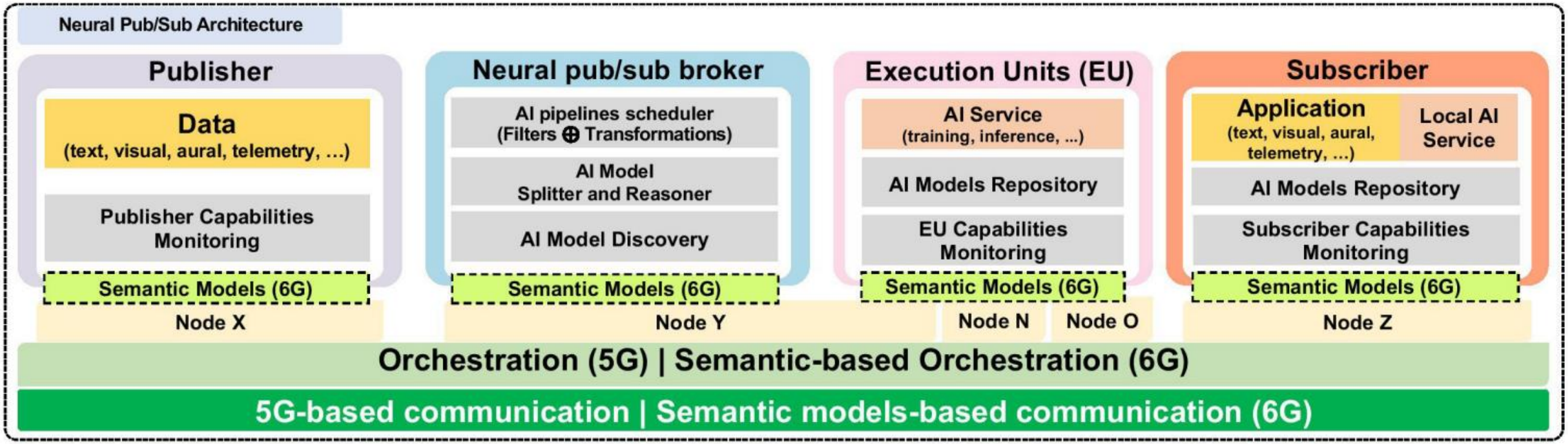
Traditional Publish-Subscribe based Interconnect



- Traditional broker-based pub/sub AI workflow. Processing occurs at client-side subscriber modules, which publish inference results.
- This design faces challenges, especially since optimization requires cooperative frameworks, and aspects like model training and updating are less explored.

Lovén, Lauri, et al. "How can ai be distributed in the computing continuum? introducing the neural pub/sub paradigm." *arXiv preprint arXiv:2309.02058* (2023).

New Paradigm: Neural Publish Subscribe for 6G



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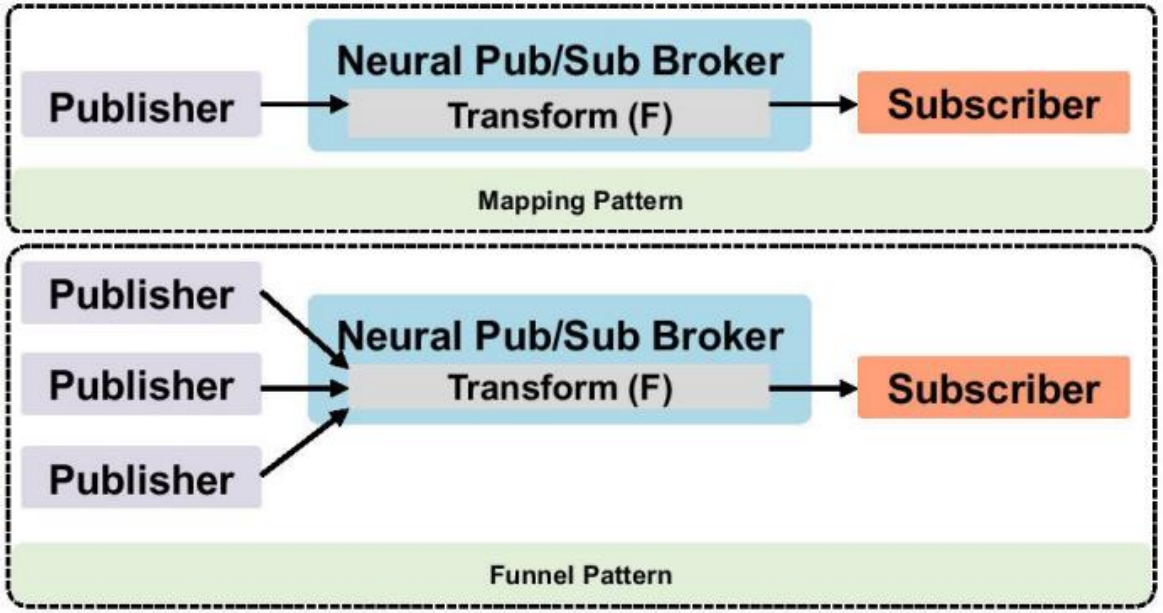
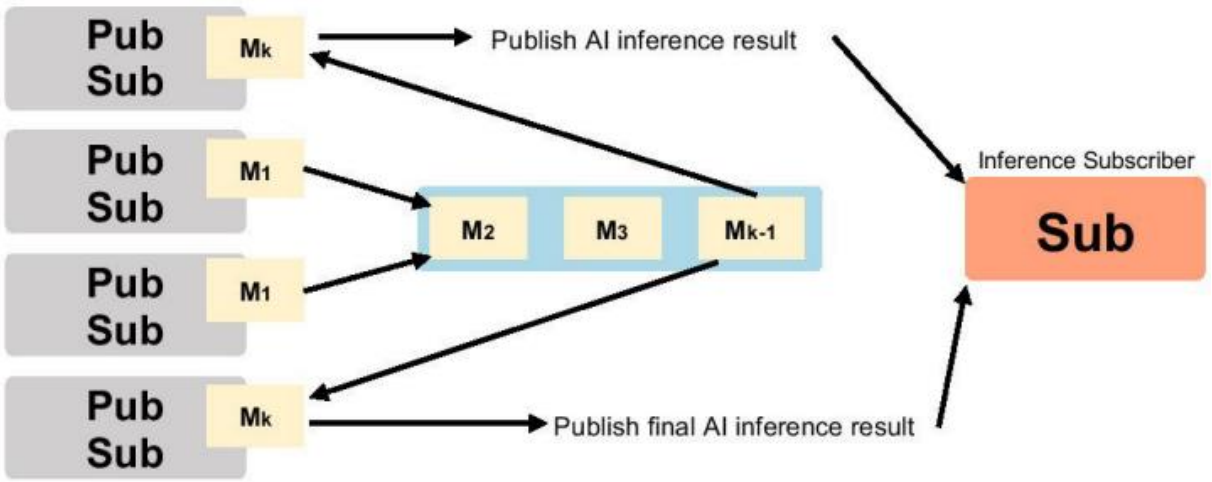
Two Key Design Patterns of Neural Publish Subscribe





- ***Mapping pattern:*** Taking a publication and applying a function to it, either transforming the original publication or leaving it unchanged.
- ***Funnel pattern:*** Builds upon the mapping pattern, combining one or more publications and applying a function to the received publications.

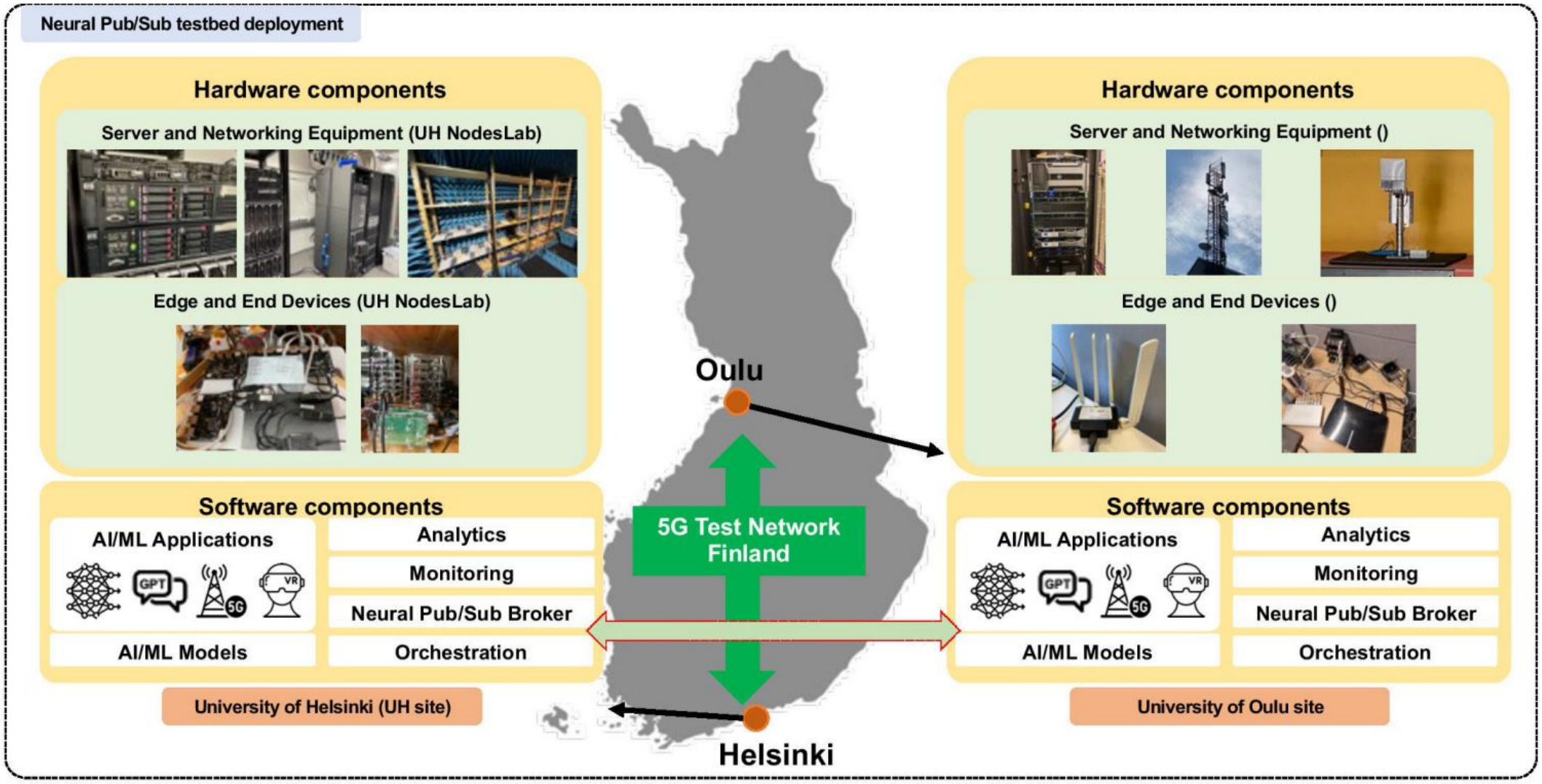
Example of design patterns application in the case of distributed AI inference orchestrated by the Neural Pub/Sub paradigm.

Lovén, Lauri, et al. "How can ai be distributed in the computing continuum? introducing the neural pub/sub paradigm." *arXiv preprint arXiv:2309.02058* (2023).

Capabilities of Neural Publish Subscribe

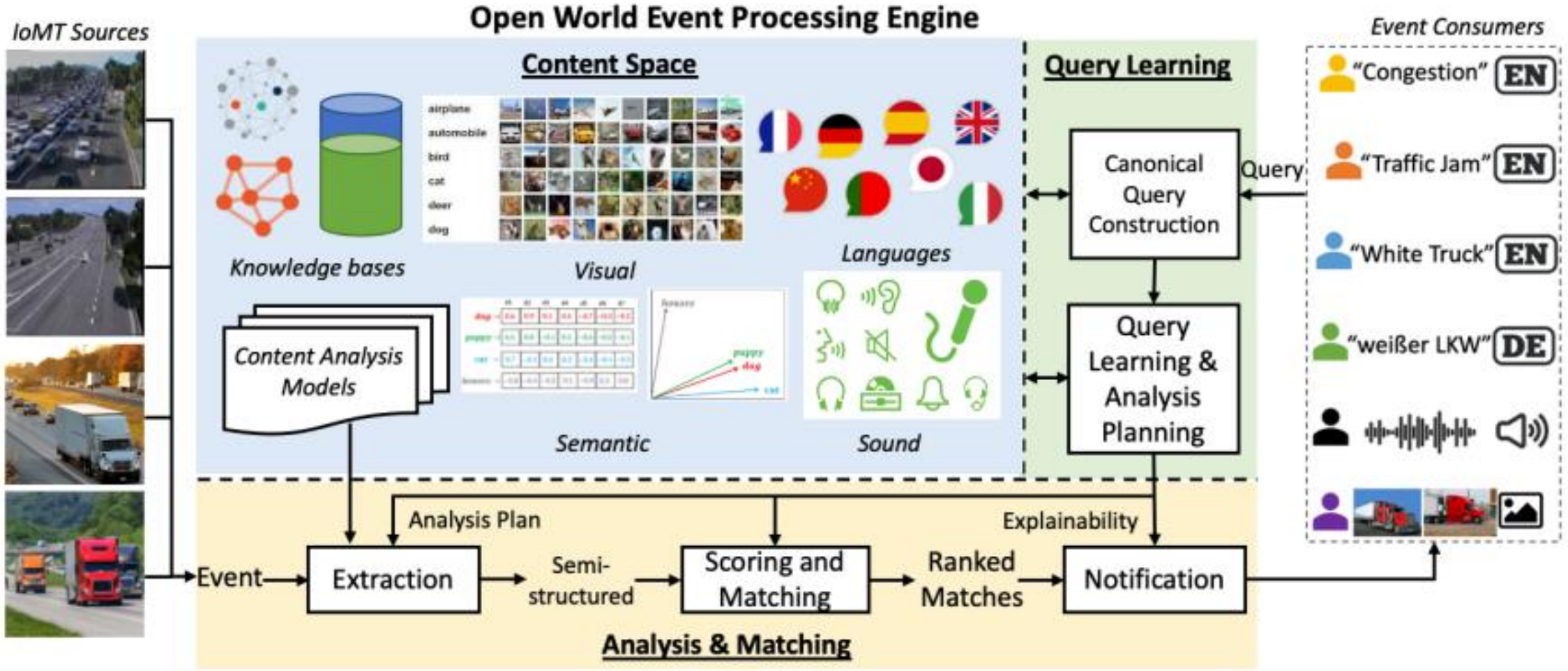
- Resource Efficiency and Management
- Latency and Bandwidth
- Model Adaptivity (for low resource constrained environment)
- Data Privacy and Security
- Distributed Learning
- Robustness and Fault Tolerance
- Heterogeneity

Neural Publish Subscribe: Deployment



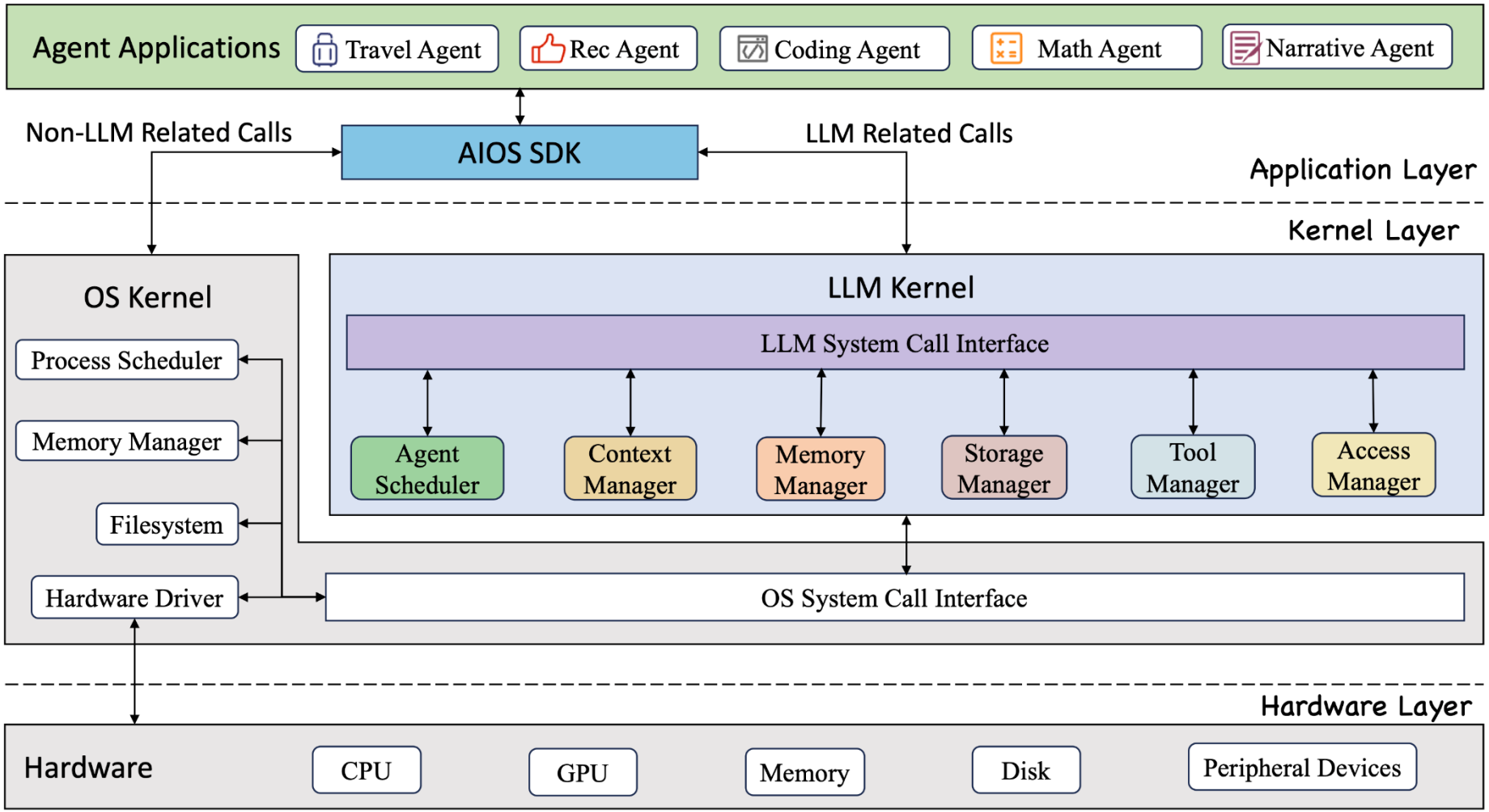
Lovén, Lauri, et al. "How can ai be distributed in the computing continuum? introducing the neural pub/sub paradigm." *arXiv preprint arXiv:2309.02058* (2023).

Towards Generic Open World Multiverse Data Fabric: *Physical Worlds + Virtual Worlds*



Curry, Edward. "Towards Open World Event Processing: A Paradigm and Research Agenda for Event Processing for the Internet of Multimedia Things (Vision Paper)." *2023 IEEE International Conference on Big Data (BigData)*. IEEE, 2023.

Towards Generic Open World Multiverse Data Fabric: *Computer Systems for Individual Metaverse Node*



Mei, Kai, et al. "AIOS: LLM Agent Operating System." *arXiv e-prints* (2024): arXiv-2403.

Open Course under Reboot Skills Project

We will cover details during the course ***"IoT for manufacturing industry"*** on *06 -07 May 2024, 9:30 – 17:00*. Location: ***University of Helsinki, Room U3040, Fabianinkatu 33, Helsinki and Online (Hybrid)*** NO registration/attendance fee.

Learning objectives:

- Functional and non-functional challenges associated with actualizing data-driven approaches
- Logical components (aka. IoT data fabric) needed to realize manufacturing as a data-driven practice at scale in an industrial framework
- Digital Twinning of the manufacturing environment to support prediction and optimization of the behavior of a production system and its components
- Artificial Intelligence/Large Language Model and 6G-assisted Customized Manufacturing

Course Registration link:
https://link.webropolsurveys.com/Participation/Public/1d6c6ad9-30fe-4b0d-8514-1e98d4af25a4

Open Course: Customization vs. Scale

> Ferrari manufactures about 10000 vehicles/year with extremely high customization, whereas Ford manufactures about 4.2 million vehicles/year with little customization.

> In future, can we have product customization at Ferrari scale, and production at Ford scale at the same time? We will discuss technical enablers of this vision during the course.

Concluding remarks

The **adoption** of new technology in the industry is UNEVEN, same will be true for the metaverse.

Old and New technology should **coexist**.

Recent advances in ICT, i.e., in particular, AI space allow us to build a truly **general open-world interconnect** which can support the **data fabric of the industrial metaverse**.

Please come and join us on 06 and 07 May to talk about these enablers in the **manufacturing industry context** in detail.

>THANK YOU_

Questions?

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