

A background network diagram consisting of interconnected nodes and lines, with some nodes highlighted in blue and others in grey. The nodes are arranged in a complex, non-linear pattern, suggesting a network or data flow.

**NOF**  
**2024**

15th International Conference on Network of the Future

NoF 2024

October 02-04, 2024

Castelldefels (Barcelona), Spain

# Interoperability in communication for Industry5.0 powered by applied AI/ML

- by Pal Varga  
(BME-TMIT)



**BME**  
**TMIT**

# Hello!

## I am Pal Varga

I am interested in  
interoperability of cyber-physical  
system of systems,  
5G / 6G mobile networks, and  
AI/ML applications in Industry5.0

**[pvarga@tmit.bme.hu](mailto:pvarga@tmit.bme.hu)**



**BME  
TMIT**

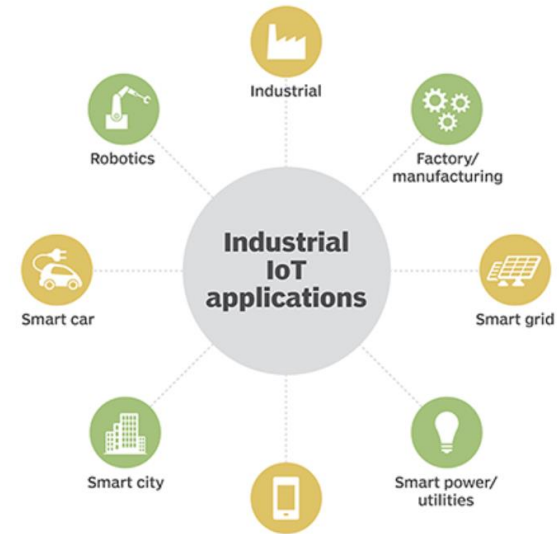
# Overview

- Industrial IoT and CPS  
from Industry 4.0 to Industry 5.0
- Interoperability
- AI in Industry 5.0
- AI for Interoperability
- Digital Twins
- Edge and Fog computing



# R&I Background

- **Eclipse Arrowhead** framework
- **Arrowhead Tools** for CPSoS
- **AIMS5.0** – AI in Manufacturing  
leading to Sustainability and Industry5.0
- **Arrowhead flexible Product Value Networks**
- IEEE Int'l WS on **Generative AI** in Network Management
- IEEE Int'l WS on **Analytics** for Service and Applications Mgmt





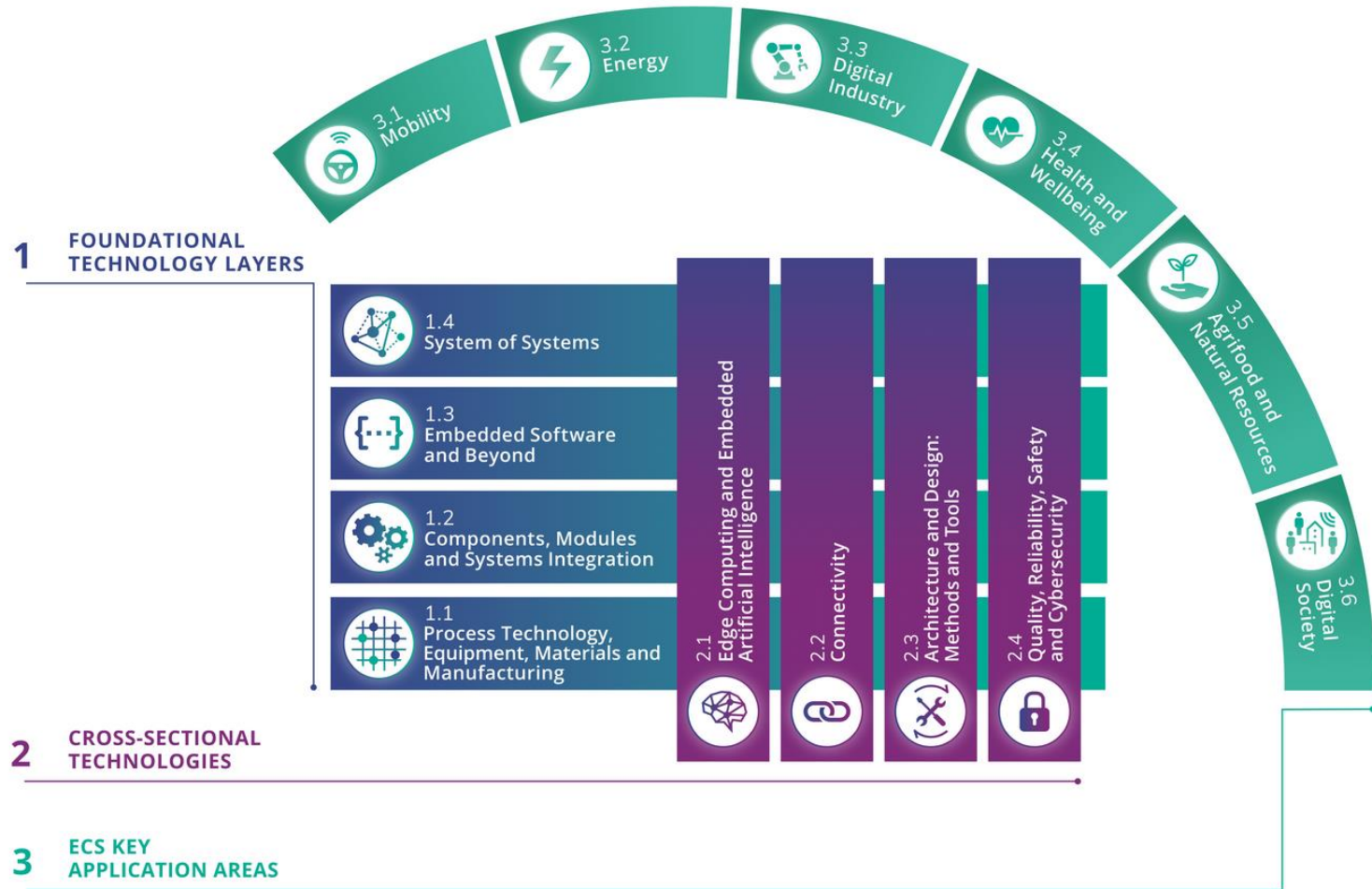
Productive 4.0

# Some of our recent project partners

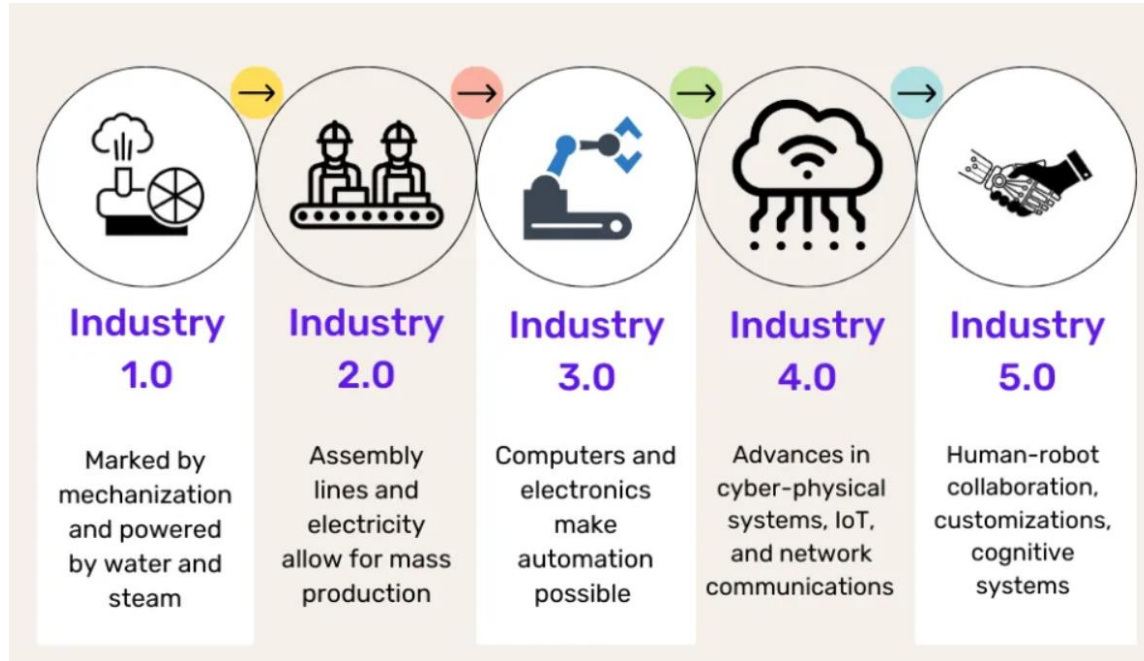




# ECS Strategic Research and Innovation Agenda (EU)

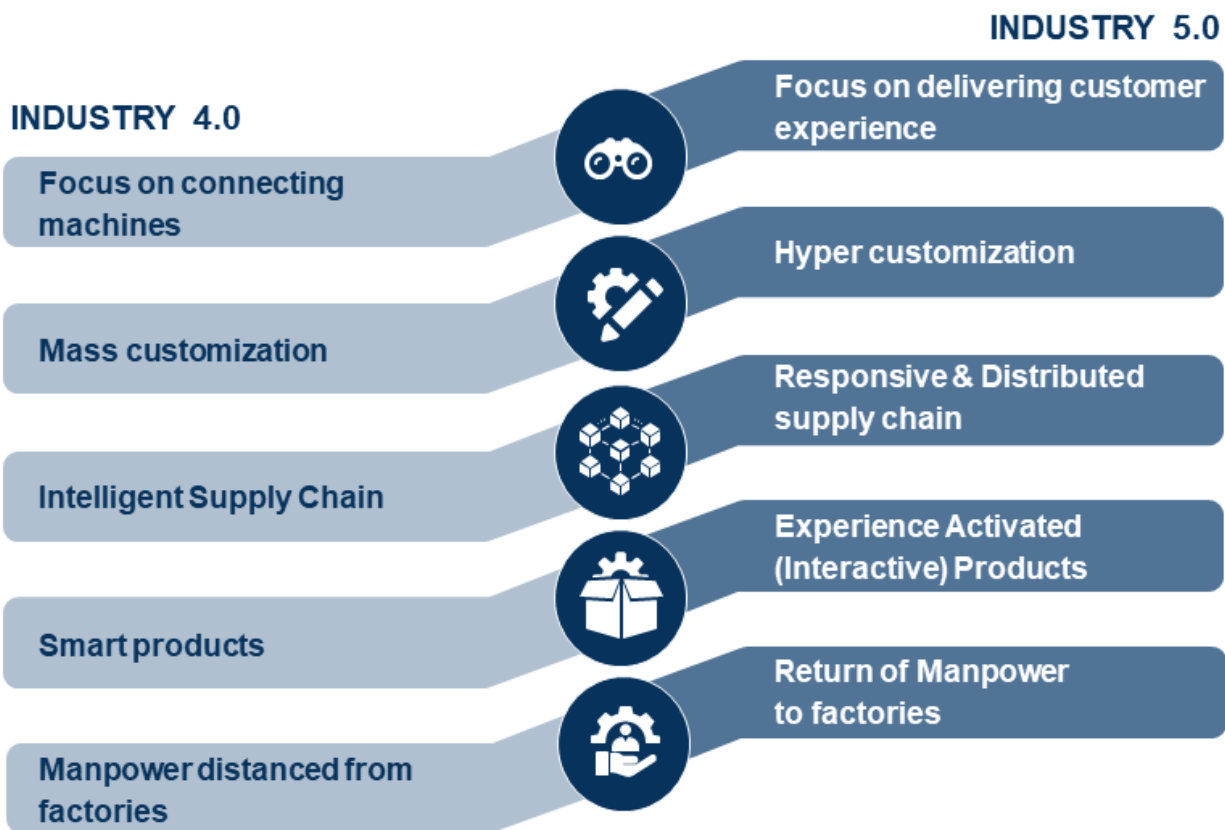


# Towards Industry5.0



Source: Google images

## Highlights of Industry 5.0 compared to Industry 4.0





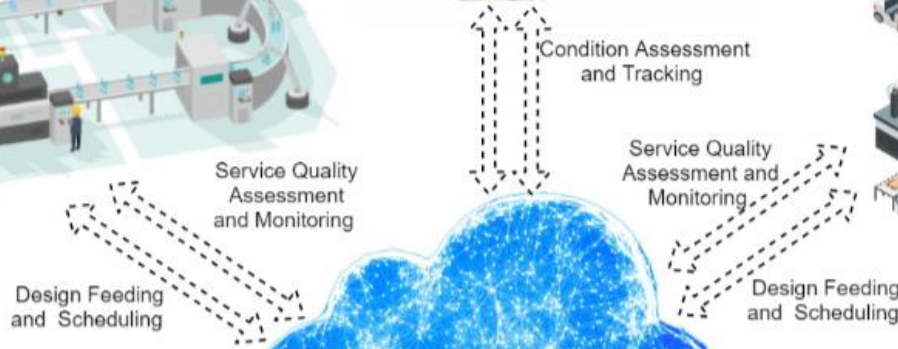
# Logistic and Shipping



Manufacturing Plant



Manufacturing Plant



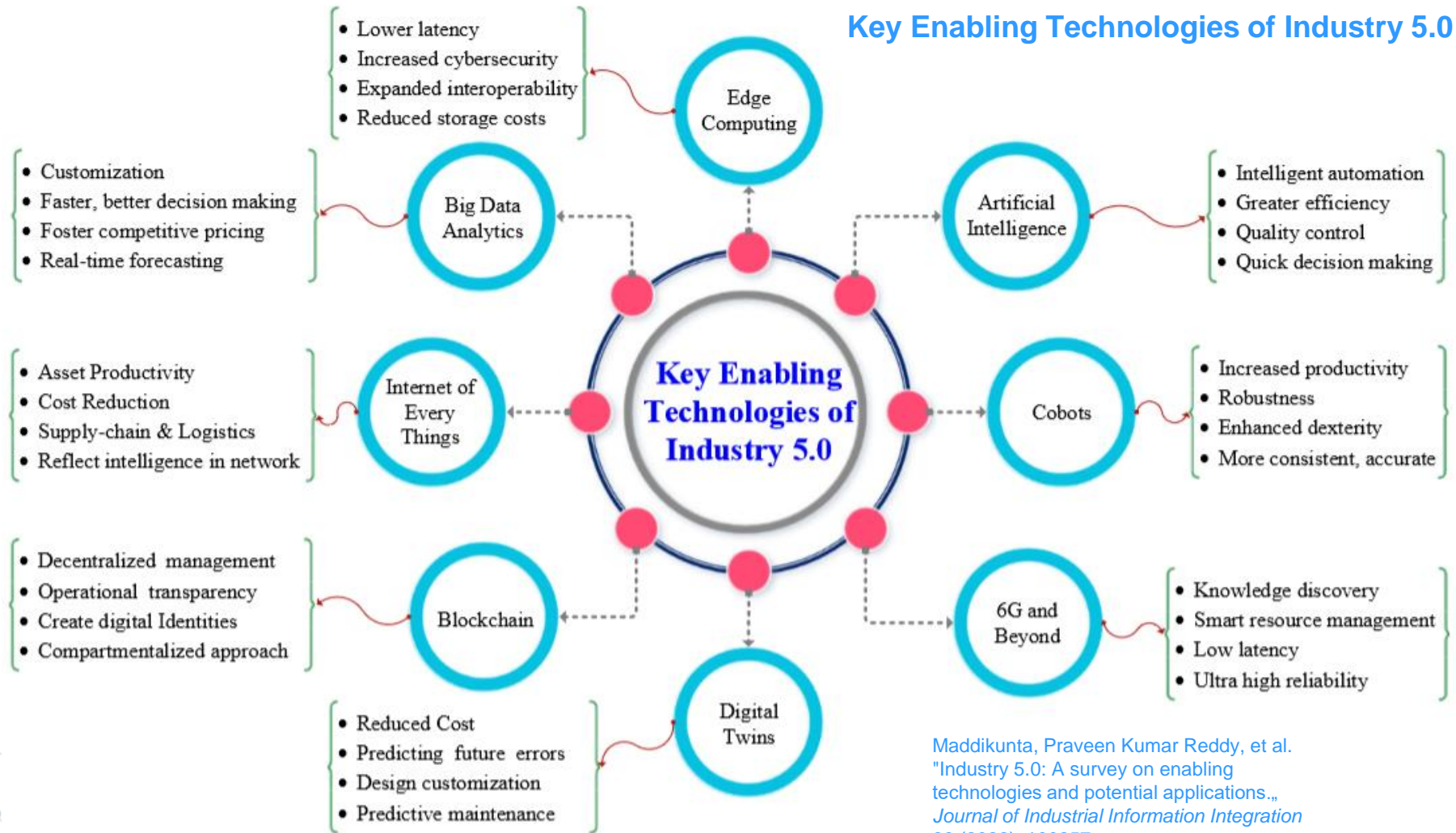
Intellectual Property Management



Monitoring and Scheduling

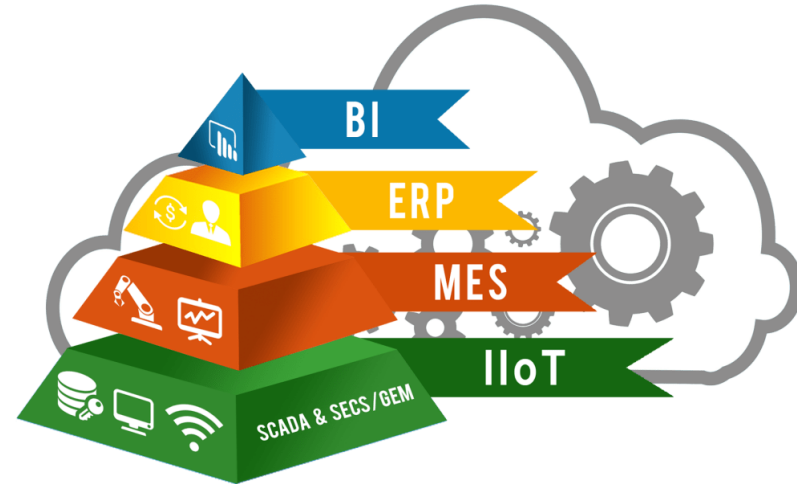
Maddikunta, Praveen Kumar Reddy, et al.  
"Industry 5.0: A survey on enabling technologies and potential applications.,,  
*Journal of Industrial Information Integration* 26 (2022): 100257.

# Key Enabling Technologies of Industry 5.0



Maddikunta, Praveen Kumar Reddy, et al.  
"Industry 5.0: A survey on enabling technologies and potential applications.,  
*Journal of Industrial Information Integration*  
26 (2022): 100257.

# Using AI at different levels of production & manufacturing



# Interoperability



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# Interoperability – the motivations of the Arrowhead framework

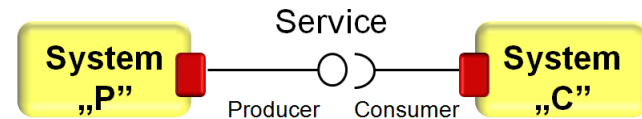
- Various CPS and Industrial IoT systems are developed all around
- Developers and integrators use great variety of tools – with lots of legacy, internal interfaces and communication patterns
- For System of Systems (non-monolithic)
  - Different vendors equipment have to work together
  - Using communication standards make sense
  - Using common design methodologies make sense

## Service Oriented Architecture

- Systems are service consumers and service producers, they exchange information (providing information as a „service”)
- Why use Service Registry and Orchestration?

So industrial systems would be as discoverable (with **security** on board) as Internet services e.g. websites

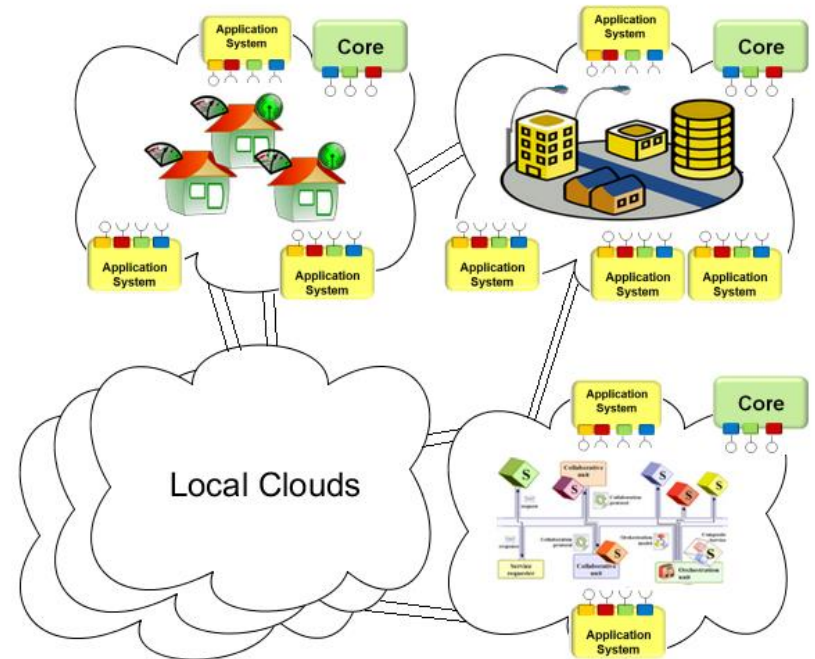
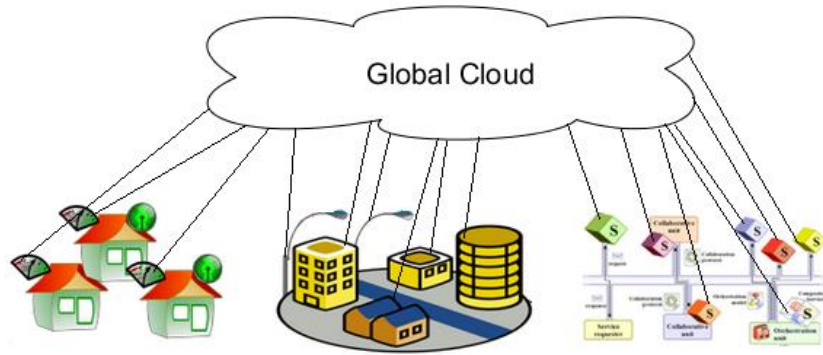
– **minimal (or no) configuration is required from the user**





# Local Automation Clouds

-> advantages

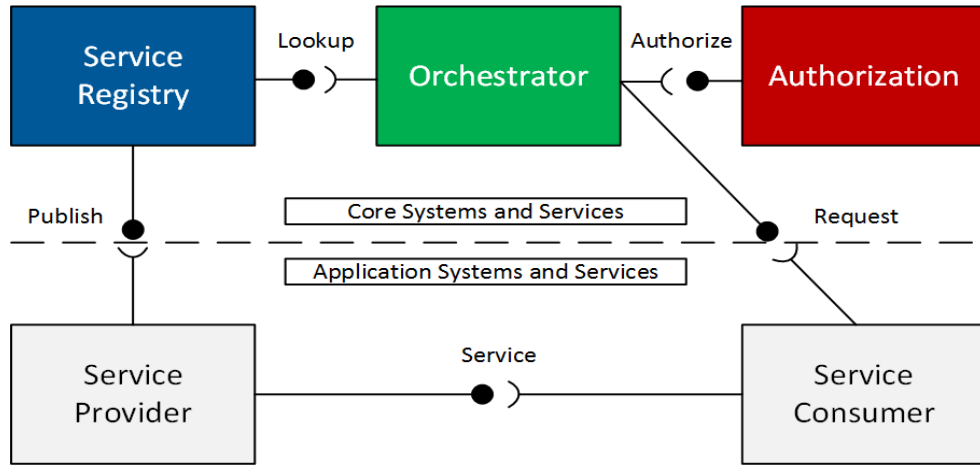


Varga, P., Blomstedt, F., Ferreira, L. L., Eliasson, J., Johansson, M., Delsing, J., & de Soria, I. M. (2017). Making system of systems interoperable—The core components of the arrowhead framework. *Journal of Network and Computer Applications*, 81, 85-95.

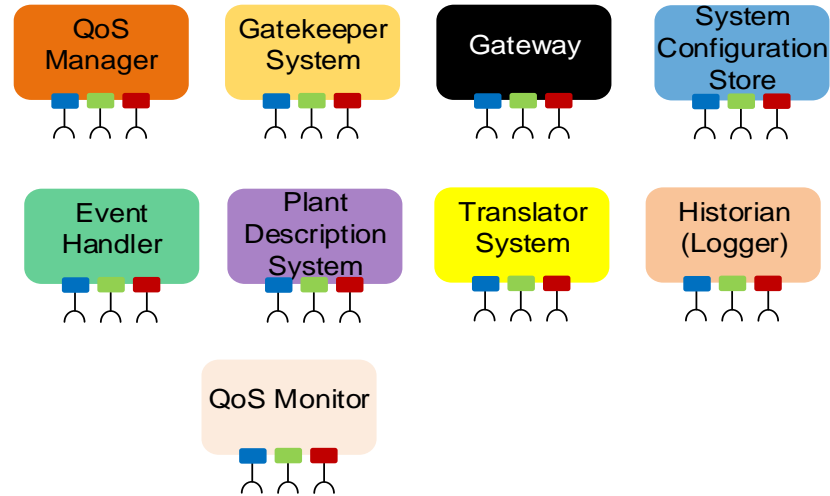


# Arrowhead Framework Core Components

Minimum working set

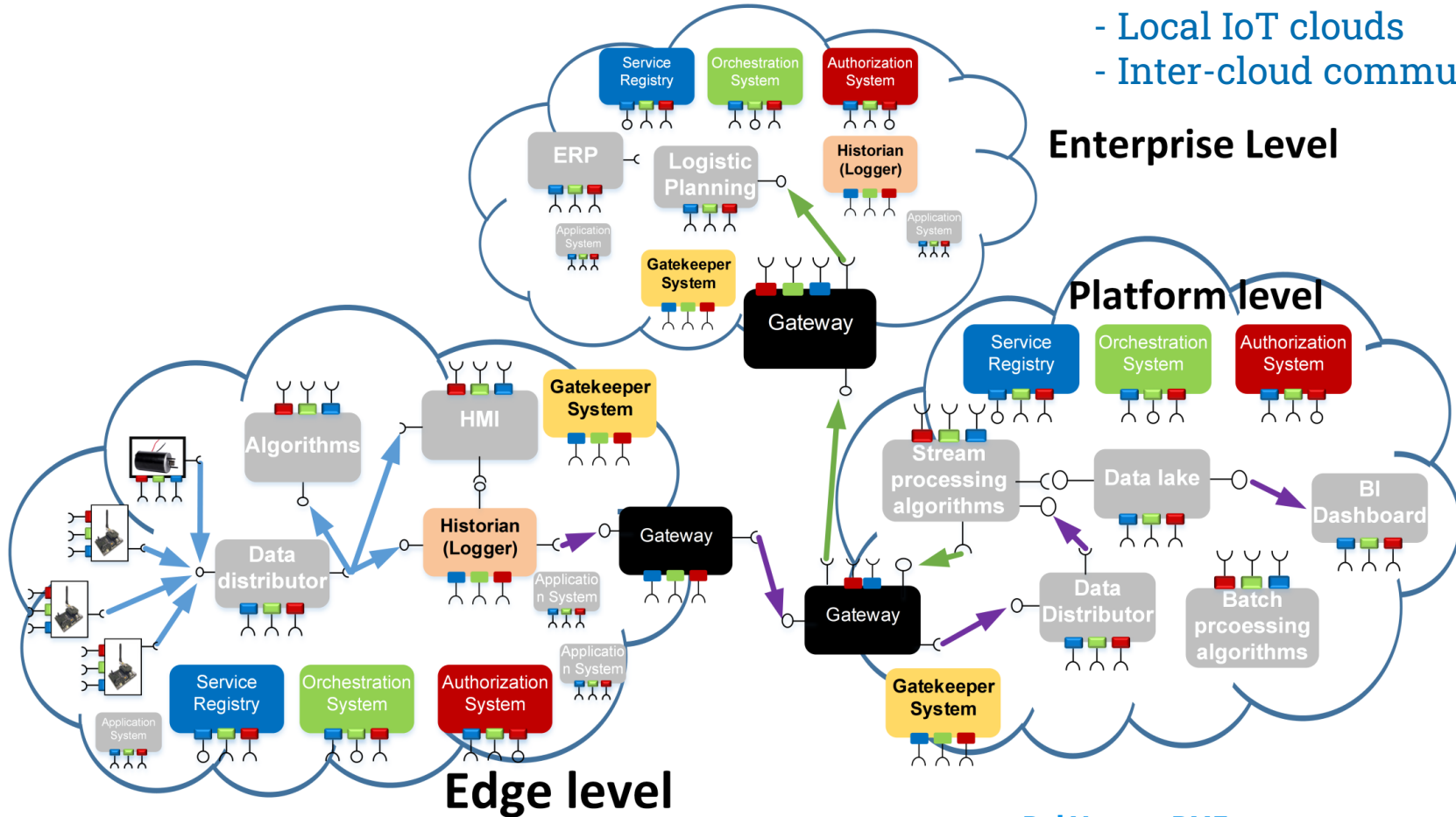


Some of the further elements



# Eclipse Arrowhead framework

- Service Oriented Architecture
- Local IoT clouds
- Inter-cloud communications

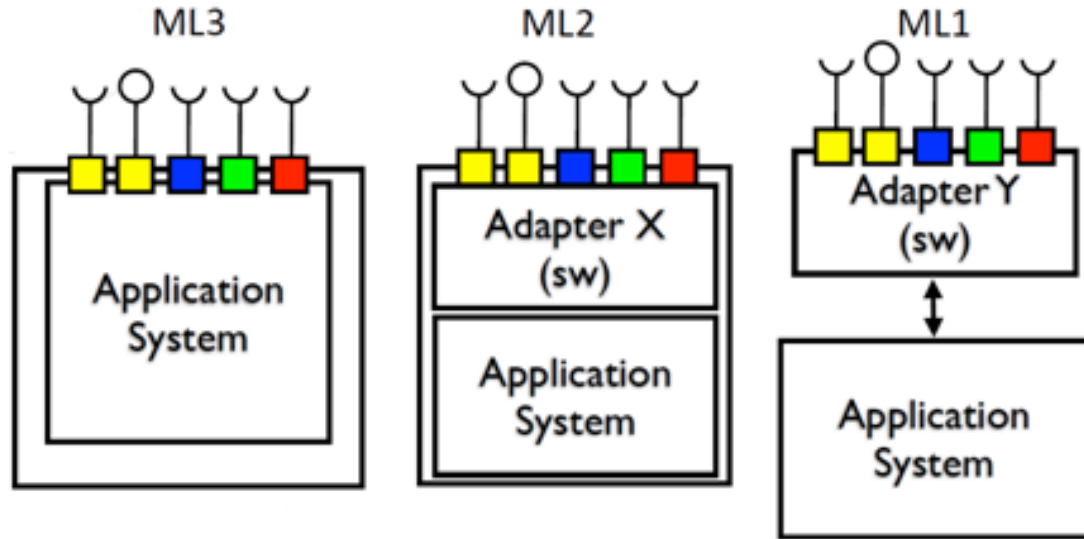


**Enterprise Level**

**Platform level**

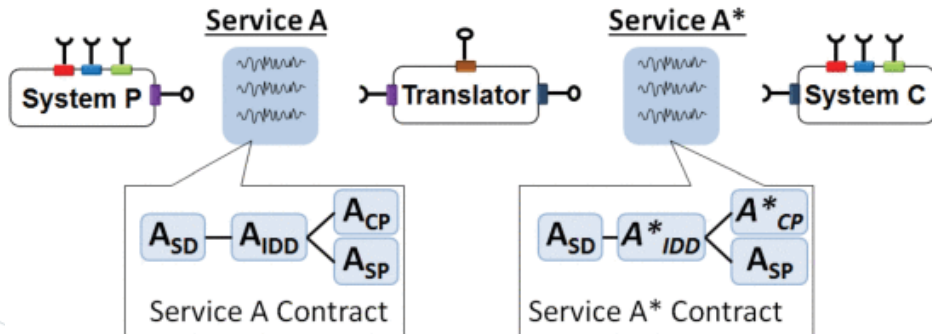
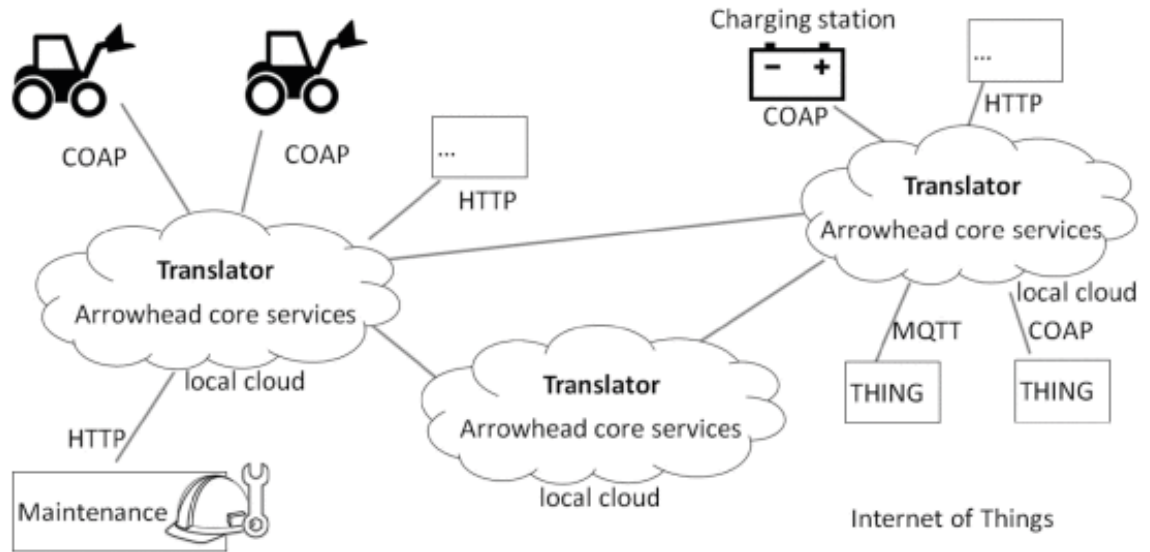
**Edge level**

# Maturity Levels of Arrowhead Integration



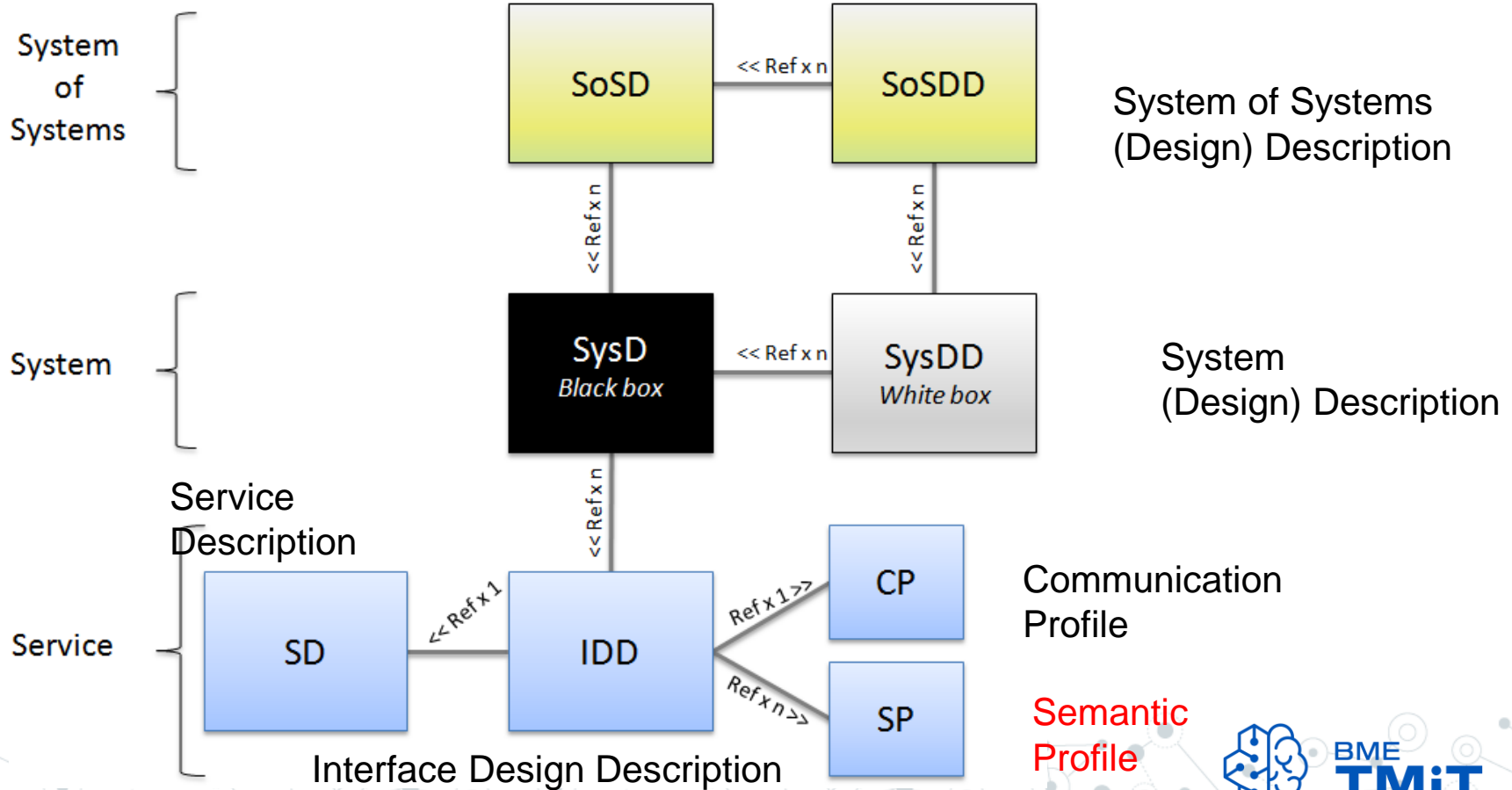
Varga, P., Blomstedt, F., Ferreira, L. L., Eliasson, J., Johansson, M., Delsing, J., & de Soria, I. M. (2017). Making system of systems interoperable—The core components of the arrowhead framework. *Journal of Network and Computer Applications*, 81, 85-95.

# Translation of Services in Arrowhead



# Arrowhead Documentation Structure

Blomstedt, F., Ferreira, L. L., Klisics, M., Chrysoulas, C., de Soria, I. M., Morin, B., ... & Varga, P. (2014, October). The arrowhead approach for SOA application development and documentation. In *IECON 2014-40th Annual Conference of the IEEE Industrial Electronics Society* (pp. 2631-2637). IEEE.

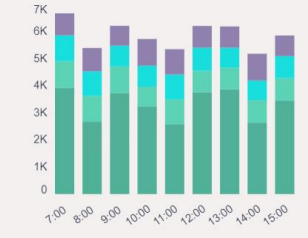
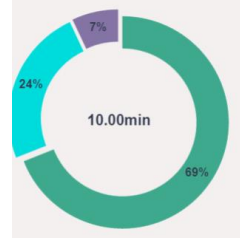


Semantic Profile

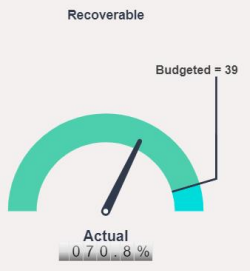


# An example for one of such Local Clouds

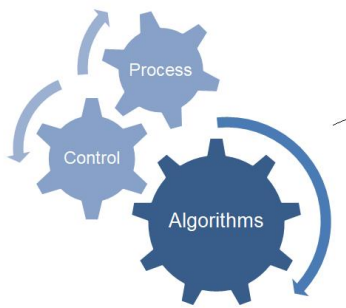
## CORE SYSTEMS



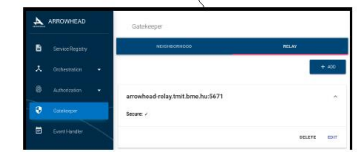
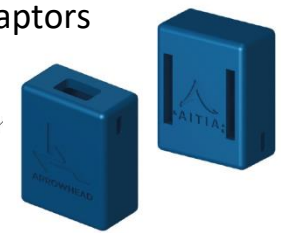
- 33,720** Expenses
- 18,192** Manpower
- 13,497** Diesel
- 28.09%** Recoverable



- Rejected Products**
- Damaged 117
  - Defective 106
  - Others 16



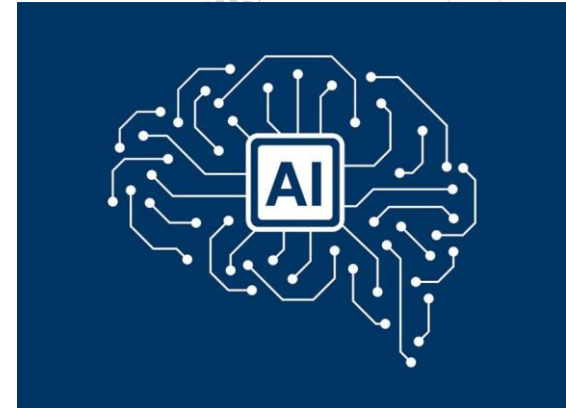
## Adaptors





# Artificial Intelligence

in Industry5.0



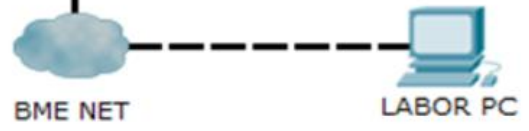
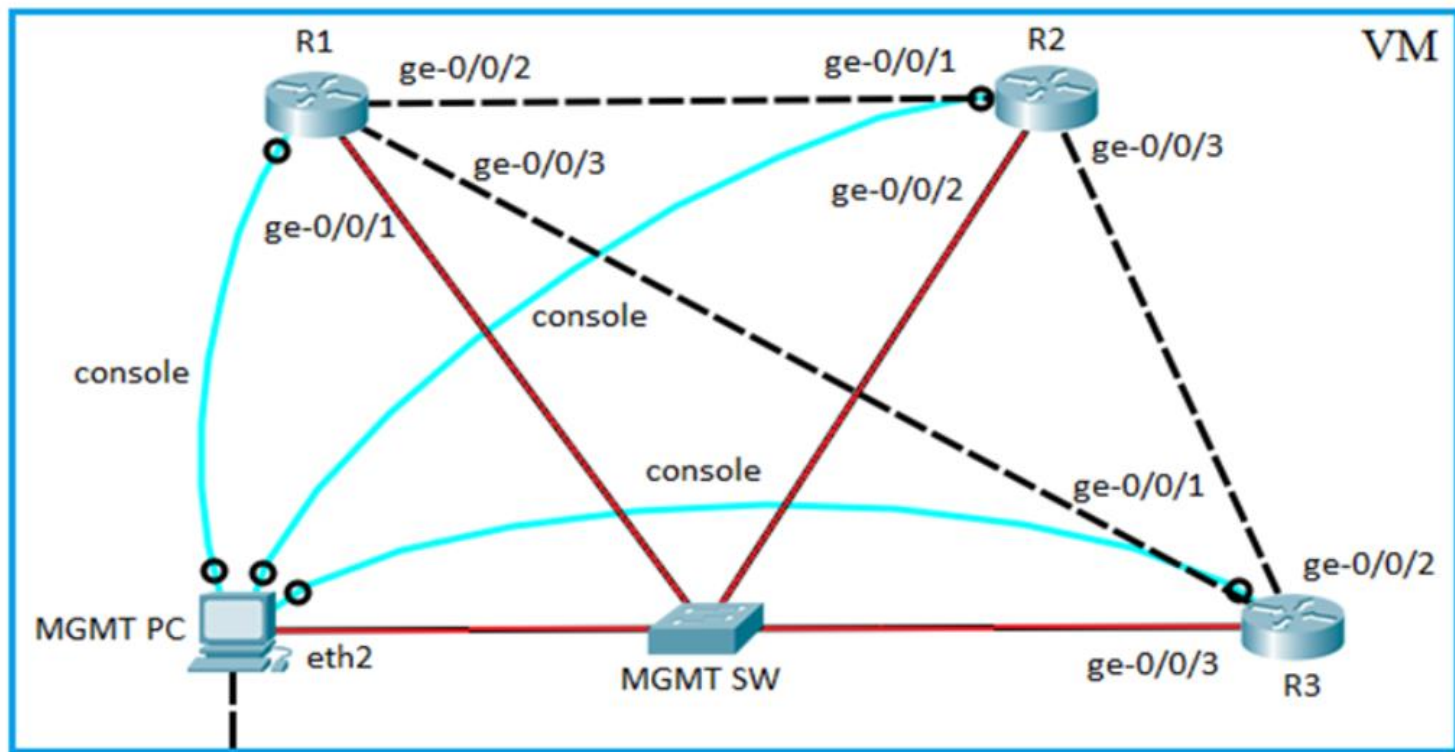
A background network diagram consisting of interconnected nodes and lines, with some nodes highlighted in blue. The nodes are represented by circles of varying sizes and colors (grey, blue, white), connected by thin grey lines. The overall structure is a complex, interconnected web.

# **„Networking laboratory” part of “Management of Information Systems”**

**completed by all informatics students at BME (yearly cca 600)**



**BME  
TMIT**



We have three Juniper routers. Their names are O1-R1, O2-R2 and O3-R3. What are the JunOS commands to configure their names?



To configure the names of the three Juniper routers (O1-R1, O2-R2, and O3-R3) using JunOS, follow these steps for each router:

### O1-R1:

1. Enter configuration mode:

```
bash Copy code  
  
configure
```

2. Set the hostname to O1-R1:

```
bash Copy code  
  
set system host-name O1-R1
```

3. Commit the changes:

```
bash Copy code  
  
commit
```

4. Exit configuration mode:

```
bash Copy code  
  
exit
```



What are the exact commands on the O2-R2 router to set the ge-0/0/1 interface for ssh, ping and traceroute services into the trust security zone?



To configure the `ge-0/0/1` interface on the `O2-R2` Juniper router for `ssh`, `ping`, and `traceroute` services and place it into the `trust` security zone, follow these steps:

1. Enter configuration mode:

```
bash Copy code  
configure
```

2. Set the `ge-0/0/1` interface to be part of the `trust` security zone:

```
bash Copy code  
set security zones security-zone trust interfaces ge-0/0/1
```

3. Allow `ssh` service in the `trust` security zone:

```
bash Copy code  
set security zones security-zone trust interfaces ge-0/0/1 host-inbound-traffic sys
```

4. Allow `ping` (ICMP) in the `trust` security zone:

```
bash Copy code  
set security zones security-zone trust interfaces ge-0/0/1 host-inbound-traffic sys
```

set security zones security-zone trust  
interfaces ge-0/0/1 host-inbound-traffic  
system-services ssh

set security zones security-zone trust  
interfaces ge-0/0/1 host-inbound-traffic  
system-services ping

set security zones security-zone trust  
interfaces ge-0/0/1 host-inbound-traffic  
system-services traceroute

6. Commit the changes:

```
bash Copy code  
commit
```

7. Exit configuration mode:

```
bash Copy code  
exit
```



## Current practices with the lecture series of

- ⦿ Applied AI models in practice
- ⦿ Data analytics in practice – based on Python Pandas and Scikit-learn
- ⦿ Deep Learning in practice – based on Python and LUA
  
- ⦿ Prompt Engineering



# Artificial Intelligence

- ◎ Various targets and methods: knowledge representation, automatized multi-stakeholder planning and execution, machine learning, NLP, machine vision, speech processing, robotics control, human-machine interactions
- ◎ These all are relevant in industrial applications as well
- ◎ There are AI-based solutions under the hood
- ◎ Why Machine/Deep Learning? -> Pattern recognition in „Big Data” volumes
- ◎ Efficient automatization of generic and specific tasks

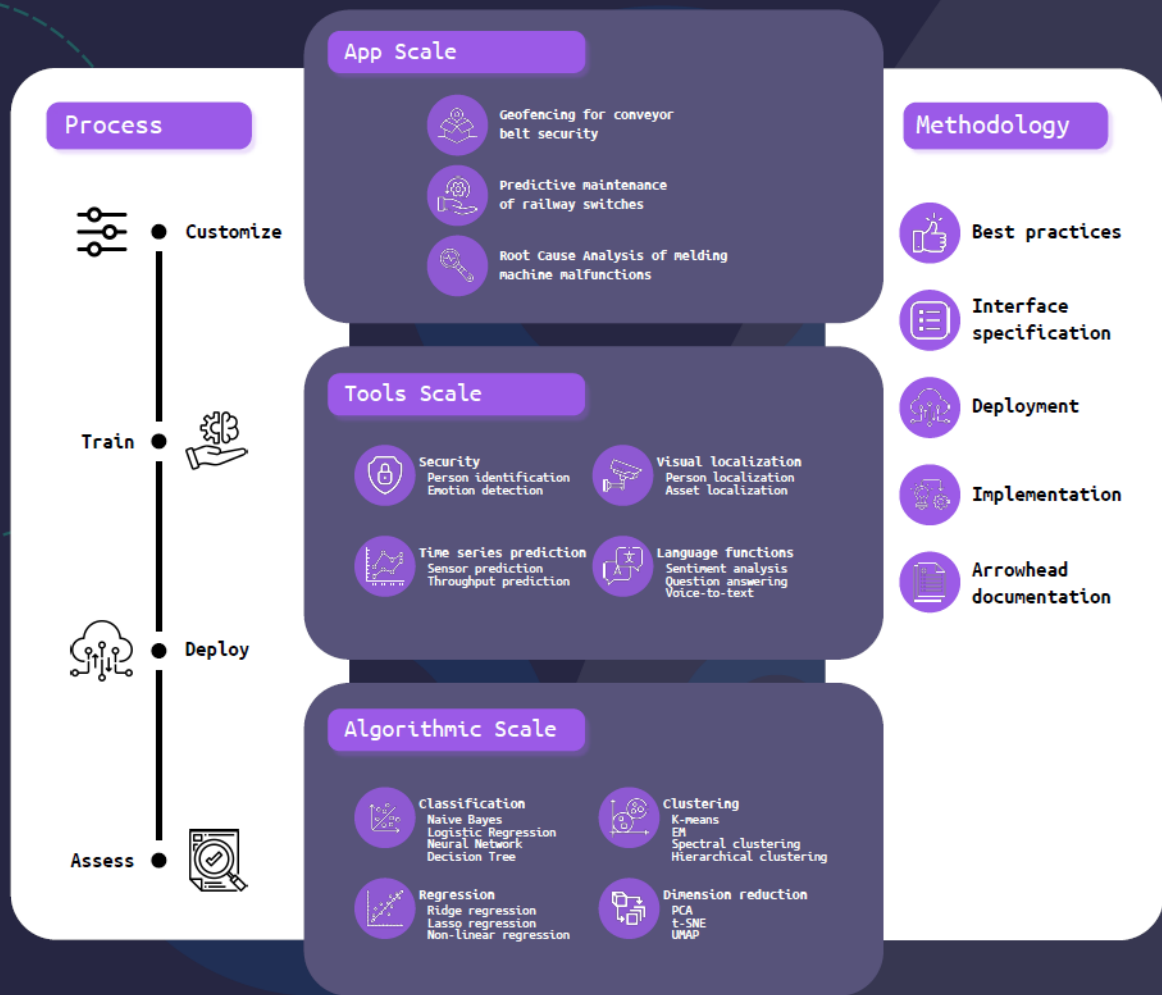
**We need DATA to learn from or to act upon**

## AI in industrial applications

- ◎ Business intelligence – hidden correlations; predictions; planning
  - ◎ Facility management
  - ◎ Planning-optimization (MES, ERP)
  - ◎ Direct applications in the physical reality
    - Robotics
    - Autonomic vehicles
    - Quality assurance systems
  - ◎ Process engineering for cyber-physical systems
  - ◎ Proactive maintenance
  - ◎ Tuning applications using heterogeneous technologies
- all along the supply chain

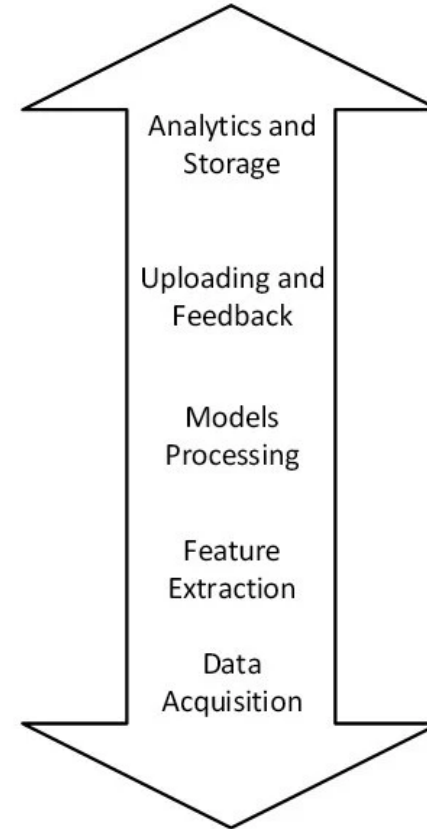
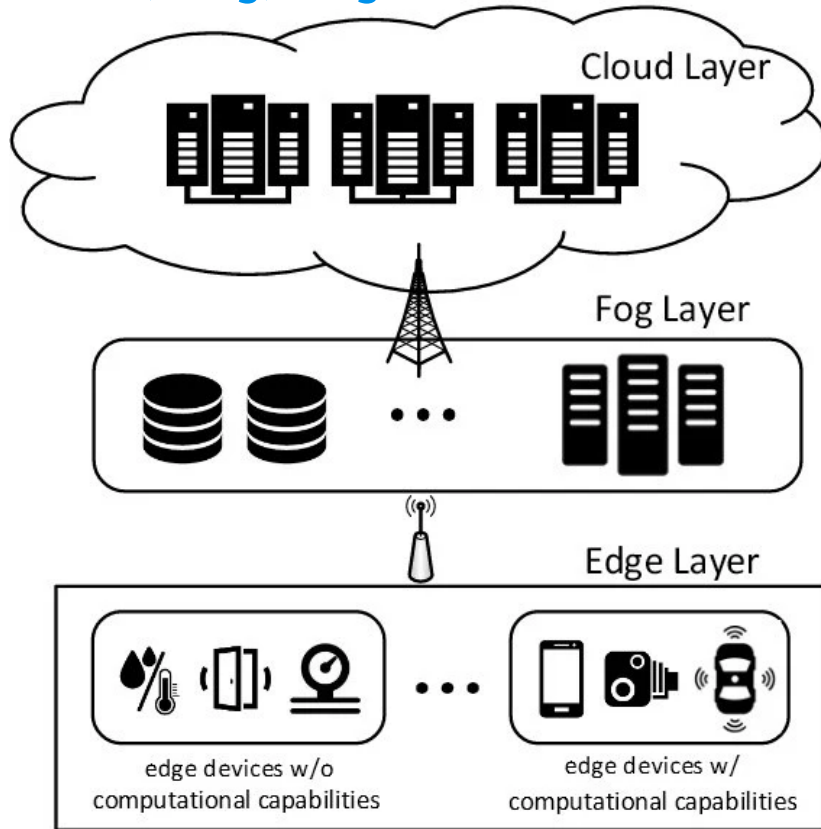


# AIMS 5.0 AI Toolbox Concept



Hollósi, G., Ficzer, D., Frankó, A., Bancsics, M., AlMahasneh, R., Lukovszki, C., & Varga, P. (2024, May). AIMS5. 0 AI Toolbox: Enabling Efficient Knowledge Sharing for Industrial AI. In *NOMS 2024-2024 IEEE Network Operations and Management Symposium* (pp. 1-6). IEEE.

# AI in the Cloud, Fog, Edge



<https://viso.ai/edge-ai/edge-ai-applications-and-trends/>

Pal Varga - BME



BME  
TMIT

## AI in Enterprise applications

- ◎ Pattern recognition and pattern analysis
  - Detecting financial frauds
  - Analyzing financial and insurance frauds
- ◎ Monitoring and prediction
  - finances, production quality assurance, process engineering
- ◎ Scheduling maintenance
- ◎ Refining strategies, decision making
- ◎ Risk management
- ◎ Market and financial process model creation

## Special Attention: AI Extras and Industry5.0

- ◎ Industry 5.0 relation: Human-Machine cooperation
  - Supporting Safety efforts e.g. on the production floor
  - Supporting „co-work”
- ◎ Large Language Models and related tools (e.g. ChatGPT, etc.):
  - Design,
  - Development,
  - APIs, plug-ins and toolchains
  - Verification and Validation



### Narrative Text

prob: 1.00  
partitionId: 6c1d1ac8-a483-4840-bc1e-48c3c96aa407

see discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/352372731>

### Title

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# A DevOps Approach for Cyber-Physical System of Systems Engineering through Arrowhead

### Narrative Text

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Conference Paper · May 2021

### Title

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### CITATIONS

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11 PUBLICATIONS 431 CITATIONS

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### Image

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### READS

295

### Narrative Text

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Pal Varga

Budapest University of Technology and Economics

135 PUBLICATIONS 1,801 CITATIONS

SEE PROFILE

# Extracting data from datasheets



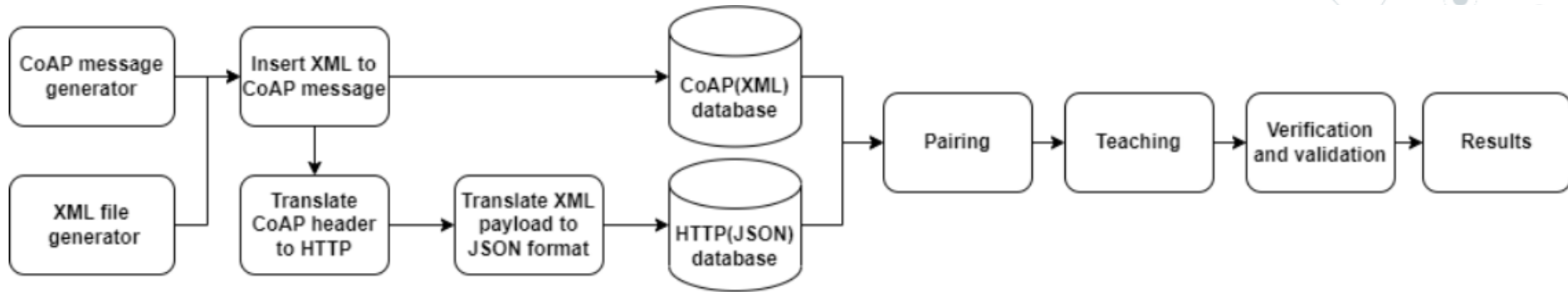
**LIR18650 Datasheet**  
Li-ion Battery  
Edition: NOV. 2010

## 5. BASIC CHARACTERISTICS

5.1 Capacity (25±5°C)	Nominal Capacity: 2600mAh (0.52A Discharge, 2.75V) Typical Capacity: 2550mAh (0.52A Discharge, 2.75V) Minimum Capacity: 2500mAh (0.52A Discharge, 2.75V)
5.2 Nominal Voltage	3.7V
5.3 Internal Impedance	≤ 70mΩ
5.4 Discharge Cut-off Voltage	3.0V
5.5 Max Charge Voltage	4.20±0.05V
5.6 Standard Charge Current	0.52A
5.7 Rapid Charge Current	1.3A
5.8 Standard Discharge Current	0.52A
5.9 Rapid Discharge Current	1.3A
5.10 Max Pulse Discharge Current	2.6A
5.11 Weight	46.5±1g
5.12 Max. Dimension	Diameter(Ø): 18.4mm Height (H): 65.2mm
5.13 Operating Temperature	Charge: 0 ~ 45°C Discharge: -20 ~ 60°C
5.14 Storage Temperature	During 1 month: -5 ~ 35°C During 6 months: 0 ~ 35°C

```
{
  "LIR18650 2600mAh": {
    "Performance": {
      "Nominal Voltage": "3.7V",
      "Nominal Capacity": "2600mAh",
      "Typical Capacity": "2550mAh",
      "Minimum Capacity": "2500mAh",
      "Internal Impedance": "≤ 70mΩ",
      "Discharge Cut-off Voltage": "3.0V",
      "Max Charge Voltage": "4.20±0.05V",
      "Standard Charge Current": "0.52A",
      "Rapid Charge Current": "1.3A",
      "Standard Discharge Current": "0.52A",
      "Rapid Discharge Current": "1.3A",
      "Max Pulse Discharge Current": "2.6A",
      "Weight": "46.5±1g",
      "Max Dimension": {
        "Diameter": "18.4mm",
        "Height": "65.2mm"
      },
      "Operating Temperature": {
        "Charge": "0 ~ 45 °C",
        "Discharge": "-20 ~ 60 °C"
      },
      "Storage Temperature": {
        "1 month": "-5 ~ 35 °C",
        "6 months": "0 ~ 35 °C"
      },
      "Cycle Life": "300 cycles with residual capacity ≥2050mAh"
    },
    "Safety Performances": {
      "Short Circuit": "No fire, no explosion",
      "Impact Test": "No fire, no explosion",
      "Low Temperature Performance": "Capacity ≥1800mAh at -20±2°C",
      "Anti-vibration": "No deformation, no leak, smoke, or explosion",
      "Drop Test": "No fire, no explosion, Discharge Time ≥102min"
    },
    "Manufacturer": "EEMB Co., Ltd.",
    "Website": "http://eemb.com",
    "Warranty": "12 months from the date of delivery",
    "Images": {
      "Image1": {
        "Observation": "Technical drawing shows total height of 65.0 mm ± 0.2 mm and diameter of 18.4 mm +0/-0.3 mm with positive and negative terminals indicated."
      }
    }
  }
}
```

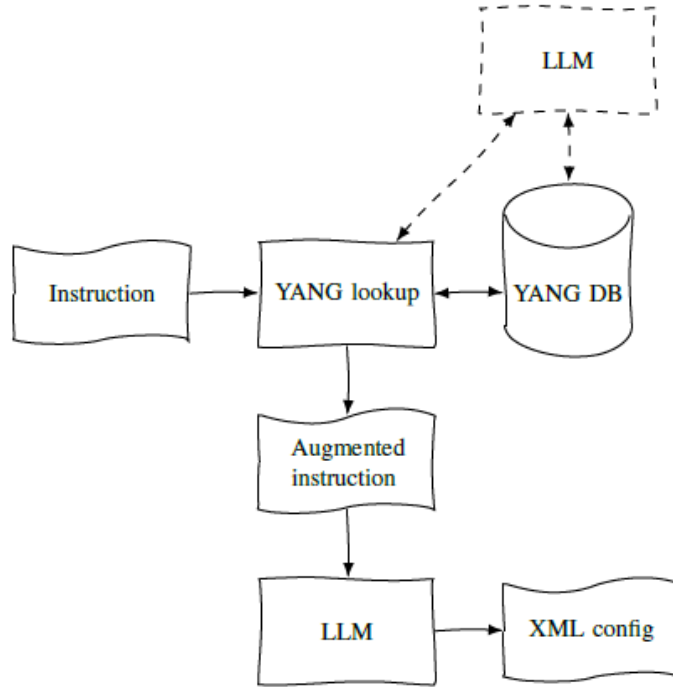
# Protocol data translation: CoAP-XML to HTTP-JSON



Header: 0.03 (T=RST, Code=0.03, MID=0x492a) URI= coap://Dlh.org/barvvMmQrb Token: 0x0 Content-Format: application/xml Max-Age: "ysTCCCAzcr" Proxy-Scheme: "tzMAGJ" Accept: "wpX" Payload: <?xml version="1.0" encoding="UTF-8" ?> <Insurance Companies> <Top_Insurance_Companies> <Name>Berkshire Hathaway (BRK A)</Name> <Market_Capitalization>\$539 billion</Market_Capitalization> </Top_Insurance_Companies> </Insurance Companies>	PUT/barvvMmQrb HTTP/1.1 Host: Dlh.org Content-Type: application/xml Cache-Control: "ysTcCCAzcr" Proxy-Authorization: "tzMAGJ" Accept: "wpX" Payload: T=RST, MID=0x492a, Token=0x0 { "Insurance_Companies":{ "Top_Insurance_Companies":{ "Name": "Berkshire Hathaway (BRK A)", "Market_Capitalization": "\$539 billion" } } }
--	--

Tothfalusi, T., Varga, E., Csiszar, Z., & Varga, P. (2023, October). ML-Based Translation Methods for Protocols and Data Formats. In *2023 19th International Conference on Network and Service Management (CNSM)* (pp. 1-5). IEEE.

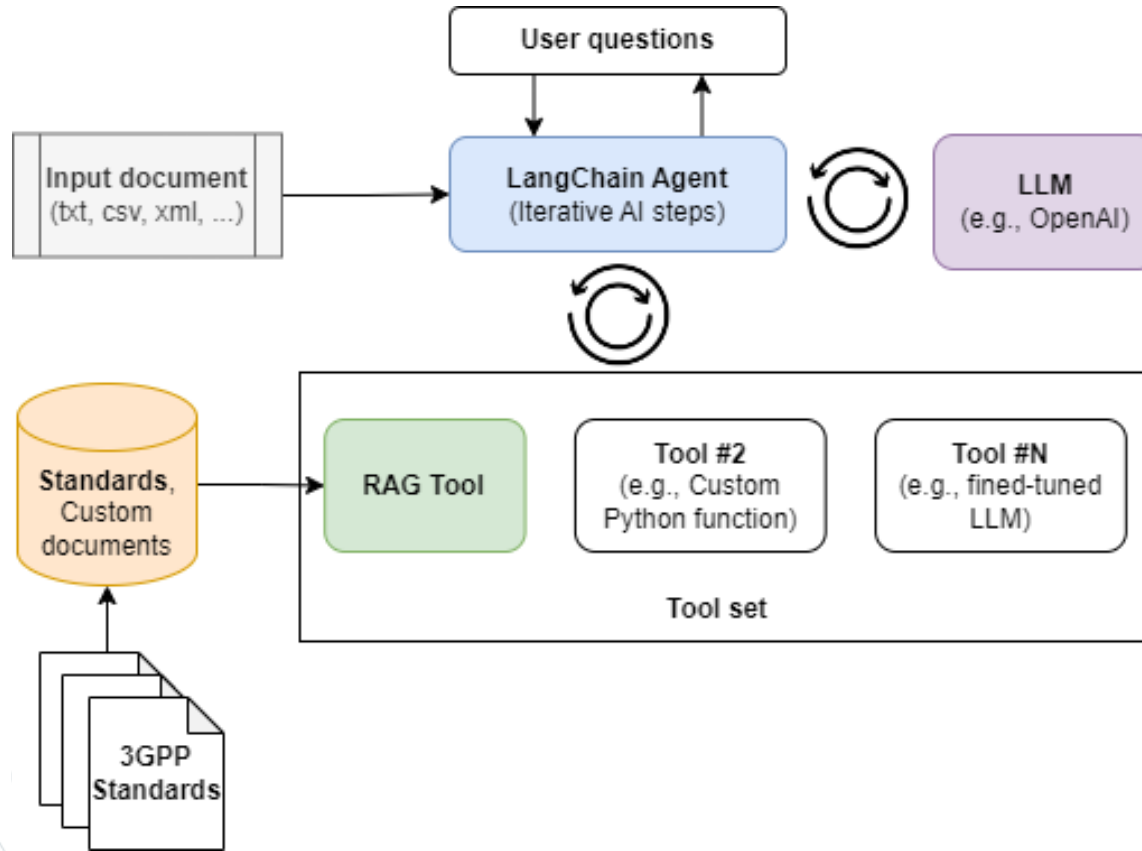
## Generating XML config: NETCONF Configuration Based on YANG Models



Hollosi, G., Ficzer, D. & Varga, P. (2024, October). *Generative AI for low-level NETCONF configuration in network management based on YANG models*. In *2024 19th International Conference on Network and Service Management (CNSM)* (pp. 1-7). IEEE/IETF

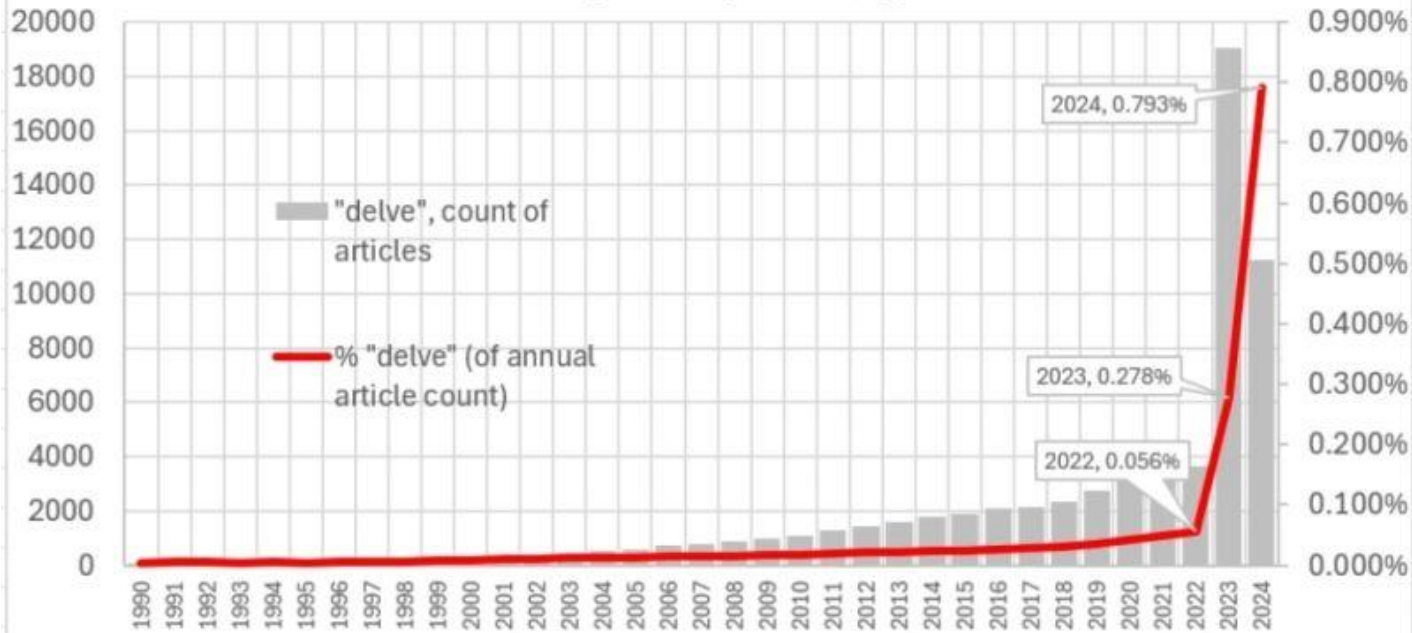
Fig. 4. The proposed pipeline for augmenting the original instructions with YANG models, necessary for enabling the LLMs to answer in a strict and well-defined format. The pipeline basically provides domain knowledge to the otherwise general LLMs. Dashed line interactions and functions are optional, but there are instances where their use is appropriate, as detailed in the text.

# Extracting insights from protocol standards (pdf)



# Papers with "delve" in title or abstract

Source: Analysis of OpenAlex, type=articles



Analysis using OpenAlex by Philip Shapira, March 31, 2024.



## The solution: set the style

Avoid fluff and jargon. Write normally. You are forbidden to use complicated English words. Using any words from the ### banned list ###, the generation will be halted immediately.

### ban list ###

Hurdles

Tapestry

Bustling

Harnessing

Unveiling the power

Realm

Depicted

Demistify

Insurmountable

New Era

Poised

Unravel

Entanglement

Unprecedented

Beacon

Unleash

Delve

Enrich

Multifaced

Discover

Unlock

Unleash

Tailored

Elegant

Dive

Ever-evolving

Adventure

Journey

Navigate

Navigation



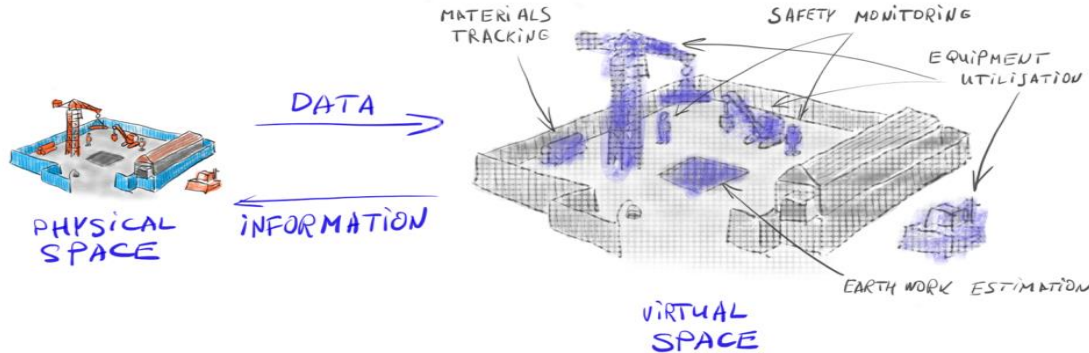
# Digital Twins - in the industry



# Digital Twins in various domains



DIGITAL TWIN  
in CONSTRUCTION



# Augmented Reality for Human-Machine cooperation

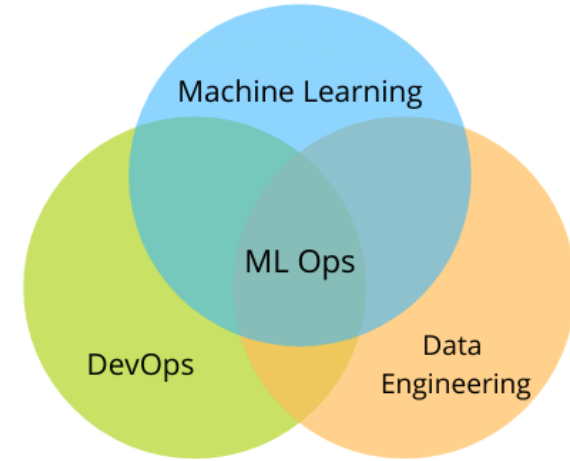
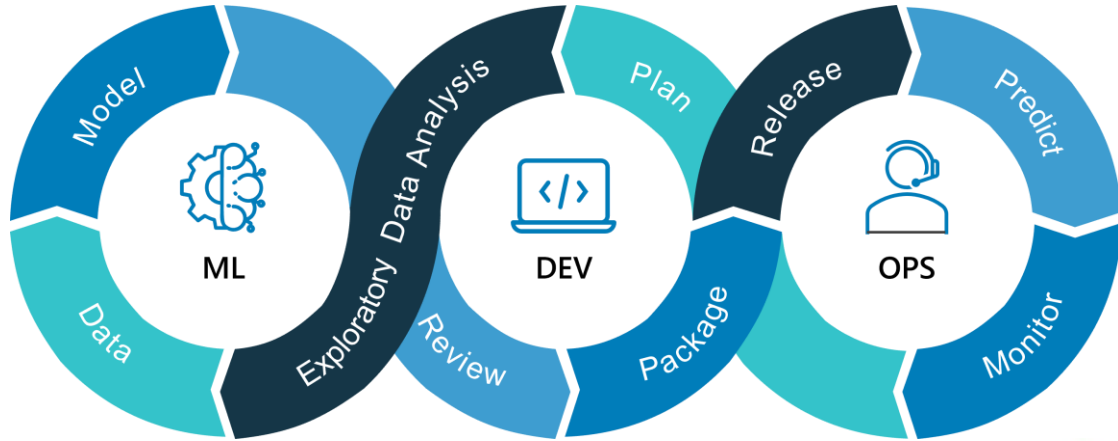






Pal Varga - BME

# MLOps – Deploying ML models in Cloud infrastructures with Hyperautomation

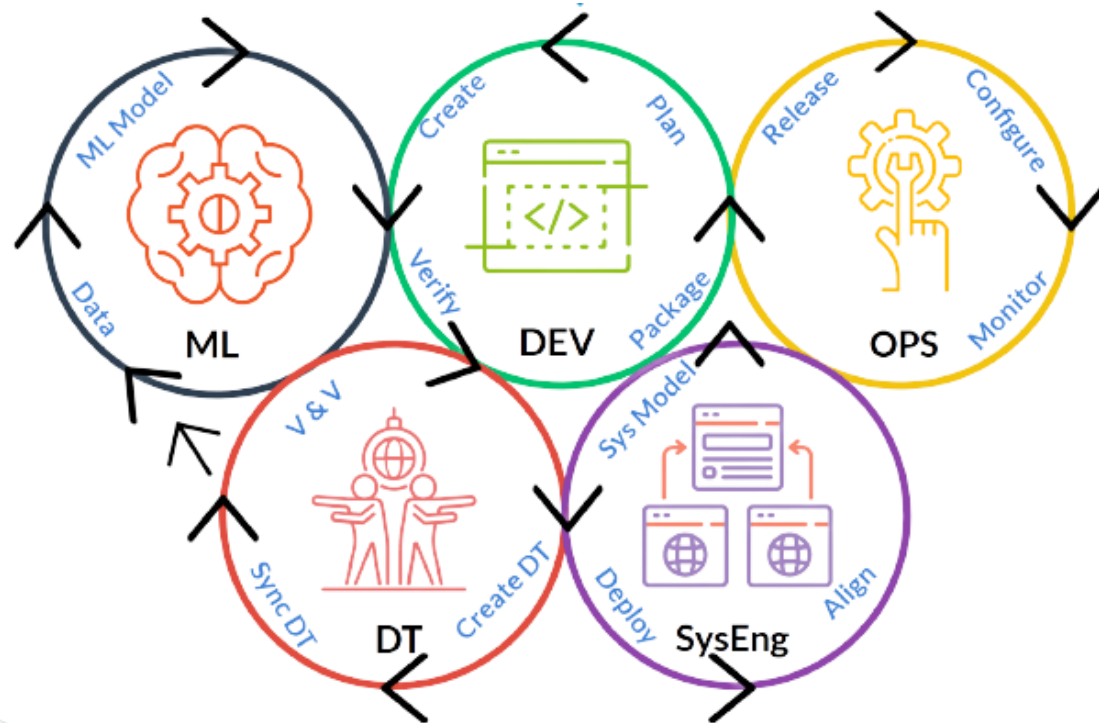


<https://sourceforge.net/software/mlops/>



<https://canonical.com/blog/what-is-mlops>

# CPS OPS: Extending MLOps to Cyber-Physical Systems



Cs. Hegedűs, P. Varga –  
Tailoring MLOps Techniques for Industry 5.0 Needs  
IEEE CNSM, Niagara Falls, Canada, 2023

**Industry 5.0 is  
collaborative  
man and machine  
system of systems  
powered by AI for a  
hypercustomizable  
and  
sustainable world**



# Thank you

## for your attention

I am interested in  
interoperability of cyber-physical  
system of systems,  
5G / 6G mobile networks, and  
AI/ML applications in Industry5.0

**Pal Varga – [pvarga@tmit.bme.hu](mailto:pvarga@tmit.bme.hu)**

