



General Challenges for a computing continuum

Michael Fritz – Fraunhofer Cluster of Excellence Cognitive Internet Technologies CCIT

The Claridge – Brussels, Belgium | 10-11 May 2023

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»FICATION«

IT landscape (infrastructure, technology and development methodologies) is becoming a commodity!

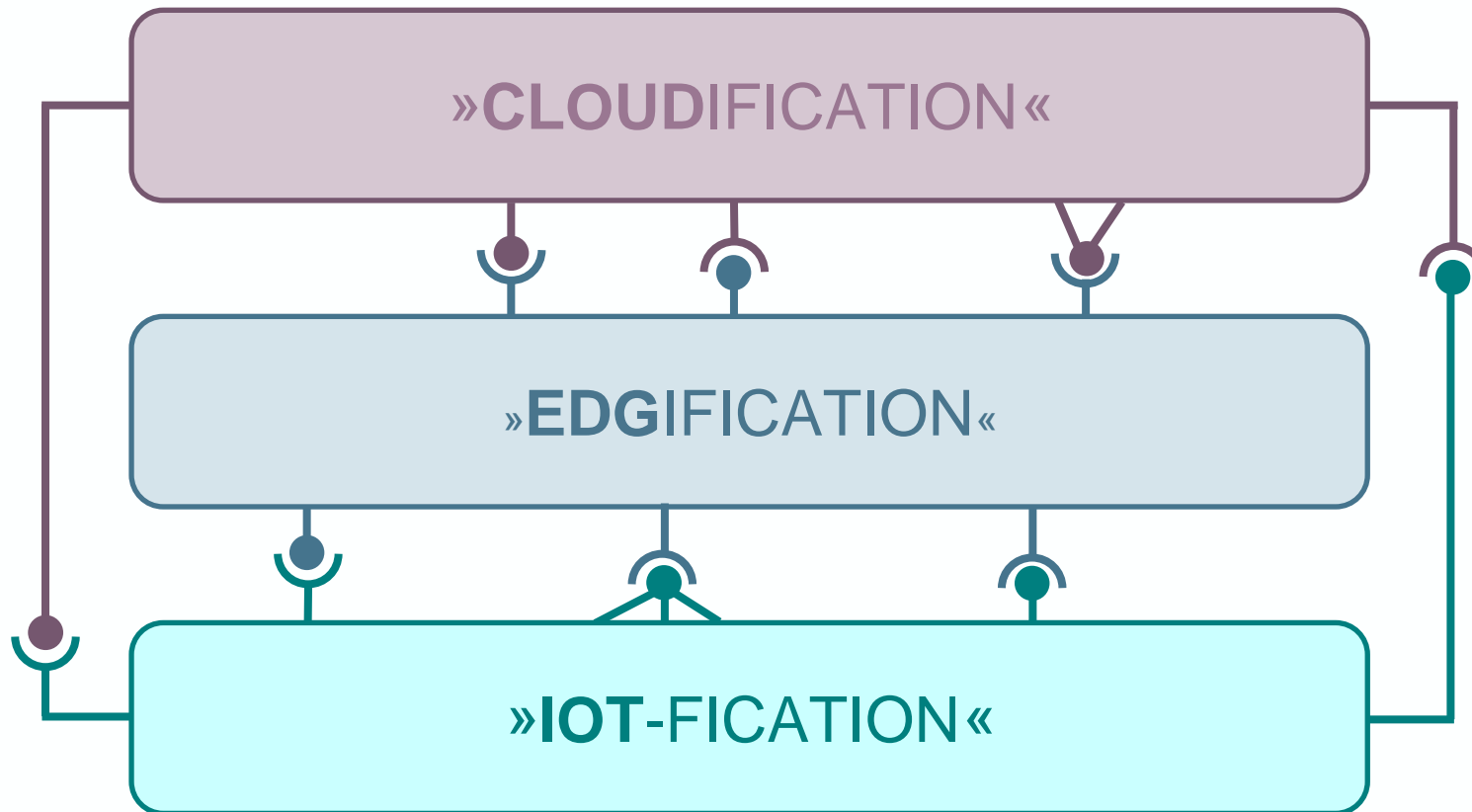
»CLOUDIFICATION«

»EDGIFICATION«

»IOT-FICATION«

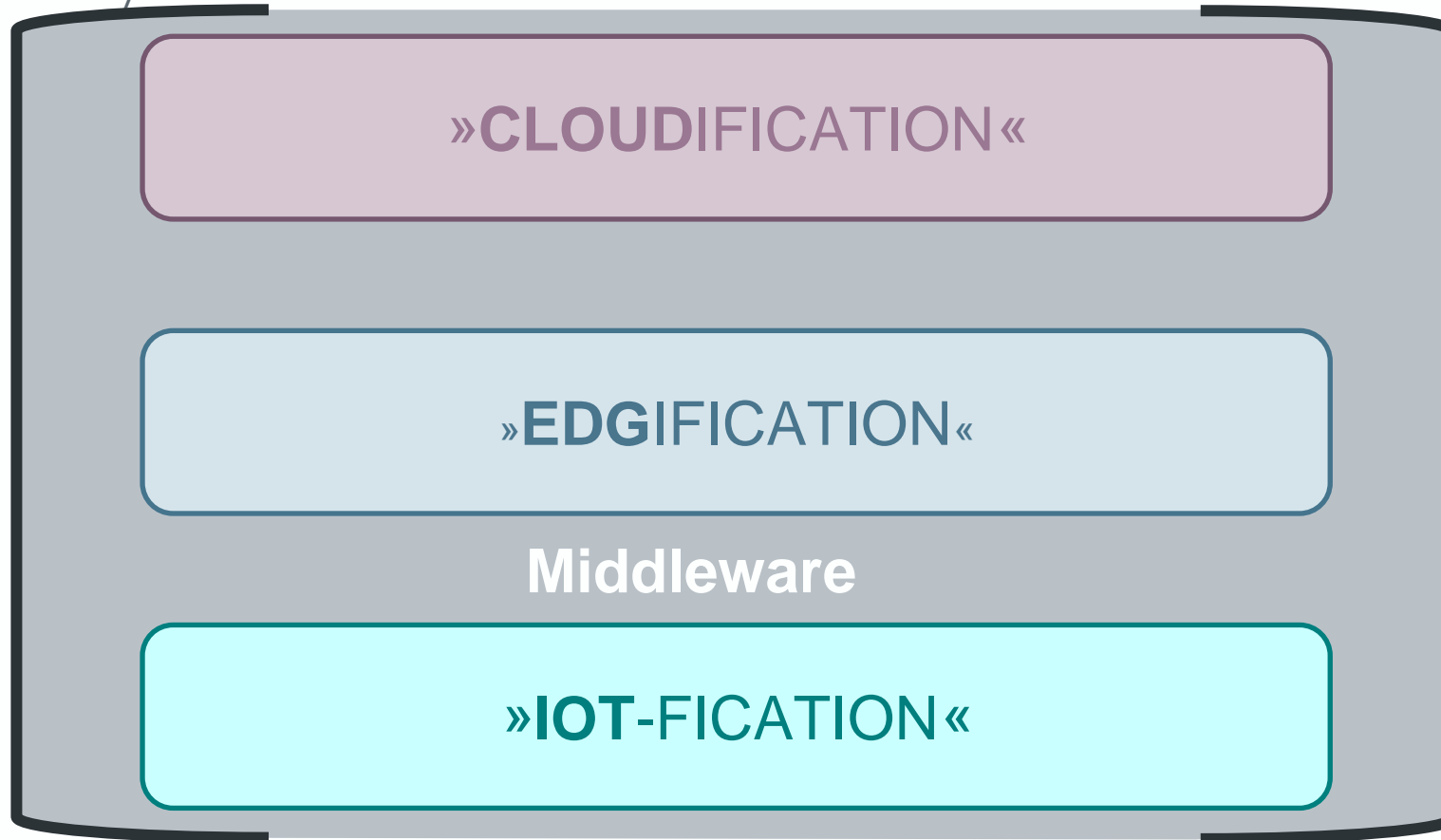
»FICATION«

IT landscape (infrastructure, technology and development methodologies) is becoming a commodity!

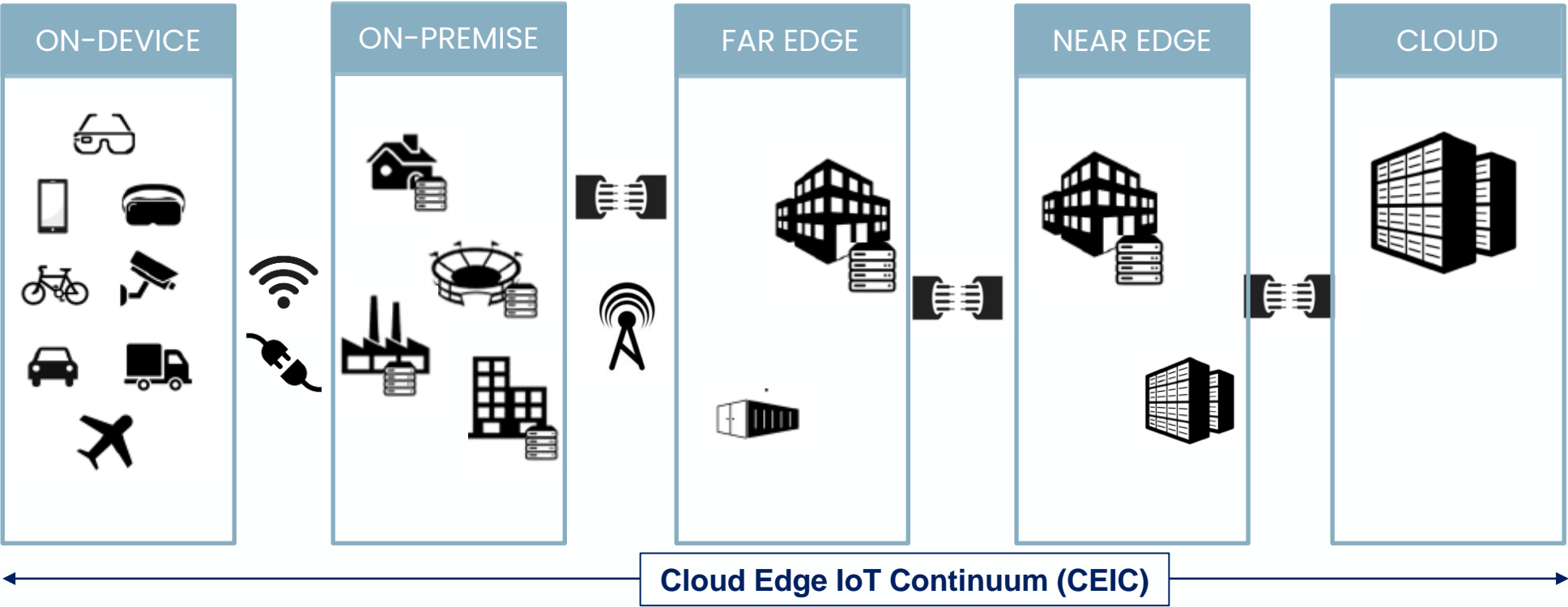


»FICATION«

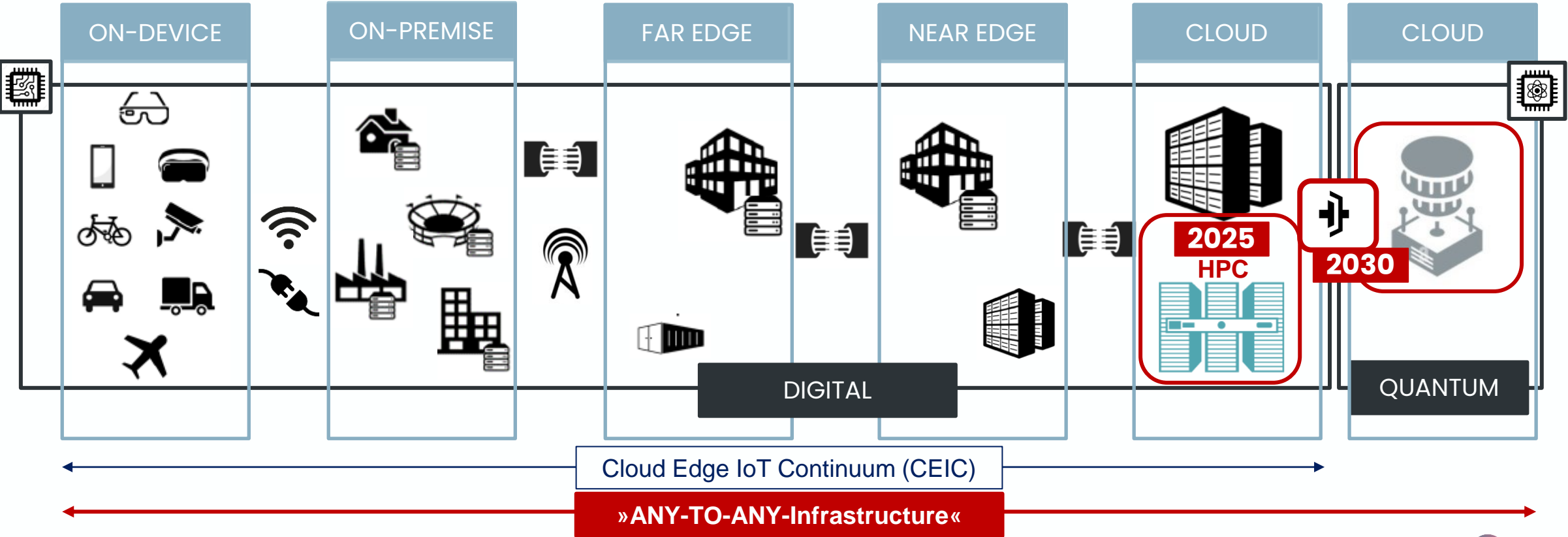
IT landscape (infrastructure, technology and development methodologies) is becoming a commodity!



Continuum – Big picture



Continuum – Big picture



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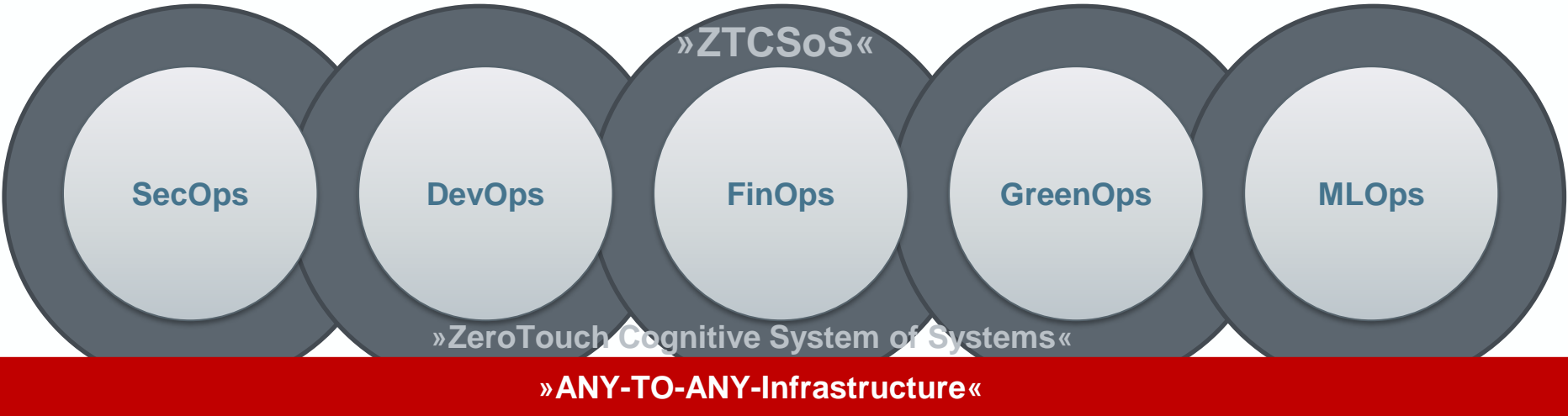


Research challenges towards the continuum

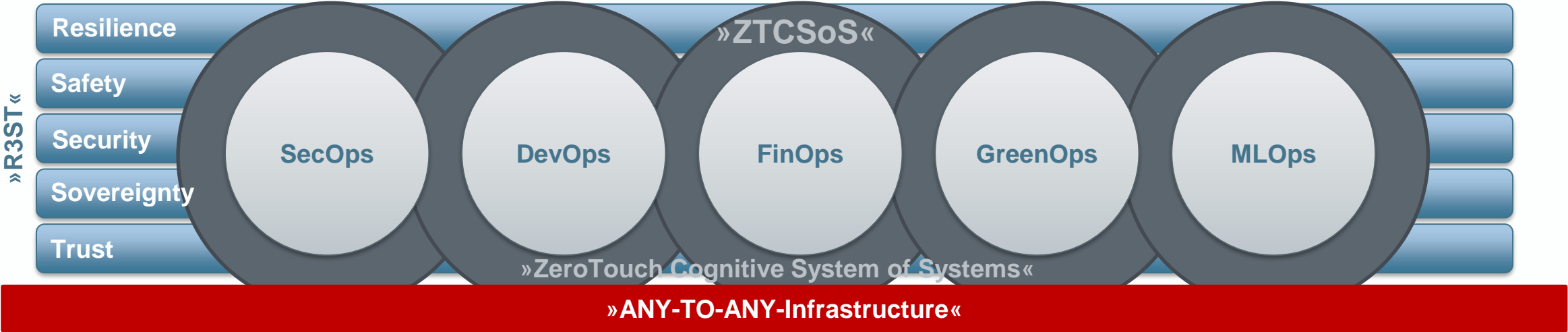
»ANY-TO-ANY-Infrastructure«



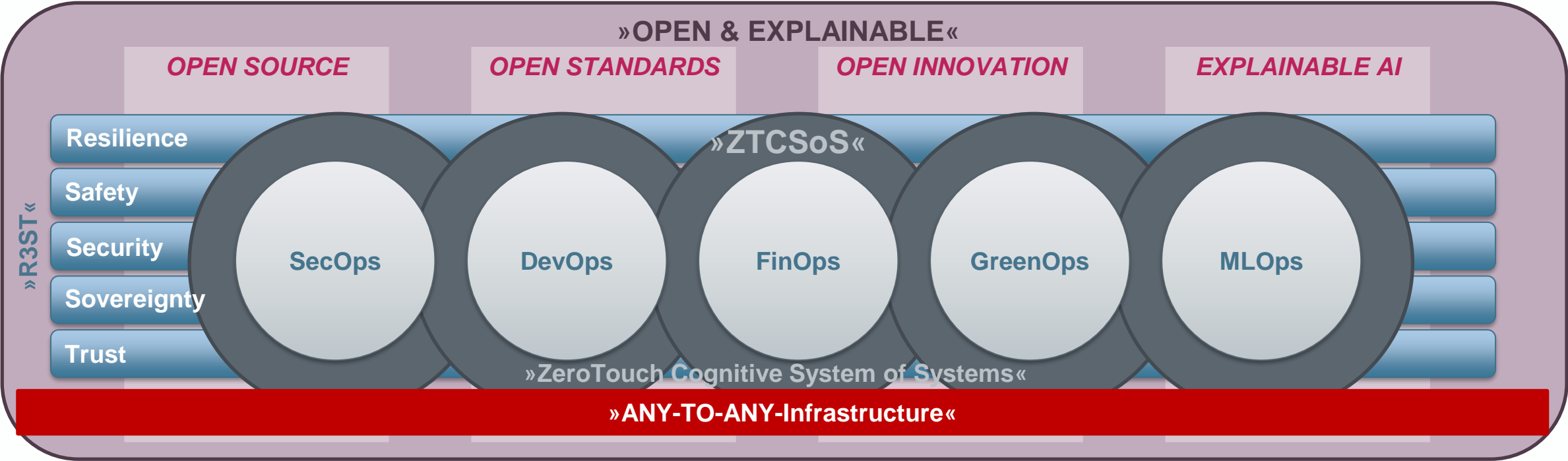
Research challenges towards the continuum



Research challenges towards the continuum



Research challenges towards the continuum



Conclusion

- ✓ Policy-driven, AI-enhanced automated middleware
- ✓ Extended infrastructural base from digital sensors to quantum based cloud services

»OPEN & EXPLAINABLE«
OPEN SOURCE OPEN STANDARDS OPEN INNOVATION EXPLAINABLE AI

✓ Highly automated, autonomous system of systems for multi-dimensional optimizations

»R3ST«
Resilience Safety Security Trust

✓ Inherent enforcement of resilience, safety, security, sovereignty and trust

SecOps DevOps FinOps GreenOps MLOps

- ✓ Based on principles of openness and traceability
- »ZeroTouch Cognitive System of Systems«
»ANY-TO-ANY-Infrastructure«





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Privacy and Compliance in the Cloud-to-Edge Continuum

Ambrish Rawat – IBM Research Europe

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Privacy in Cloud-to-Edge (Today)

Current Situation

- AI is a key driver for innovation in cloud capabilities
- Ease of development can lead to inadvertent oversight of **privacy** and **compliance**
- **Heterogeneous environments** can lead to increased exposure of privacy risks
- **Increasing costs of compliance** (up to 30%^[1]) when dealing with data heavy applications

Complexities

- AI is **inherently statistical** which makes it challenging to establish standards
- It is essential to ensure **interoperability** across services as infrastructures tend to be diverse

^[1] <https://www.accenture.com/nz-en/insights/consulting/compliance-risk-study>

Essential themes for next round of calls

1. Equip the cloud continuum to help combat security and privacy risks of AI solutions
1. Standardise the use of Privacy Enhancing Technologies (PETs) within a computing continuum to assist regulatory compliance
1. Foster equitable and accountable development of capabilities in the continuum



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A Vision for the Future of Research in the Cloud-Edge-IoT Domain

Martel Innovate GmbH

Massimo NERI, CTO

Giovanni RIMASSA, CIO

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Our Evolutionary Vision for the Cloud-Edge-IoT Domain



- **Current phase:**

- Generative
- Exploratory
- Preliminarily structured
- Targeting low TRLs

- **Next phase (2025-2027):**

- Targeting medium+ TRLs
- As we will get closer to commercialization, there will be an evolutionary selection of the best and most effective solutions at scale
- Will be ready to become a commodity

- **Critical success factors**

- Validated in real use cases
- Consolidated and structured technology
- Enabled by Open source and recognized in Open Standards
- AI-orchestrated and ready to scale
- Availability of a solid DevSecOps toolset
- Achieving medium-high TRLs and ready to support commercial apps



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Specific Research Directions and Challenges: AI

AI for Continuum

- AI-powered Resource Management
 - Dynamically adapting to changing conditions
 - Real-time decision-making
 - Handle heterogeneous environments
 - Incorporate adaptive learning algorithms
 - Research should prioritise
 - energy efficiency
 - fault tolerance
 - resilience (while ensuring scalability)
 - Research should integrate
 - Privacy-preserving techniques
 - Secure communication protocols
 - Robust access control

Continuum for AI

- Continuum Infrastructure Support for Trustworthy AI
 - AI support should be offered at the infrastructure level
 - Trustworthy edge intelligence
 - Should enhance European values
 - Infrastructure support for AI will
 - lower barriers for SMEs and other players to smoothly develop and introduce their own AI models
 - increase competitiveness of European SMEs through business differentiation

Specific Research Directions and Challenges (*continued*)

- **Metaverse@theEdge**
 - Will require lower latency, improved scalability, and better security, enabling efficient bandwidth usage and real-time processing for dynamic experiences.
 - Semantic communications will likely play a key role as an enabling technology.
- **Integrated Smart City Infrastructure**
 - Address research challenges in integrating IoT, edge computing, and 6G networks for smart cities through communication protocols, security, energy efficiency, and collaborative regulatory frameworks.
- **Edge-to-Cloud Interoperability and Standard Interfaces**
 - Achieving seamless Cloud-Edge-IoT integration requires developing **standard** protocols for interoperability, efficient data transfer, and application-level integration.
- **End-to-end Software Engineering for the Cloud-Edge-IoT Continuum**
 - Research and innovation on programming models, languages, and design tools are needed for application-level development, considering industry-specific use cases and network topologies, with connections to open source and European digital autonomy.



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Continuum AI

Lauri Lovén – 6G Flagship, University of Oulu, Finland

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Status: Computing Continuum

Computing Continuum

+

Edge Intelligence

=

Cognitive Computing Continuum



However...

- How can AI models be seamlessly connected across the cognitive computing continuum?
 - How do you train and use them, and manage their workflows?
 - How do you manage the resource usage of connected AI models?
 - Can connected AI models, in turn, help orchestrate resources in the continuum continuum?
 - How do you cross administrative boundaries?
 - How do you map between different semantic models?
 - How do you ensure security and privacy?

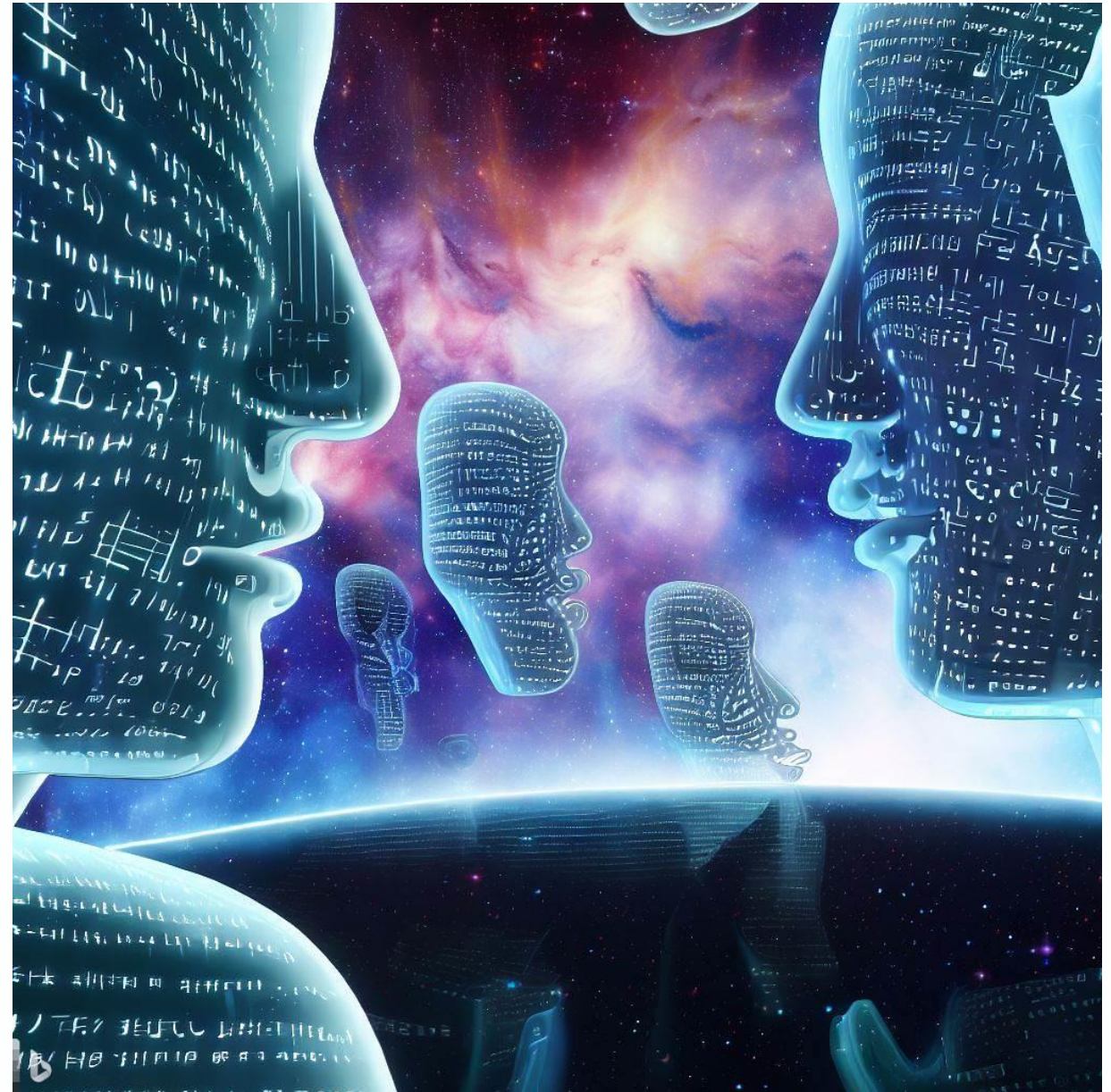
Status: Foundation AI

Large language models:

- OpenAI: GPT-x
- Meta: LLaMa
- Google: PaLM, LaMDA, Bard
- OS: Alpaca, Vicuna, GPT-J, etc...

+ Image, video, speech generation, ...

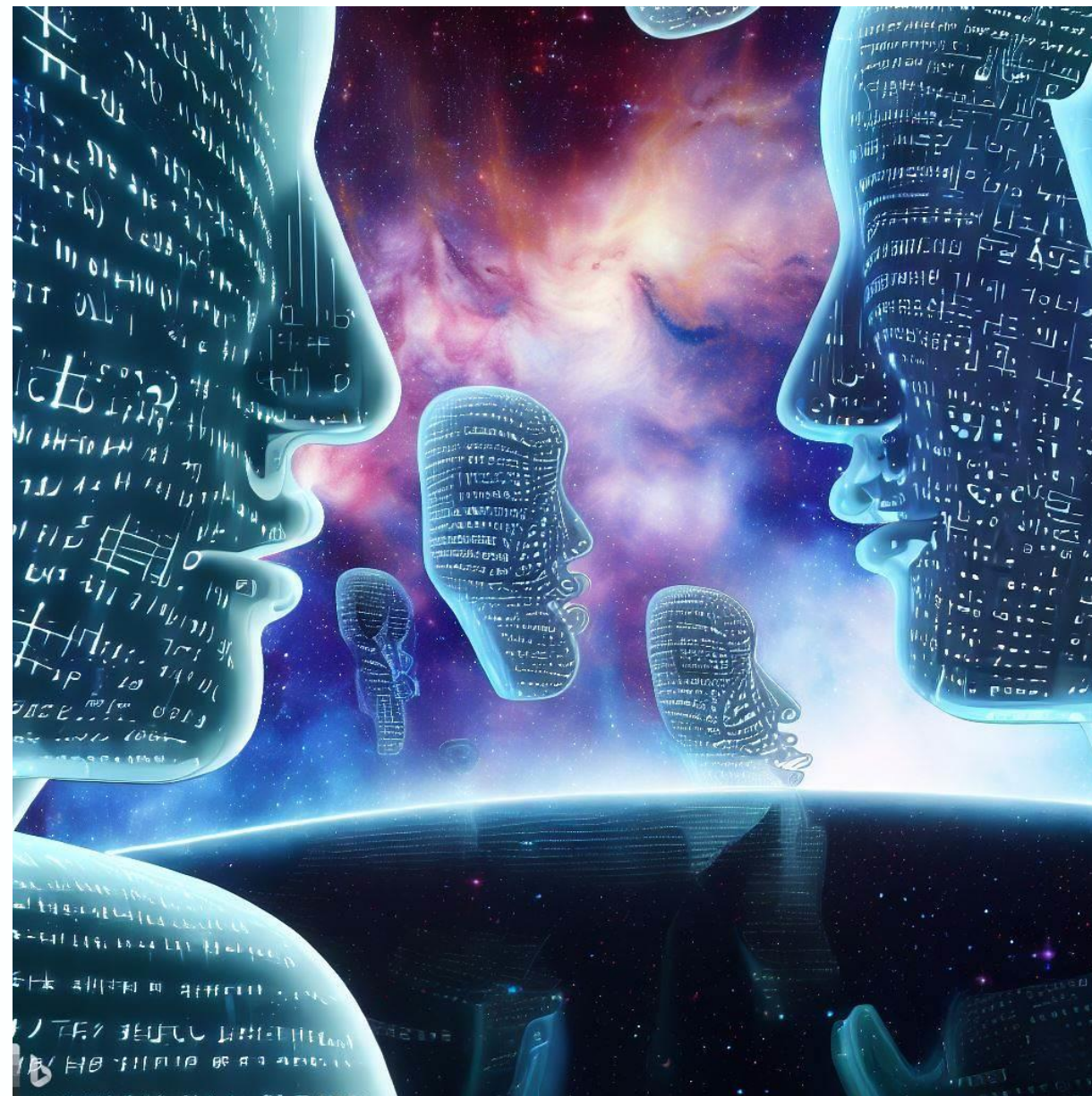
+ Agent ecosystems (e.g. LangChain, Hugging Face)



Status: Foundation AI

A strong foundation for:

- Execution of complex tasks
- Model aggregation
- Autonomous operation



However...

- How can AI models be seamlessly connected across the cognitive computing continuum?
 - How do you train and use them, and manage their workflows?
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 - Can connected AI models, in turn, help orchestrate resources in the continuum continuum?
 - How do you cross administrative boundaries?
 - How do you map between different semantic models?
 - How do you ensure security and privacy?

However...

- How can you integrate foundation model training, fine-tuning, deployment, and use in the cognitive computing continuum?
 - How do you ensure the alignment of the models?
- How do you decide on the level of autonomy of AI agents in the computing continuum?
 - How loose should agent coupling be?
- How can AI agents from different administrative domains be seamlessly connected to each other?
 - How do agents from different administrative domains negotiate for co-operation and resource usage?
 - How can co-operating agents orchestrate resources in the continuum continuum?
 - How do you ensure the security of co-operating agents?



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Thank you!

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Reinforcement Learning Across Computing Continua

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Context

- In a cloud/edge context, **guaranteeing** the performance of mission-critical applications is extremely challenging:
 - **distributed nature** of computing
 - ever-increasing **complexity** in terms of heterogeneity and dynamicity of the components
 - **limited capacity** of the edge layer
- **Reinforcement Learning (RL)** techniques have recently attracted increasing attention:
 - **autonomously learn** the optimal behaviour with little or no prior knowledge
 - **most promising approach** to cope with computing continua

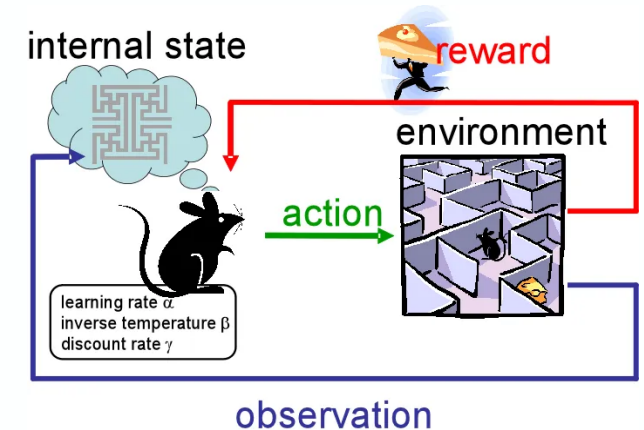
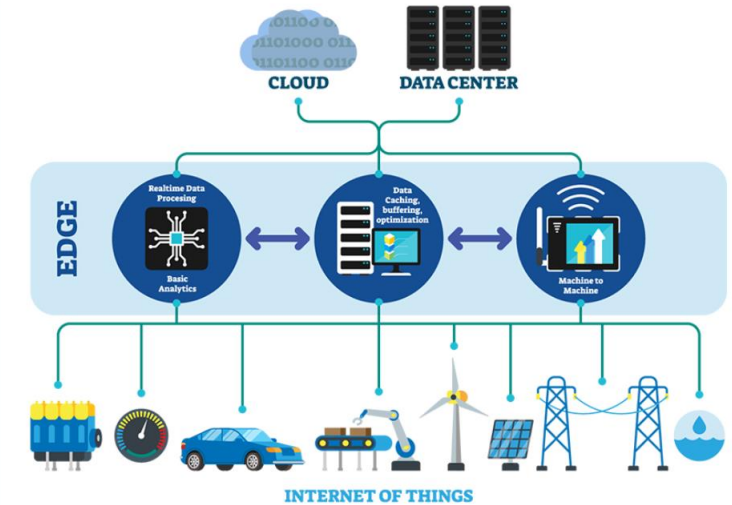


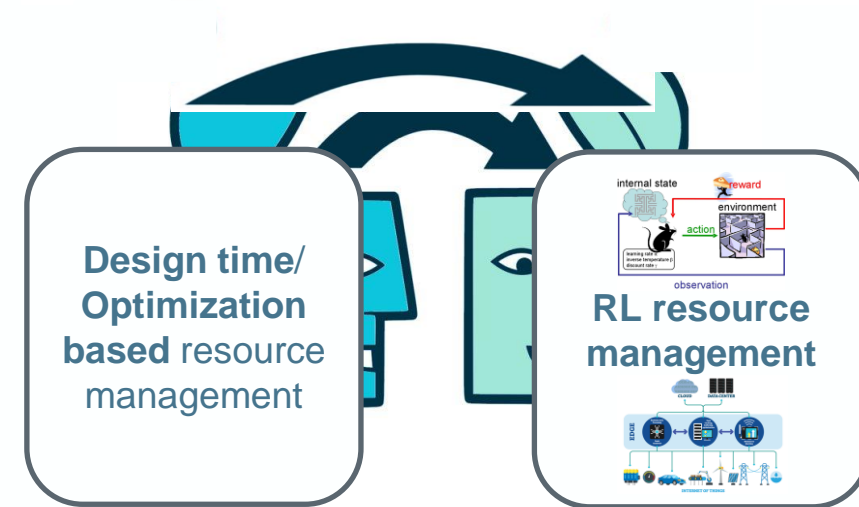
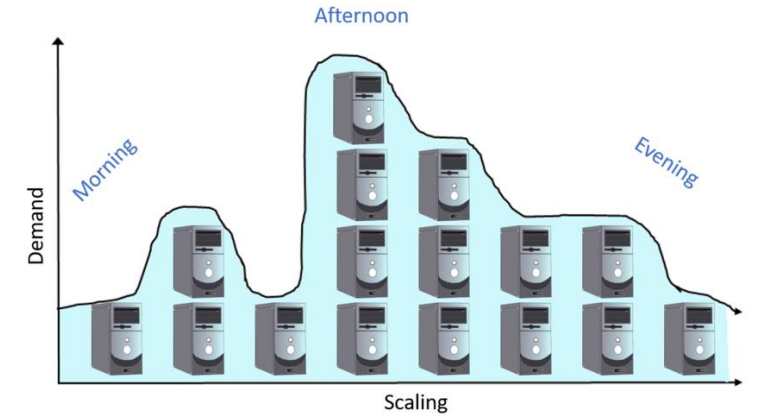
Image taken from: <https://becominghuman.ai/>

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Research proposal

- Current cloud-based/edge systems implement basic policies for resource management:
 - adaptation actions **triggered** by **threshold violations**
 - **no performance** guarantees neither providing costs nor energy consumption minimization
- Development of novel **runtime management solutions** based on RL:
 - trade-off application performance and energy consumption
 - guarantee reliable execution even under edge-cloud network partitioning
 - **transfer learning** of design time knowledge





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AI Ops, Data at the Edge, Hybrid & Green Computing as Drivers for the Continuum

Jesus Santamaria – TECNALIA

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Slide 1 of 2

Motivation

- The connected world has brought an explosion in data generation
- Pillars for digitization are data and computational models/infrastructure
- Secure and **smart exploitation of the data** is the final goal of developing new and sophisticated computing paradigms (e.g. edge computing, MLOps)
- CC combined with advanced technologies allows a powerful data exploitation

Research Challenges

AI Ops

Extend DevOps to the CC with intelligent tools for automated deployment and operation

- Next version of the **self-adapting Cognitive Cloud** = sensing + learning + adapting
- **Intelligent assistant** for the operation in the Cloud Continuum
- **NLP to accelerate** solutions in the cloud continuum

Research Challenges

Data at the edge

- Edge data quality (new algorithms and metrics)
- Data virtualization at the edge

Hybrid computing

- New architectures to combine different paradigms (e.g. classic-quantum computing)
- New patterns and models to implement and deploy hybrid apps/services/processes
- Additional **security** and **performance** requirements for **secure distributed processing** (e.g. MPC or homomorphic encryption)

Efficient & green computing

Tools for the efficient use of computing resources with a focus on sustainability

- Transfer computing to devices
- Embedded AI + 6G networks
- Computational load sharing, device energy management



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Semantic Web of Things

**Synergy within Standards, Alliances, Technologies, Projects, and Concepts
(Semantic Web, IoT, and Data Spaces)**

Dr. Amelie GYRARD – TRIALOG

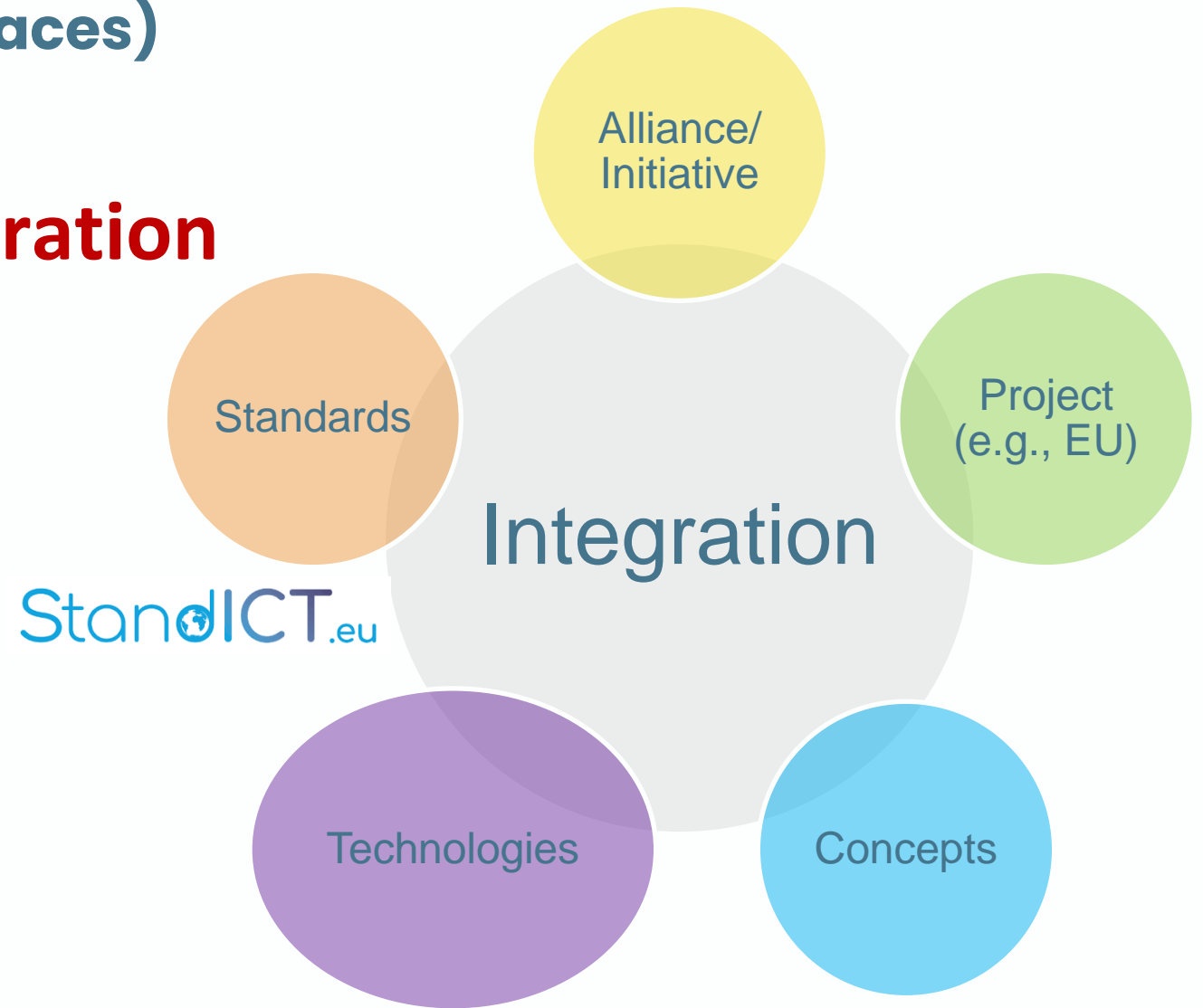
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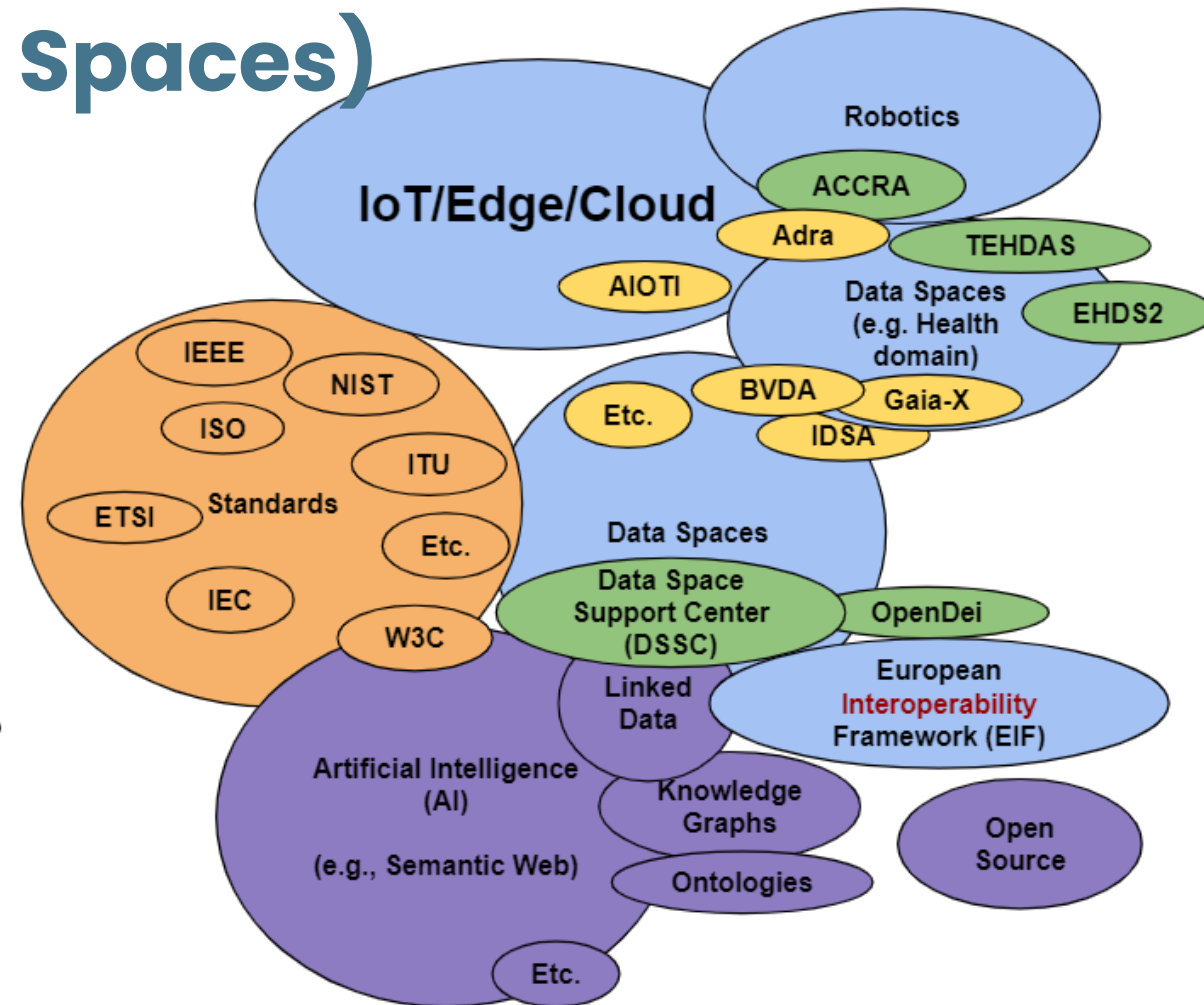
Better Synergy is needed within Standards, Alliances, Technologies, Projects, and Concepts (Semantic Web, IoT, and Data Spaces)

- => Need to focus on **integration**



Synergy among Standards, Alliances, Technologies, Projects, and Concepts (Semantic Web, IoT, and Data Spaces)

- Research Challenges:
 - RC1: Knowledge Extraction using Natural Language Processing (NLP) techniques
 - Ontology catalog for IoT
 - RC2: Synergies within standardization
 - RC3: Synergies within data space
 - RC4: IoT/Edge/Cloud Computing Semantic interoperability



Source: <https://www.w3.org/DesignIssues/LinkedData.html>

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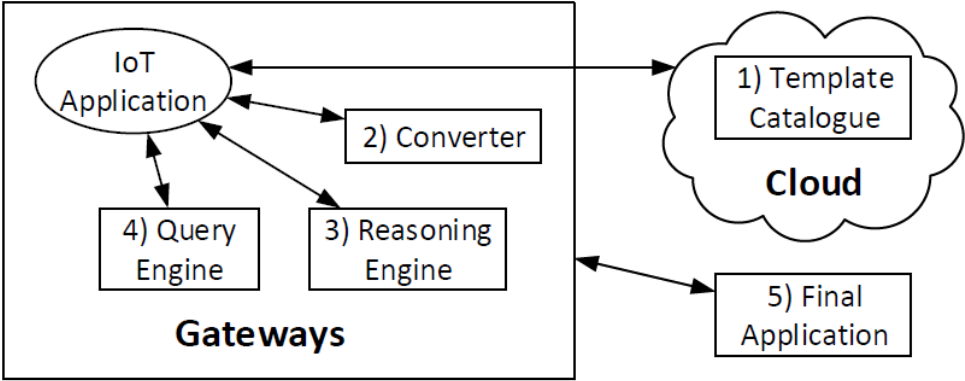
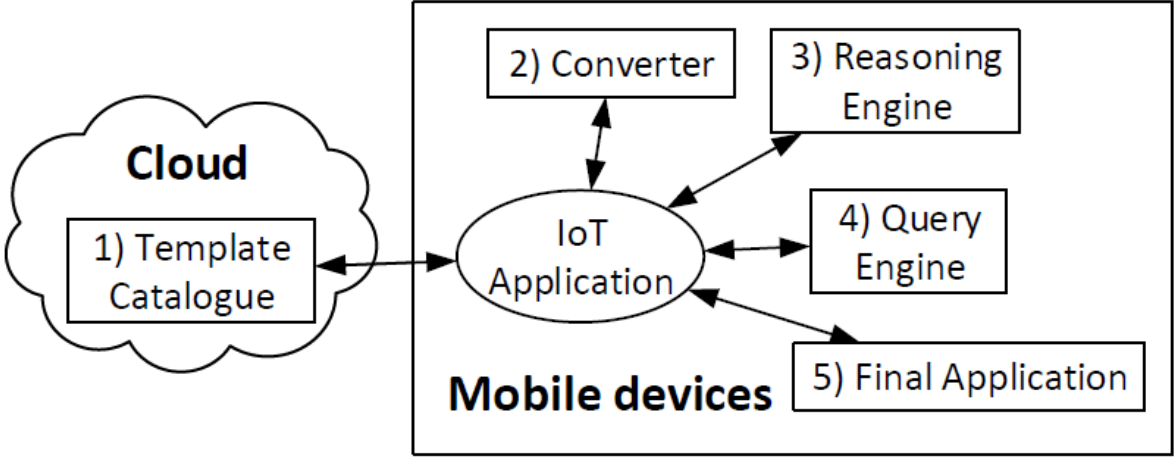
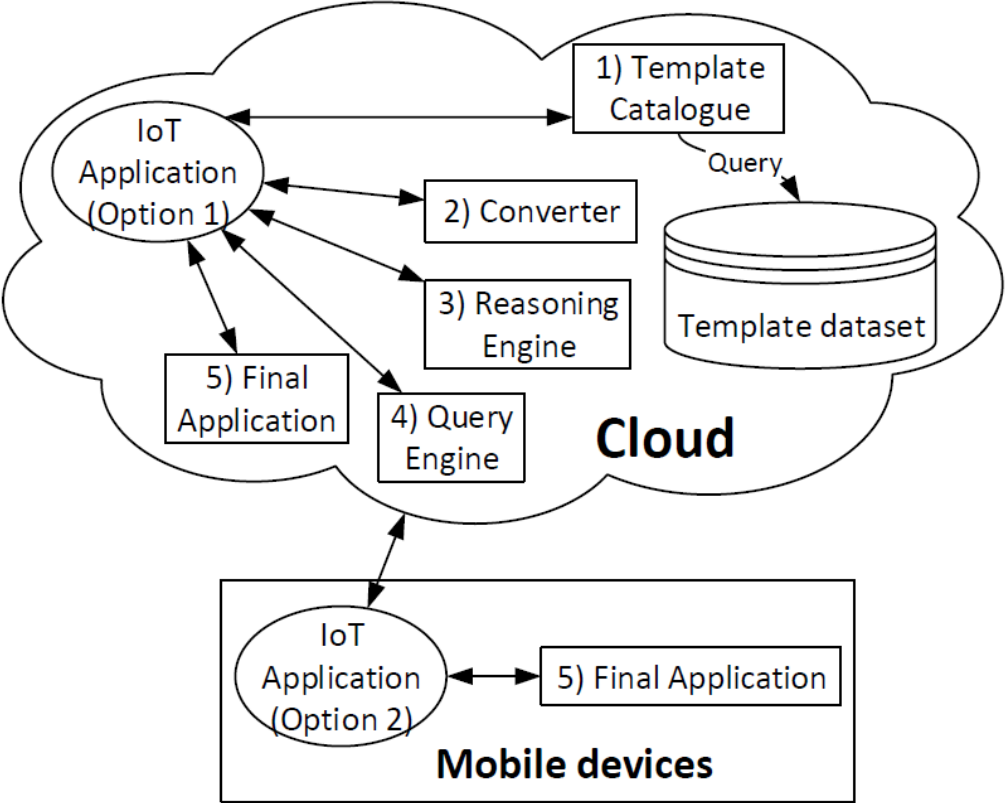
Appendix

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Appendix: Gateway



ISO/IEC 5392 Knowledge Engineering Reference Architecture (KERA)
 A Semantic Engine for Internet of Things: Cloud, Mobile Devices and Gateways. Gyrard et al. 2015.



Appendix: Semantic Web of Things

Can Sensors Sense Emotion?

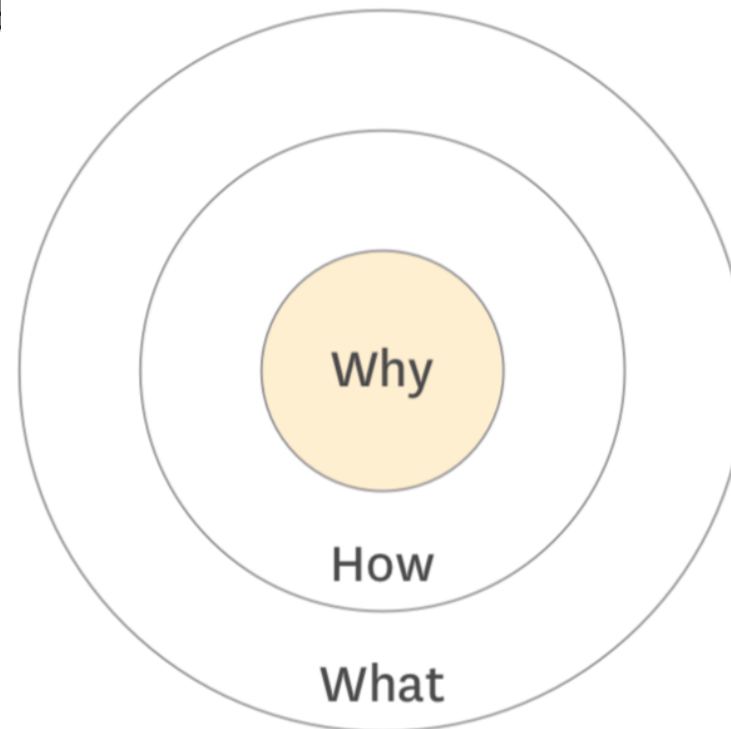
- Motivation: Approximately 280 million people in the world have depression. Depression can be caused by stress and lack of motivation. Simon Sinek says "Working hard for something we don't care about is called **stress**: Working hard for something we love is called **passion**." <https://www.who.int/news-room/fact-sheets/detail/depression>
- Current Status:
 - Example: **ACCRA (H2020, 2016-2020, <https://www.accra-project.org/>)** with the French Buddy **Emotional Robot**
 - Information available on the Web, representing the World, and machine-processable, that can be exploited such as ontology catalogs.

Appendix: References

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- <http://wiki.aiisc.ai/index.php/AmelieGyrard#Publications>
- Google knowledge graph: <https://www.youtube.com/watch?v=mmQl6VGvX-c>
- [A Semantic Engine for Internet of Things: Cloud, Mobile Devices and Gateways](#). Gyrard et al. 2015

Appendix: Simon Sinek

- Why: Approximately 280 million people in the world have depression. Depression can be caused by stress and lack of motivation. Simon Sinek says "Working hard for something we don't care about is called **stress**: Working hard something we love is called **passion**."
<https://www.who.int/news-room/fact-sheets/detail/depression>



Why - Your Purpose

What is your cause? What do you believe?

How - Your Process

Specific actions taken to realise your Why.

What - Your Process

What do you do? The result of Why. Proof.



Meta-Intelligence for the Meta-Continuum

Patrizio Dazzi – University of Pisa
Emanuele Carlini, Matteo Mordacchini – National Research Council of Italy
Konstantinos Tserpes – Harokopio University of Athens

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From Clouds to the Cognitive Continuum

Cloud



Cloud Management



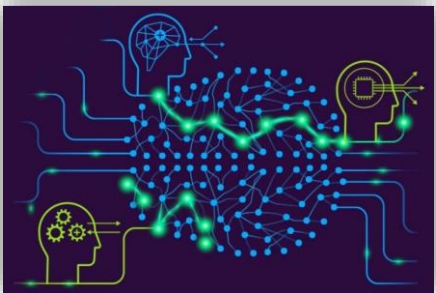
Continuum



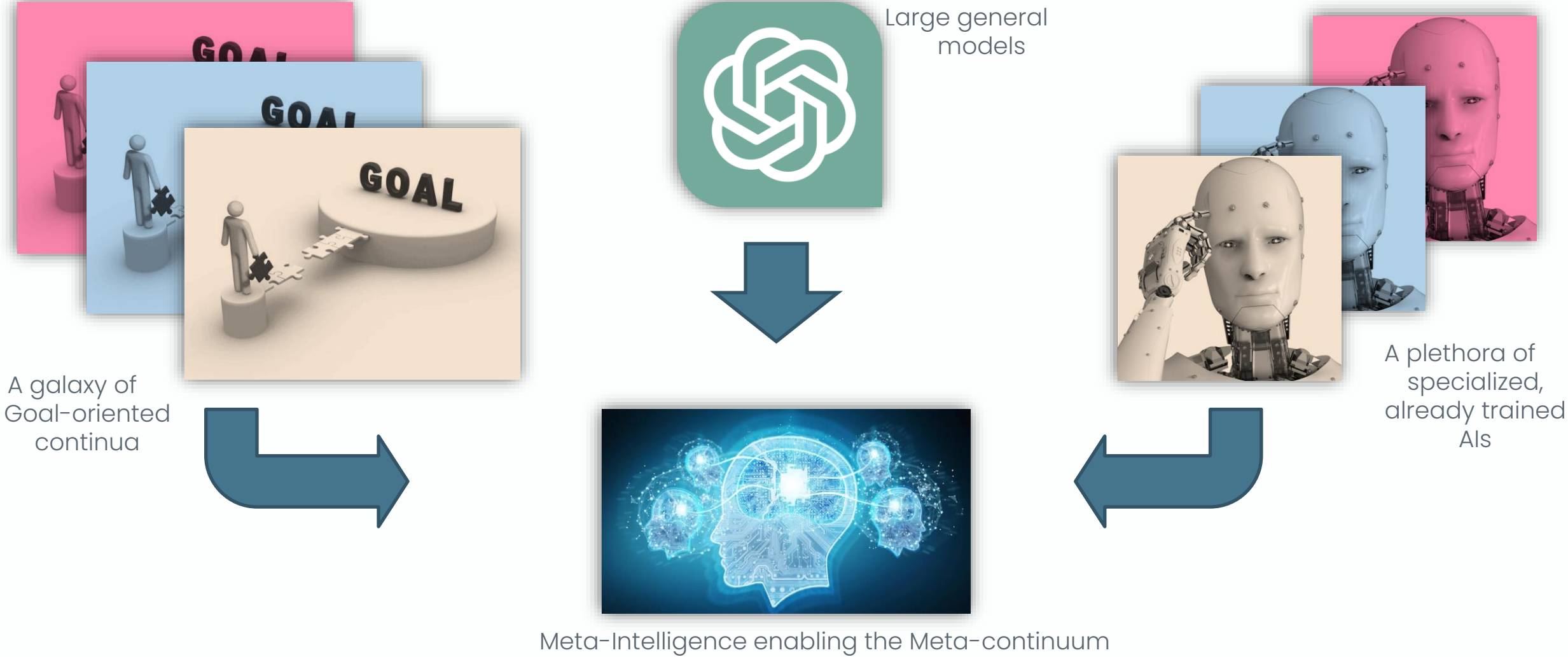
Cognitive Cloud



Cognitive Continuum



Meta-Intelligence for the Meta-Continuum





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A Vision of an AI-enabled Cloud-Edge Continuum

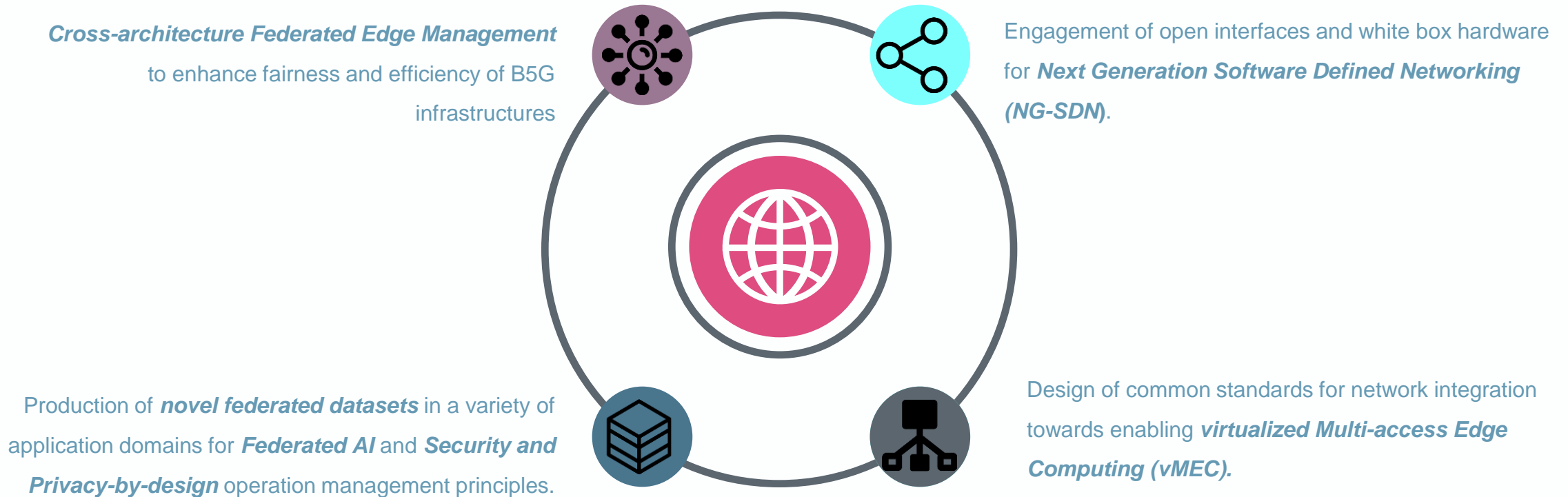
Prof. Panagiotis Sarigiannidis – University of Western Macedonia (UOWM)

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Architectural Challenges for an AI Enabled Cloud-Edge Continuum



Technological Challenges for an AI Enabled Cloud-Edge Continuum

SDN-enabled MEC environment as a key enabler for IoT and mission-critical, vertical solutions

- IoT orchestration, data collection and decentralized analytics
 - Latency-aware dynamic resource allocation

Efficient Edge to Cloud data localization and cognitive processing offloading

- To increase the adaptability of future frameworks based on devices' demands and preferences

Federated Learning & Distributed Model Personalisation

- Distributed Model Optimisation and Synchronisation
 - Refinement of next-generation global models

AI-powered IDPS systems avoiding data collection and offering decentralized analytics, privacy by design and data protection

- To enhance fault tolerance, privacy, and controllability of distributed data
 - To avoid misuse and secure the user's identity

Attestation modelling, Distributed and Decentralized Blockchain

- To automate the offering and acceptance of user data, and exchange
 - To verify learning model updates

Social and Ethical Challenges for an AI Enabled Cloud-Edge Continuum



Self-regulation frameworks

Societies must establish *self-regulation frameworks* to **detect and mitigate ethical and social risks** associated with NG-IoT by design.



Unbiased AI

The NG-IoT requires the *design and deployment of unbiased AI systems* to **prevent undesired discrimination** of vulnerable groups.



Green MetaOS

Sustainable solutions for *charging batteries* and *daily charging routines* need to be explored to **reduce greenhouse gas emissions**.



Tactile IoT & AR/VR

Contextual frameworks for supporting cutting-edge AR/VR tools are needed to support modern IoT applications, while opening new business opportunities.



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