Intelligent Orchestration of Communication and Compute Infrastructure



Carolina Fortuna

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International Research Centre
on Artificial Intelligence
under the auspices of UNESCO

SETTING THE CONTEXT

Jozef Stefan Institute

- The institute was founded by the State Security Administration (Yugoslavia) in 1949 for atomic weapons research.

- It is named after the distinguished 19th-century physicist Josef Stefan (Slovene: Jožef Stefan), best known for his work on the Stefan–Boltzmann law of black-body radiation.

- The main research areas are physics, chemistry, molecular biology, biotechnology, information technologies, reactor physics, energy, and the environment.
- > 1,170 employees, of whom > 568 are PhD holders





About me: Carolina Fortuna



2001-2006 BSc&MSc, research assist., intern *Technical Uni. of Cluj-Napoca, Siemens (RO), Jožef Stefan Inst. (SI)*

Electrical engineering degree, competitive mathematics top 5% and contribution to EU CAPANINA and regional research projects. Obtained scholarship for students with outstanding achievements, industry scholarship from Siemens Ro.

2006-2013 PhD, intern, career break *Jožef Stefan Postgraduate School (SI), Bloomberg LP (USA)*

Information and Communication Technologies programme and further contribution to EU research projects. Research internship at Bloomberg LP in NY, USA and career break.

2013-2016 Postdoctoral period, career break *Jožef Stefan Inst. (SI), Gent University (BE)*

Pushing the frontiers of science in cognitive radio and networks, experimental platforms and elastic networking while spending 1 year at IDLAb as a post-doc with prof. Moerman.

2017-2023 Academia&industry *Jožef Stefan Inst. (SI), Bloomberg LP (USA), Stanford University (USA)*

Continued my research career in a part time position, visiting Infolab at Stanford and observing prof. Leskovec's research group while developing various cutting edge functionalities for BloombergAiQ.

2021-2025 Scientific group leader, technical leader *Jožef Stefan Inst. (SI), Bloomberg LP (USA)*



SensorLab at Jozef Stefan Institute

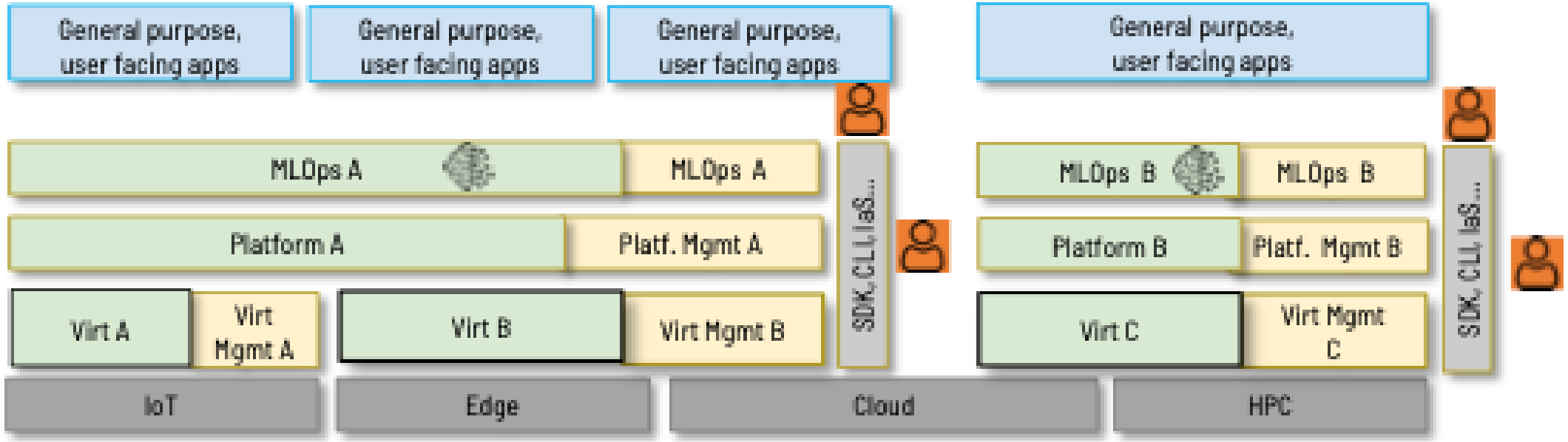
We are advancing the state of the art in smart infrastructure and pushing the boundaries of AI and data-driven technologies to enable intelligent, adaptive, and sustainable systems.

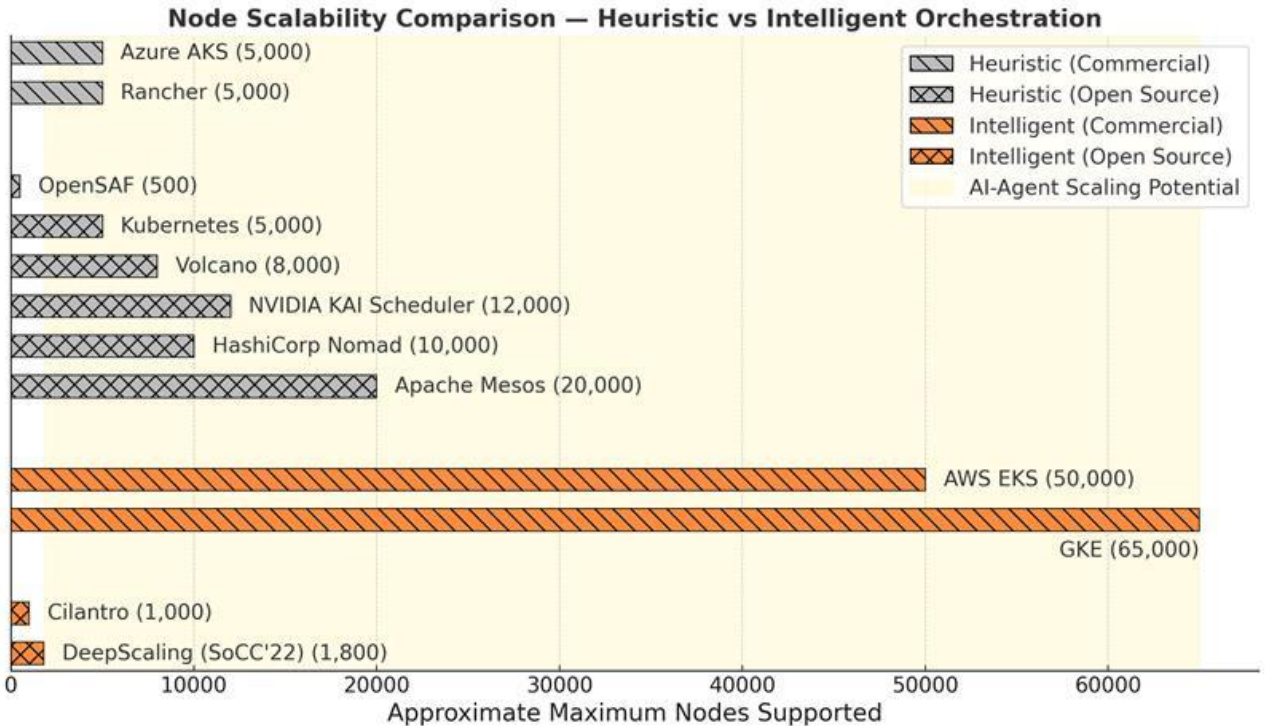
- Group ~20 people

- Involved in EU projects since FP7, example recent projects:
  - EnerTEF: Common European-scale Energy Artificial Intelligence Federated Testing and Experimentation Facility
  - NANCY: An Artificial Intelligent Aided Unified Network for Secure Beyond 5G Long Term Evolution

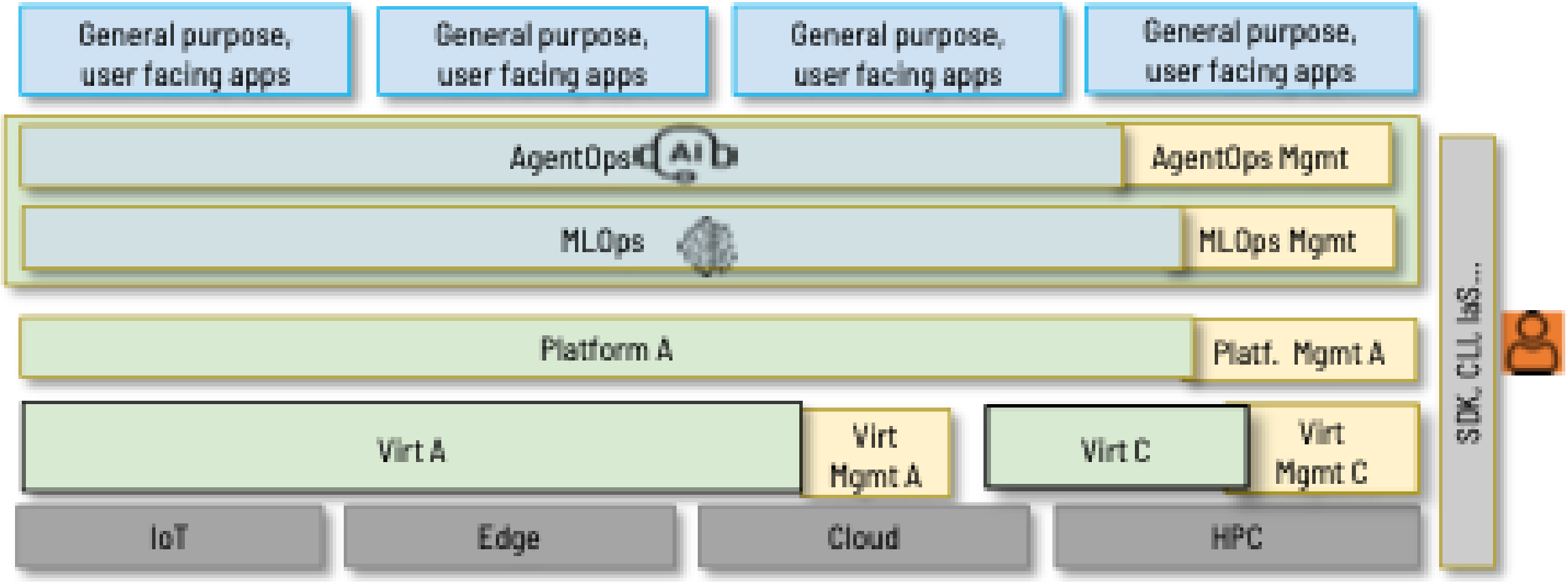
SETTING THE TECHNICAL CONTEXT

SotA of Edge-Cloud-HPC Today



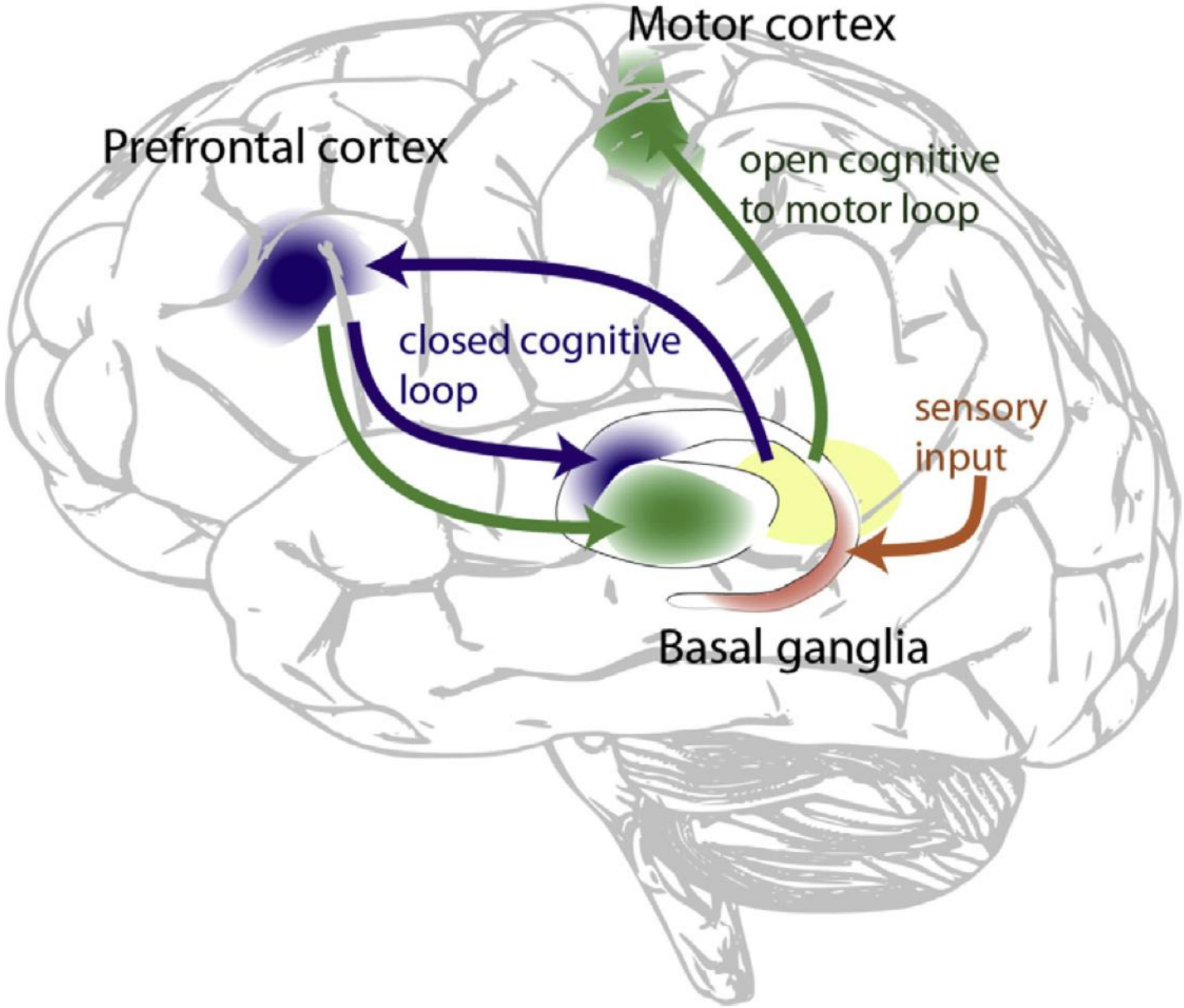


Beyond SotA with Computing Continuum and GenAI EU Projects



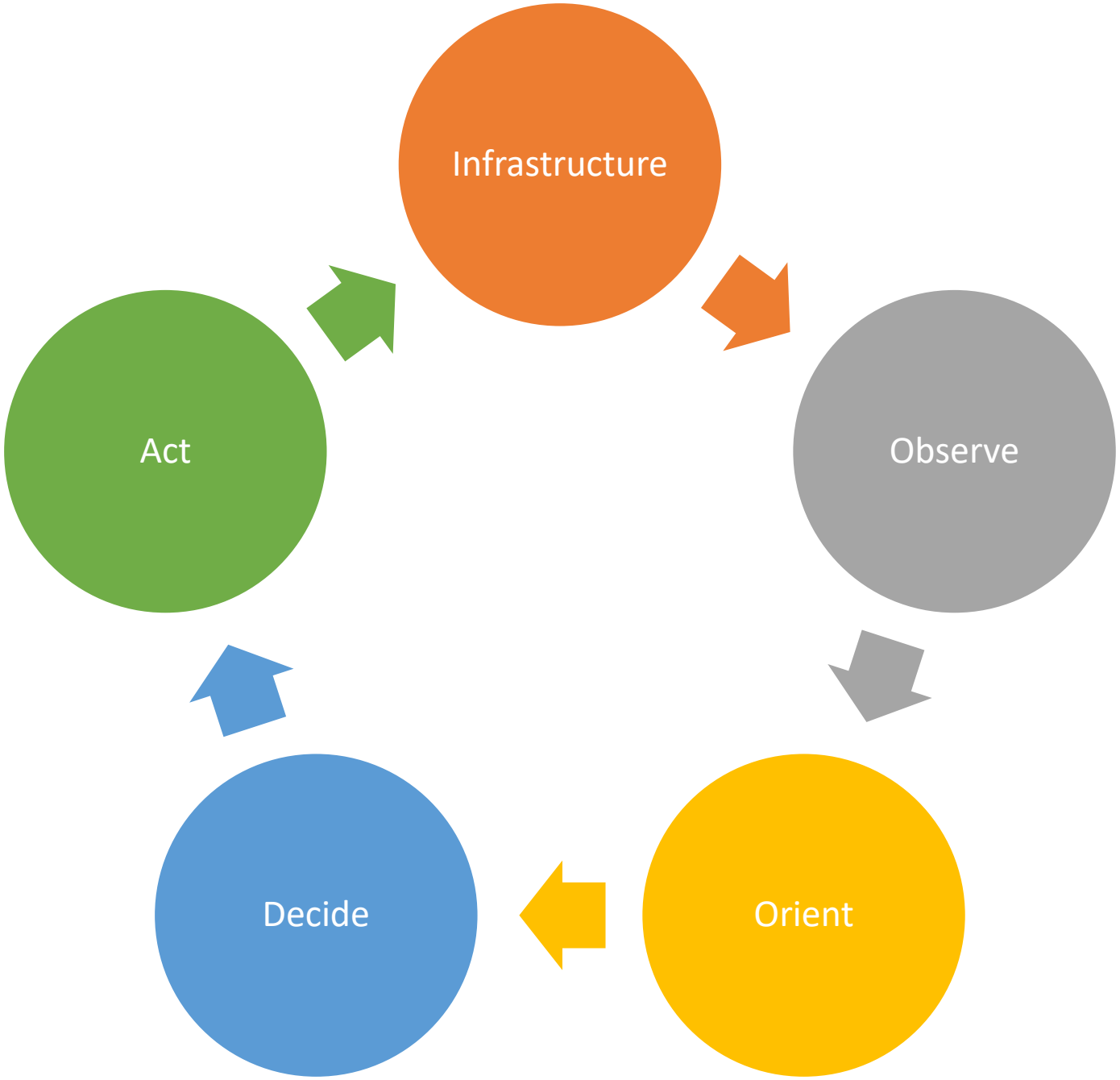
How to decrease human effort in orchestration?

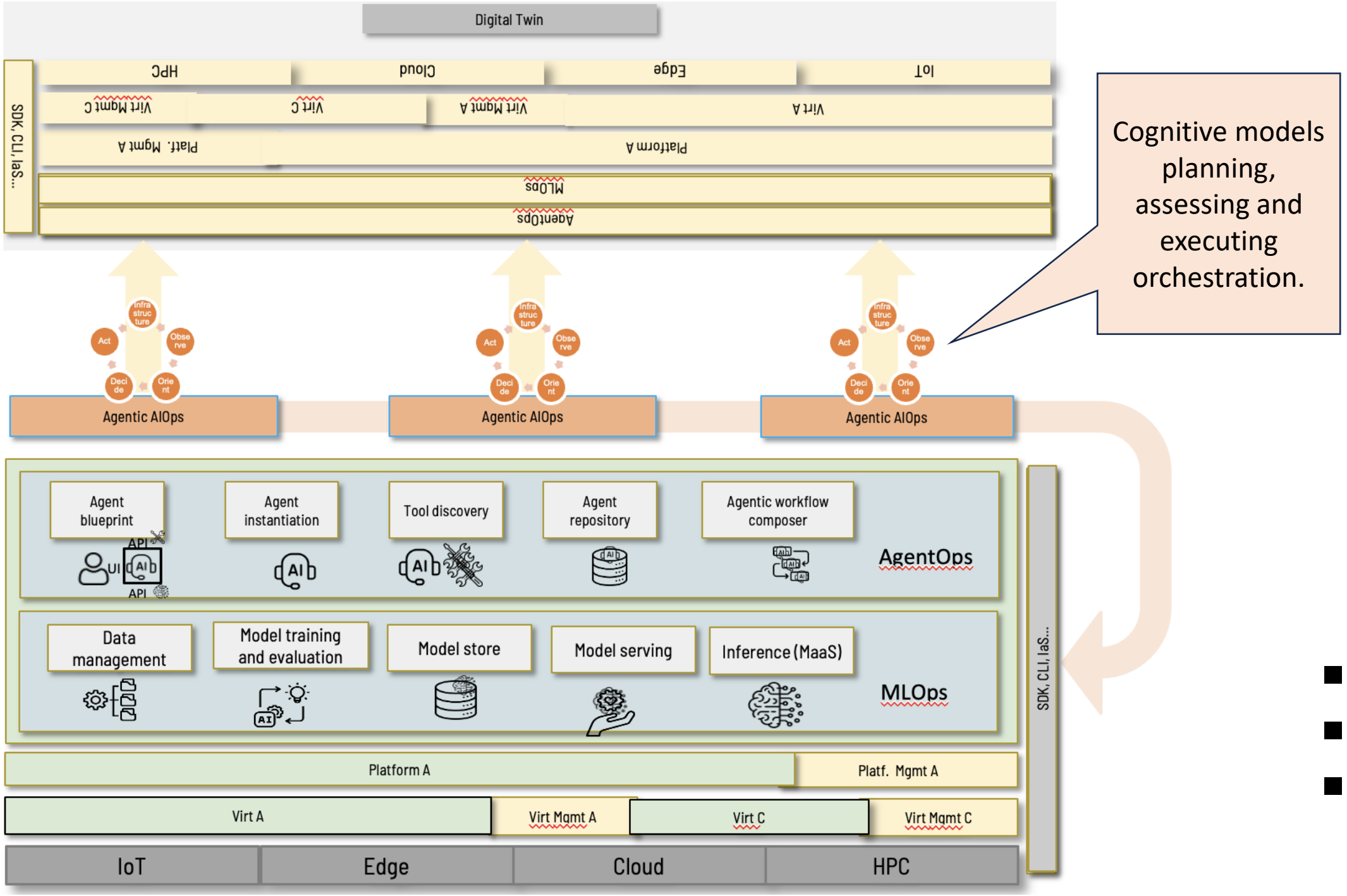
By modelling human cognitive processes?



https://www.tu-chemnitz.de/informatik/KI/research/2015/EbnerSchrollWintherNiedeggenHamker2015.pdf

OODA Loop
Cognitive loop
Cognitive cycle
…

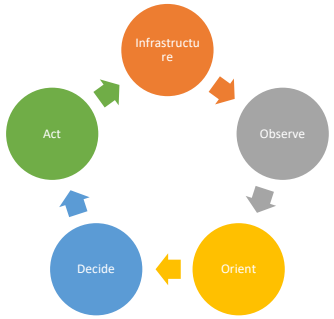




Cognitive models planning, assessing and executing orchestration.

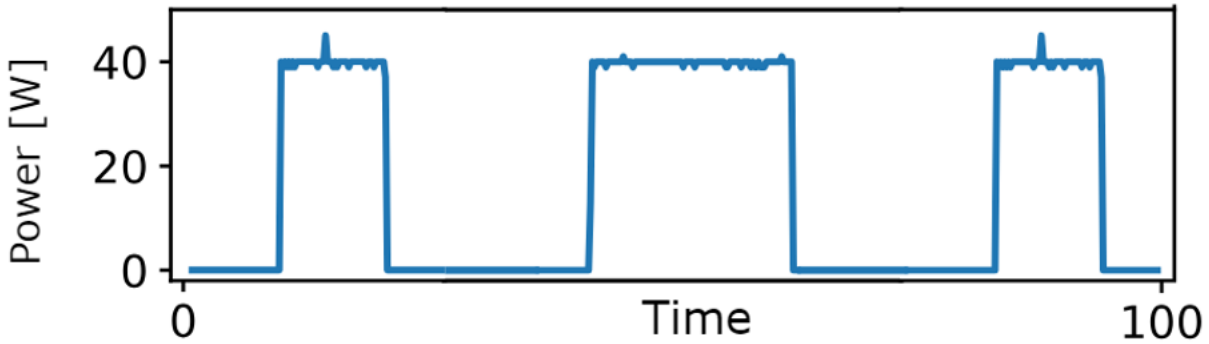
DEVELOPING COGNITIVE LOOPS

Observe

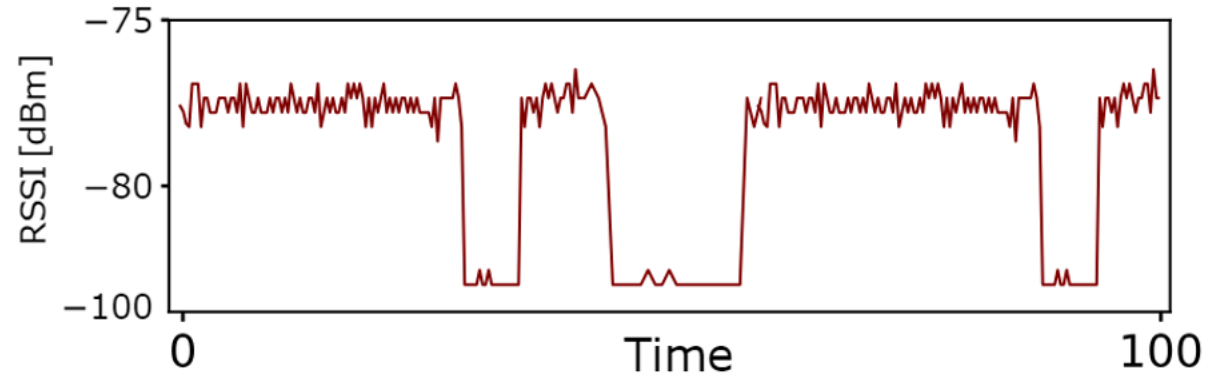


- Time series
- Context

a)



b)

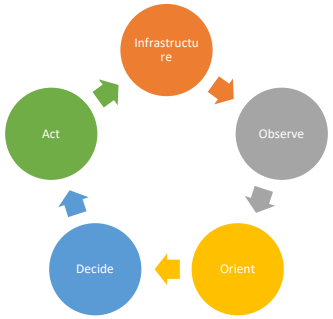




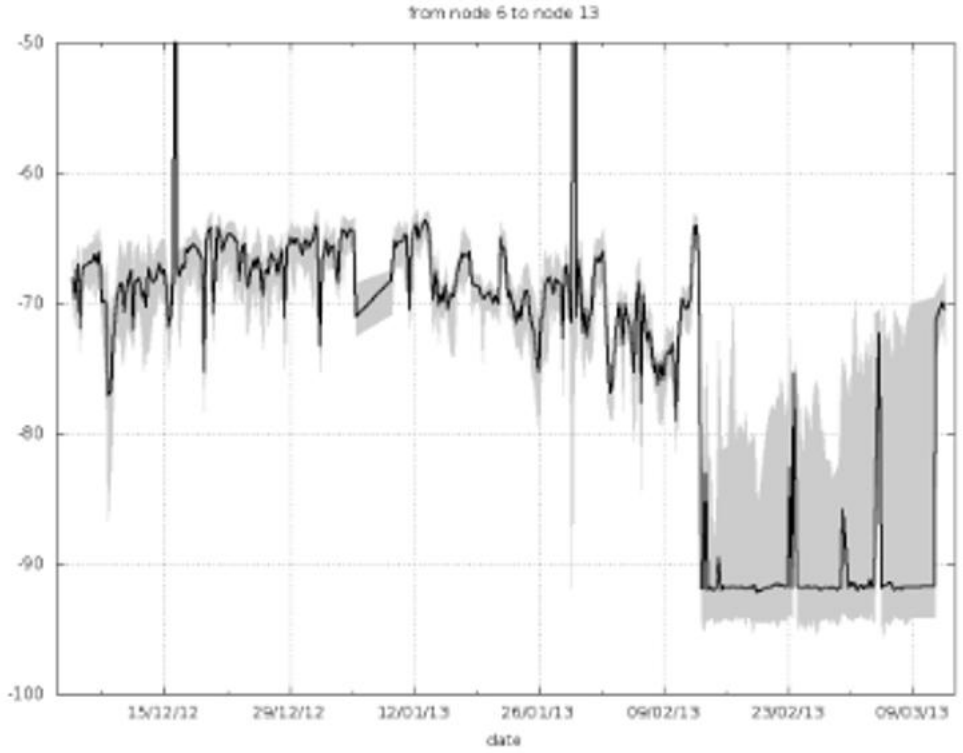


CONFIGURATION AND FEATURES OF TESTBED DEVICES.

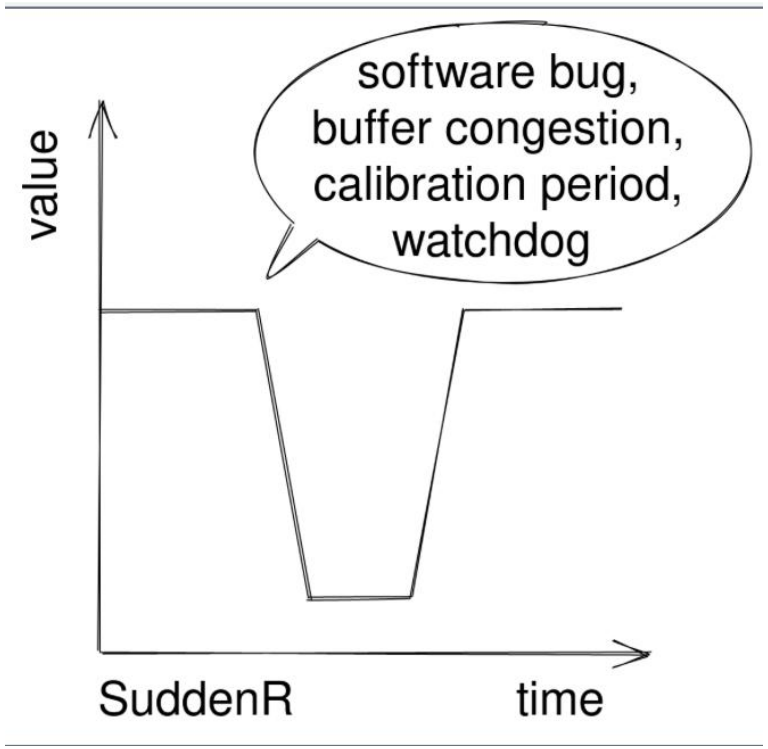
Orient



- Anomaly detection and contextualization based on issues observed with the LOG-a-TEC testbed



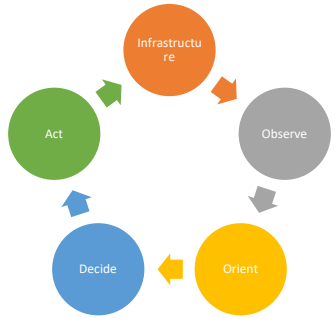
b) Sudden degradation with recovery between Node 6 and Node 13.

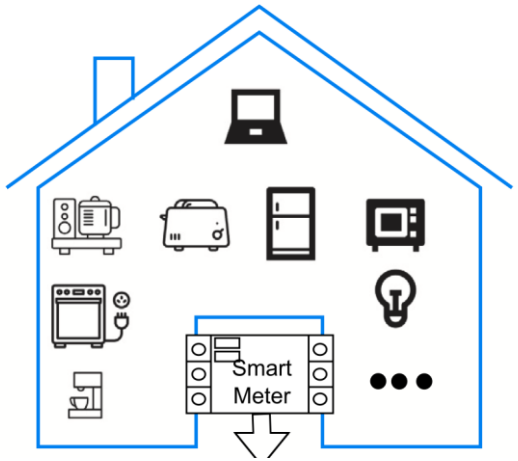


Machine Learning for Wireless Link Quality Estimation: A Survey, Gregor Cerar, Halil Yetgin, Mihael Mohorčič, Carolina Fortuna, IEEE Communications Surveys and Tutorials, 2021

Resource-Aware Time Series Imaging Classification for Wireless Link Layer Anomalies, Blaž Bertalanič, Marko Meža, Carolina Fortuna, IEEE Transactions on Neural Networks and Learning Systems, 2023

Orient

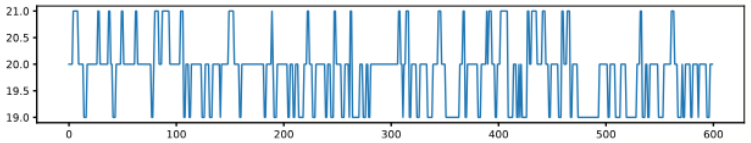




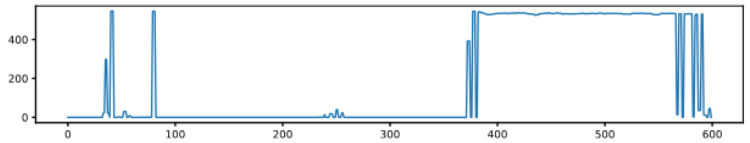
- Disaggregation, ON/OFF classification

CARMEL: Capturing Spatio-Temporal Correlations via Time-Series Sub-Window Imaging for Home Appliance Classification
Blaž Bertalanič, Carolina Fortuna
Engineering Applications of Artificial Intelligence, 2024

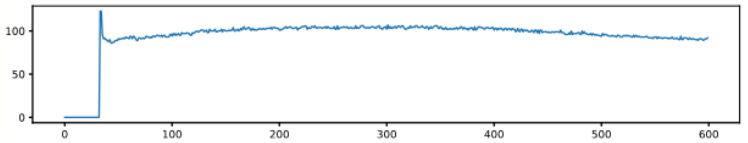
Audio system



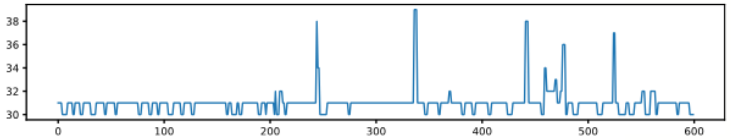
Breadmaker



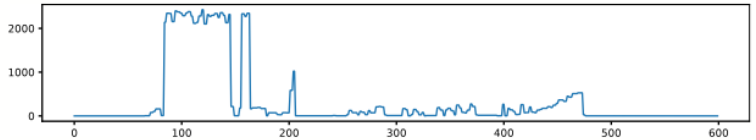
Food processor



Television

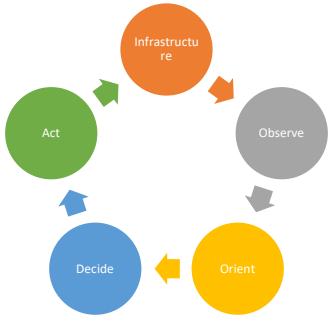


Washing machine

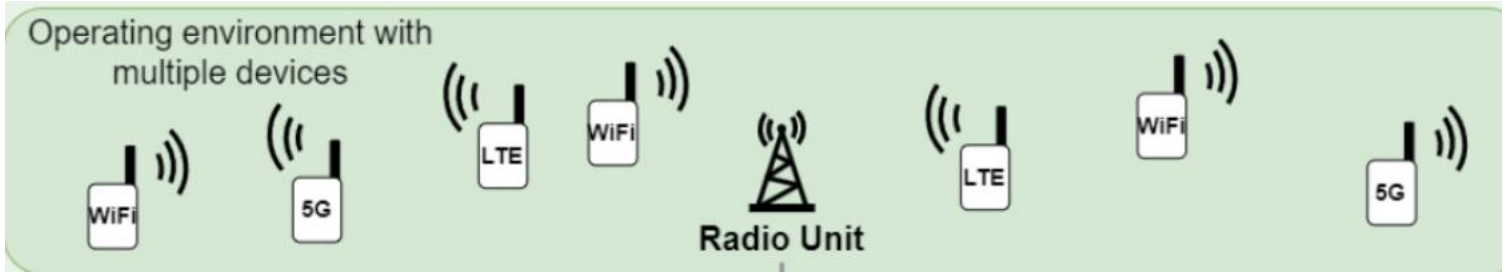


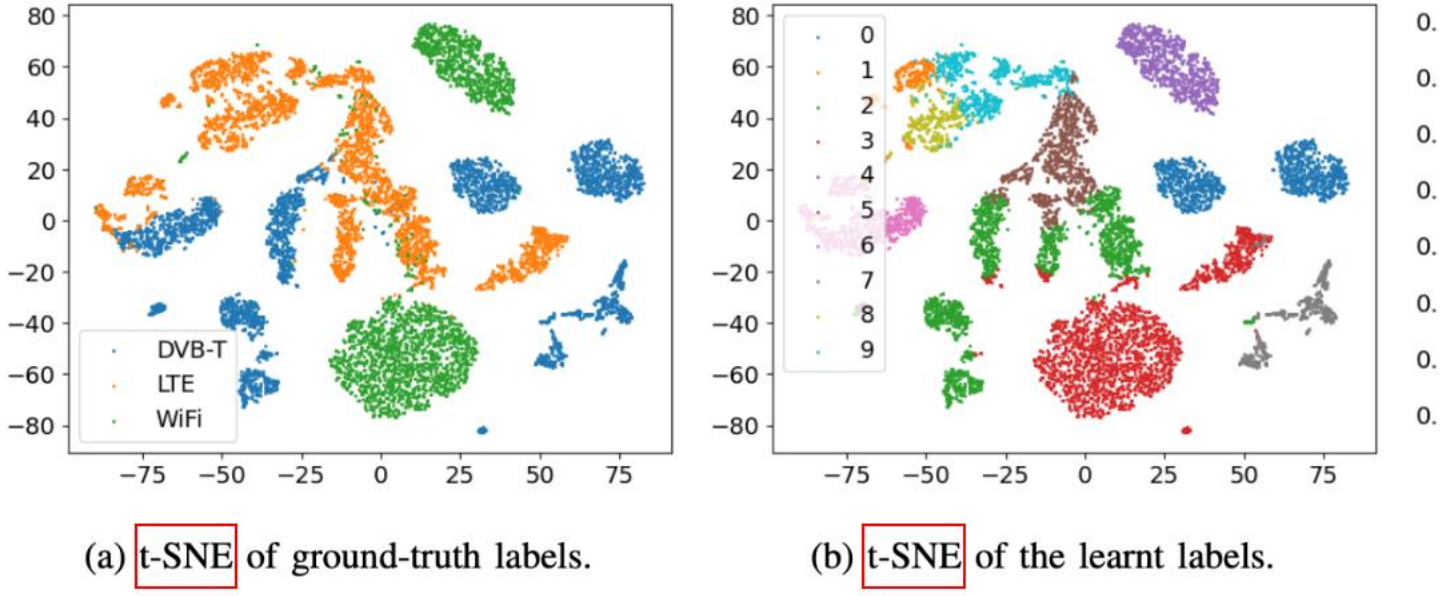
● ● ●

Orient



- Unknown emitter detection, technology recognition





(a) t-SNE of ground-truth labels. (b) t-SNE of the learnt labels.



Spectrum Sensing With Deep Clustering: Label-Free Radio Access Technology Recognition
Ljupcho Milosheski, Mihael Mohorčič, Carolina Fortuna
IEEE Open Journal of the Communications Society, 2024

Orient

- Segmentation,
- Classification
- Clustering

Enrichment/Contextualization



Towards Data-Driven Electricity Management: Multi-Region Uniform Data and Knowledge Graph

Vid Hanžel, Blaž Bertalanič, Carolina Fortuna

Scientific Data, 2025

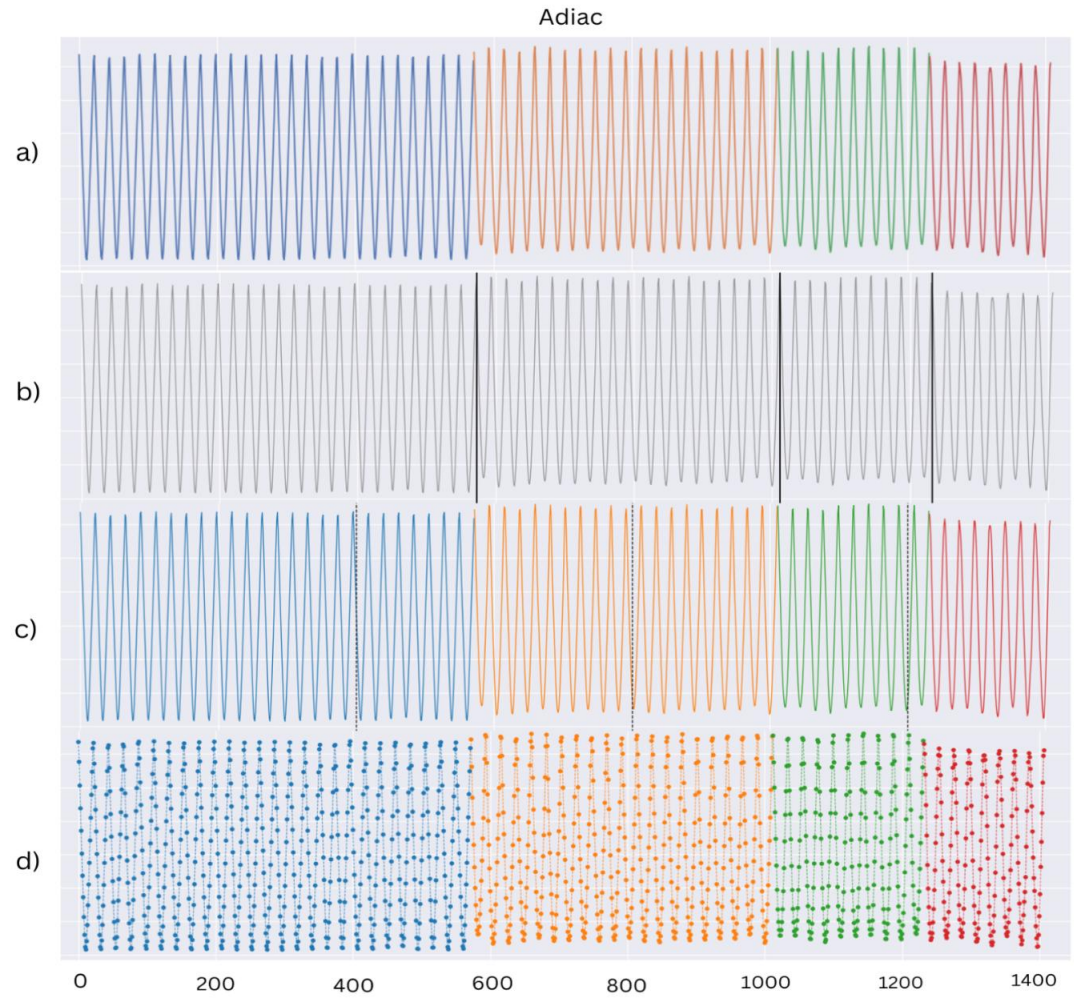
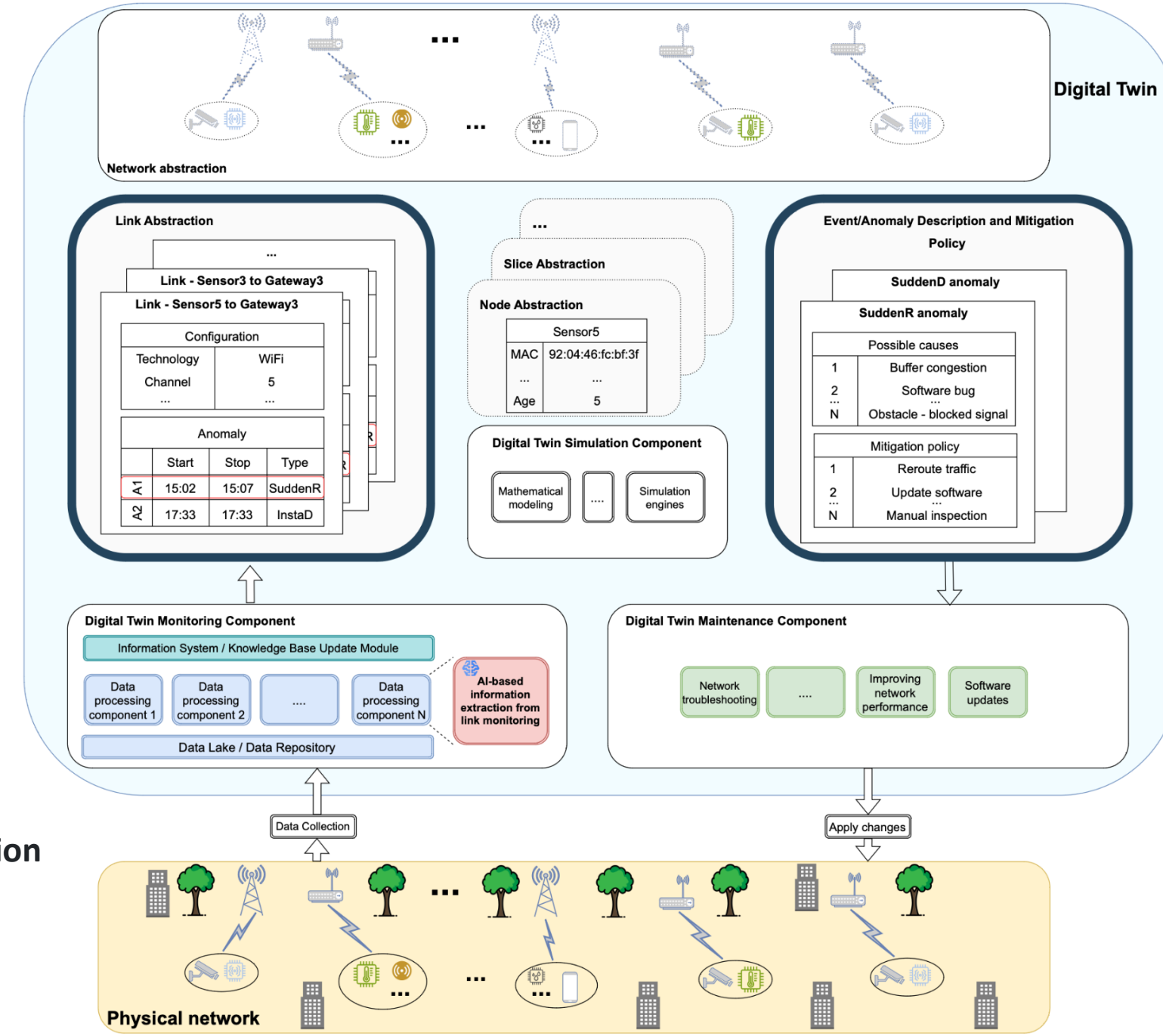


Figure 1. Example of three existing segmentation categories. a) Ground truth, b) CPD, c) WSC, d) DLPS

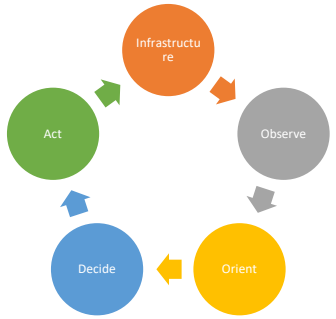
Orient

- Ideally we would have know how and technology that, based on TS and some metadata could understand and contextualize what is happening in any smart infra.

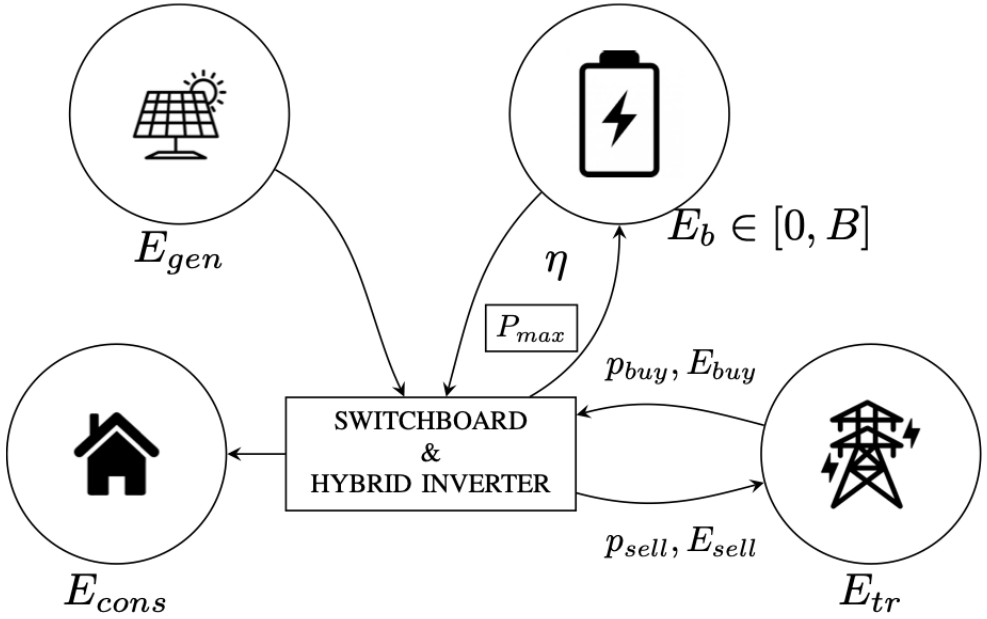


Visibility Graph-Based Wireless Anomaly Detection for Digital Twin Edge Networks
Blaž Bertalanič, Jernej Hribar, Carolina Fortuna
IEEE Open Journal of the Communications Society, 2024

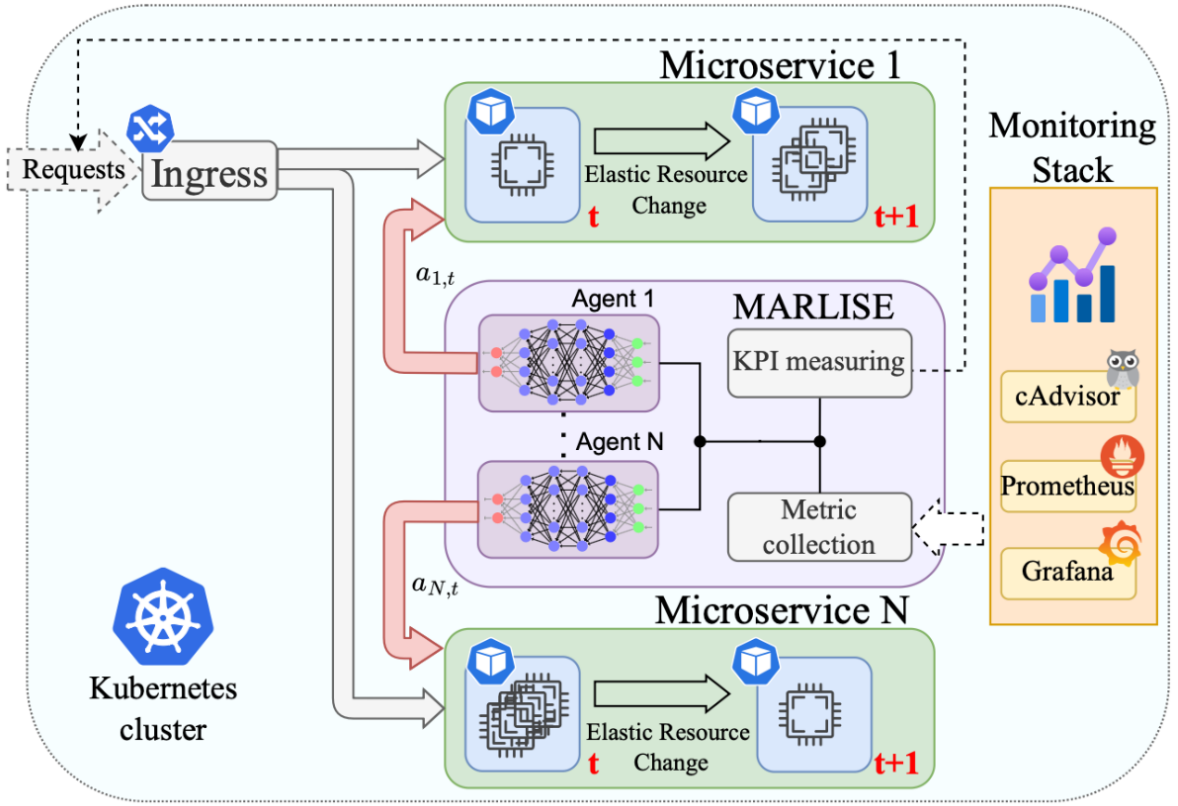
Decide



Should I charge from the battery or mains?



Should I allocate more CPU/RAM resources?

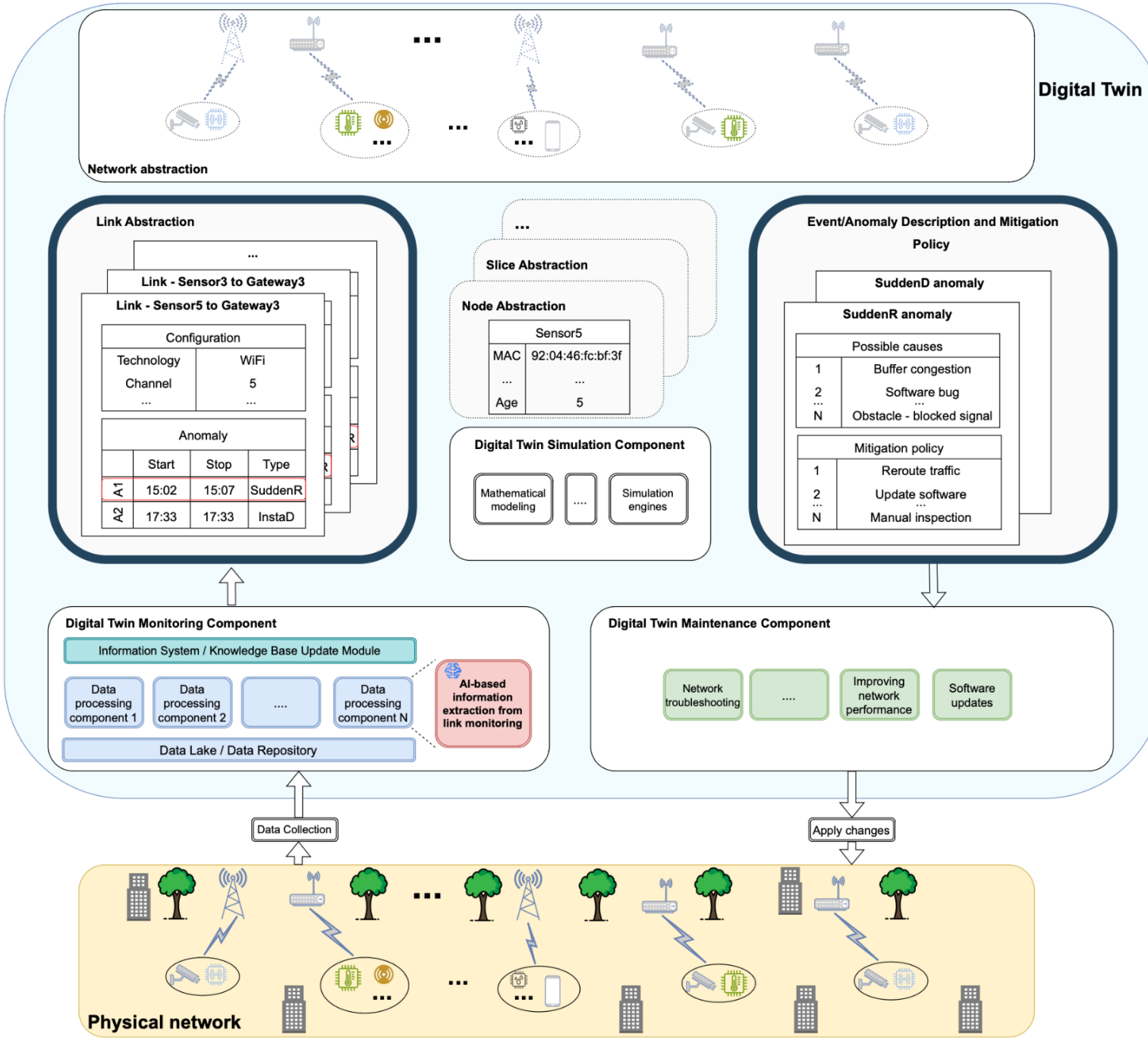


Multi-Agent Reinforcement Learning-Based In-Place Scaling Engine for Edge-Cloud Systems

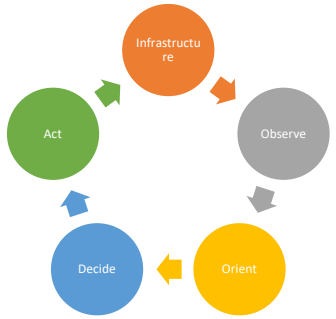
Jovan Prodanov, Blaž Bertalanič, Carolina Fortuna, Shih-Kai Chou, Matjaž B. Jurič, Ramon Sanchez-Iborra, Jernej Hribar, IEEE CLOUD: 7-12 July 2025

Decide

- Ideally we would have know how and technology that, based on some representation resulting from orientation could decide autonomously.
- Without pre-defined states and actions.

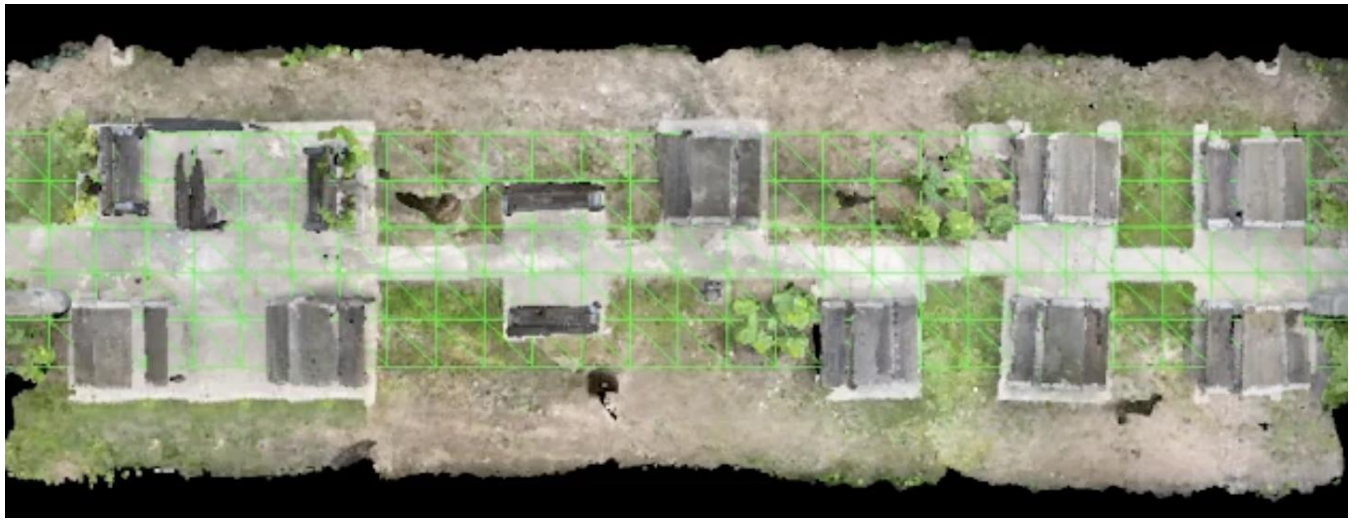


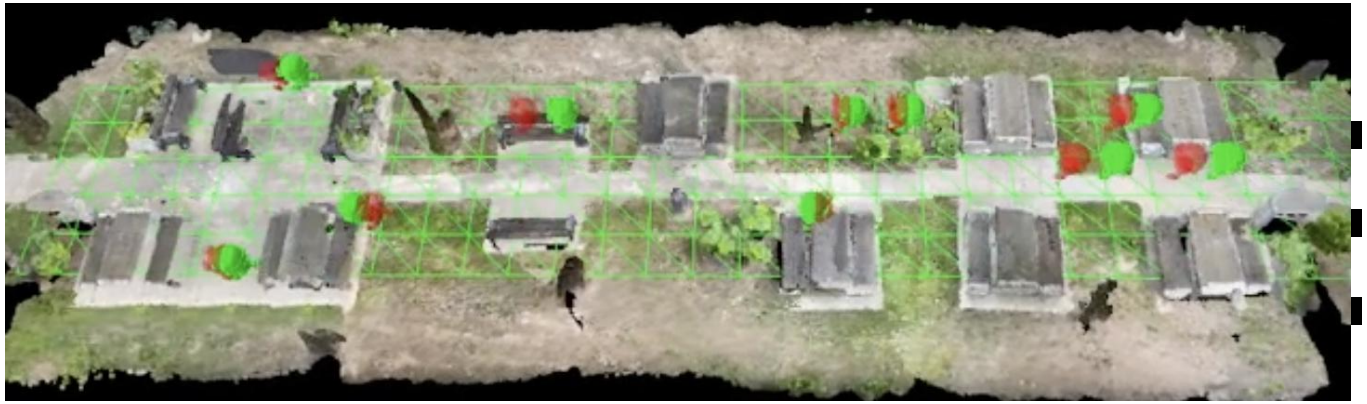
Act



A location forecasting at the edge scenario: location data collection and digital twin (-point cloud).







- Measured location
- Forecasted location

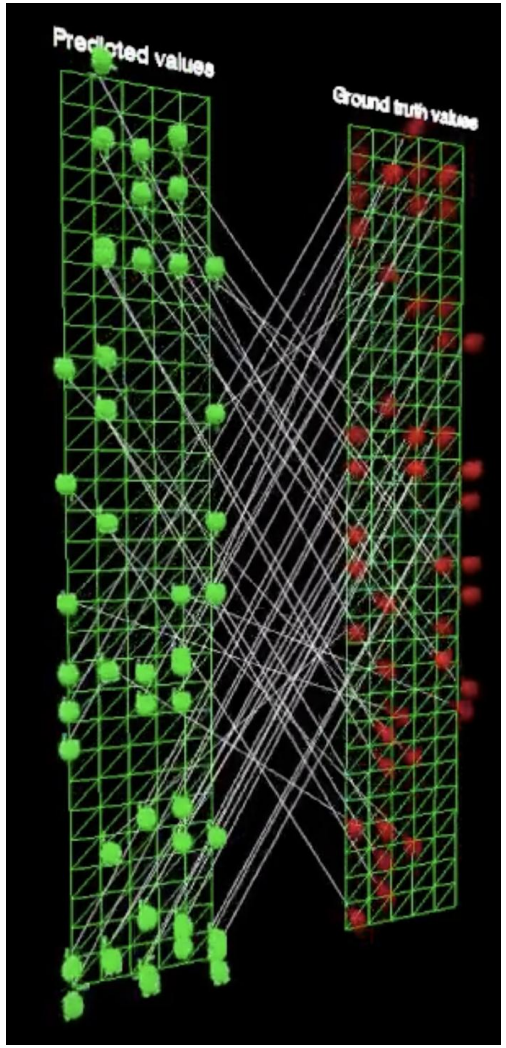
Act

A location forecasting at the edge scenario: delayed forecasts upon increased demand.

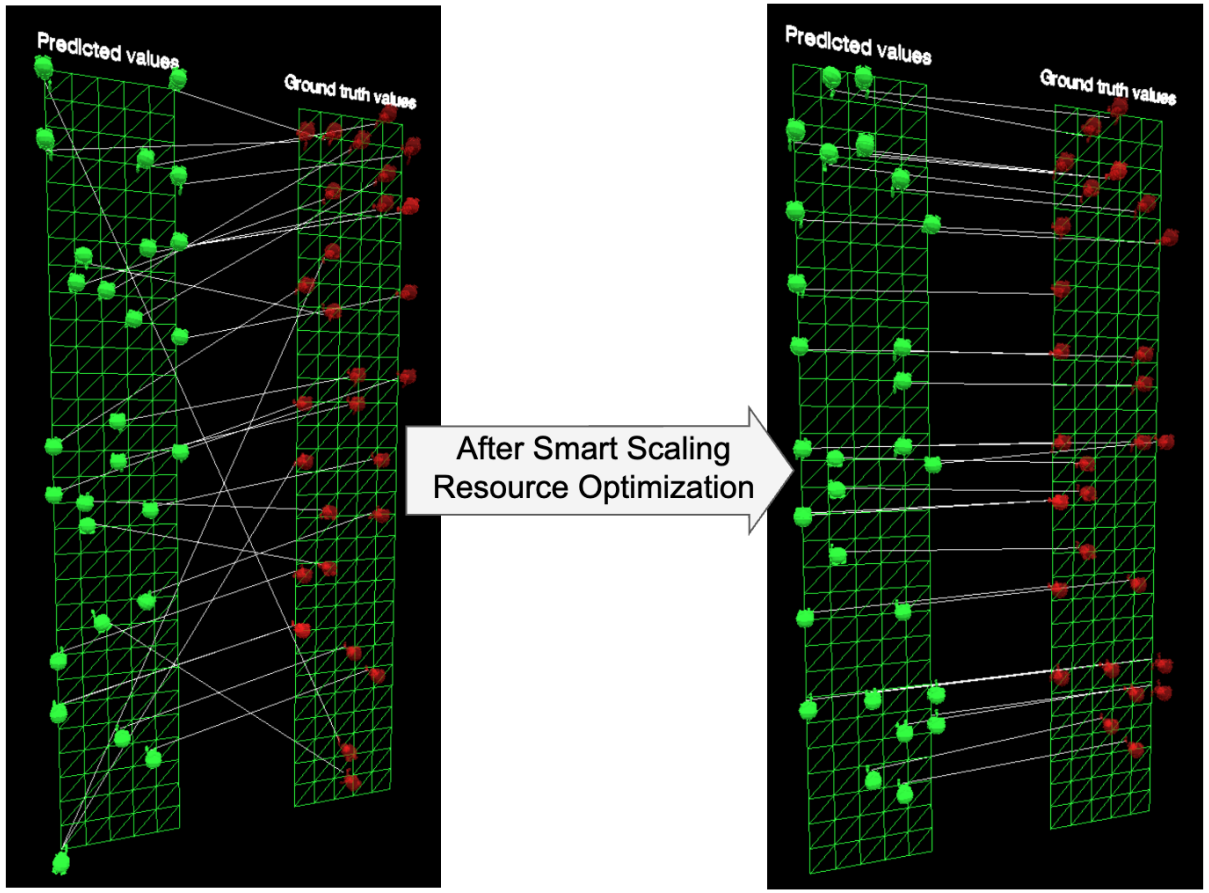
- Due to compute resource constraints on the back-end server
- Need for autoscaling of resources WITHOUT disrupting the service
- Traditional scaling approaches typically rely on static thresholds and predefined rules

- Can AI help?





Demonstration



J. Prodanov, B. Bertalanič, C. Fortuna and J. Hribar. Demonstrating Smart Scaling of AI-Services for Future Networks," in Proc. IEEE WCNC 2025, Milan, Italy. https://doi.org/10.1109/WCNC61545.2025.10978455

Act

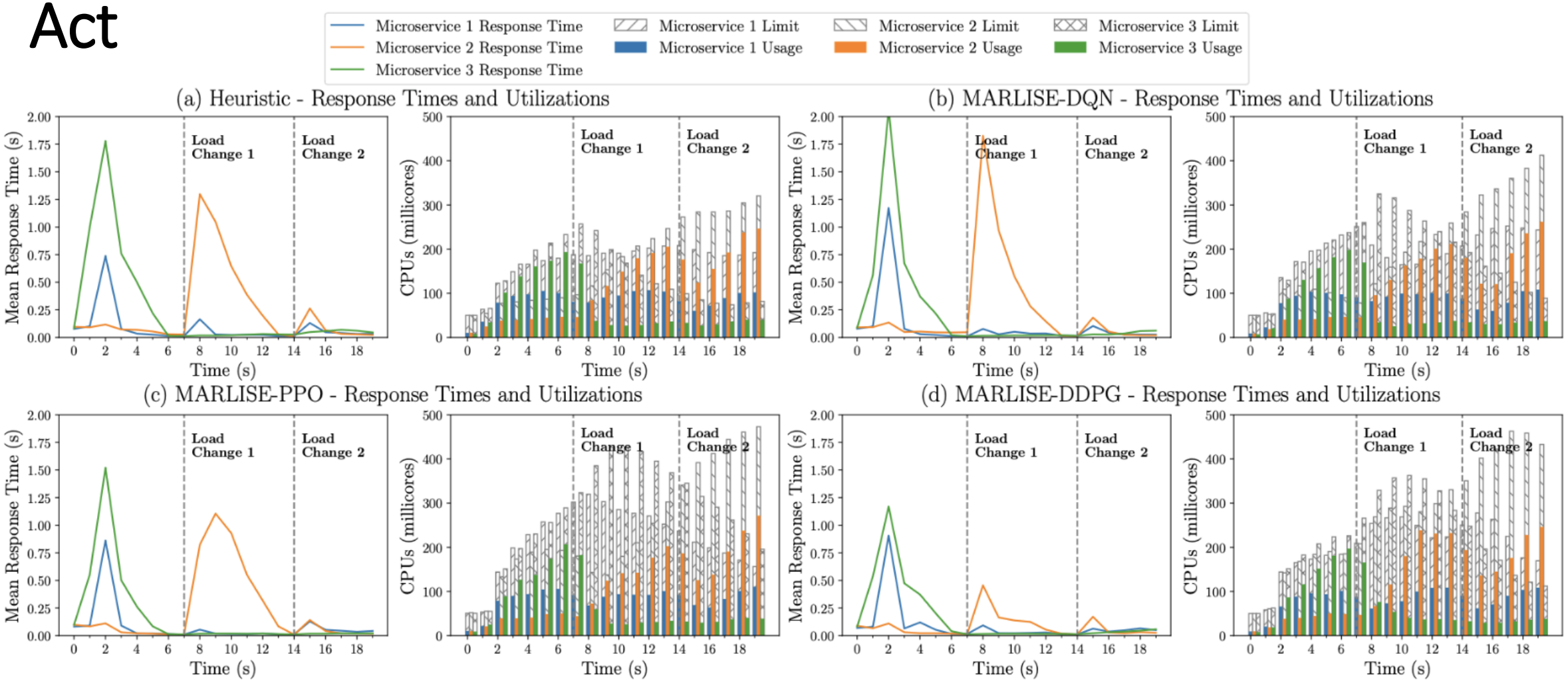


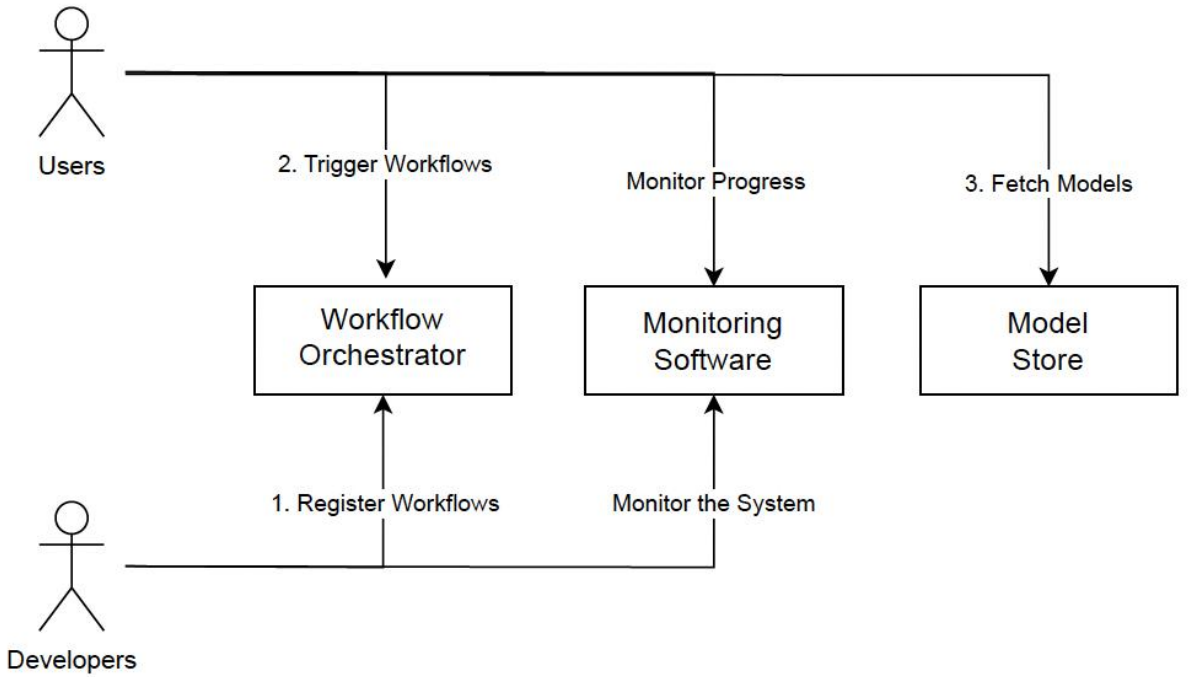
Figure 4: Averaged performance of different algorithms under dynamic load testing.

Multi-Agent Reinforcement Learning-Based In-Place Scaling Engine for Edge-Cloud Systems, Jovan Prodanov, Blaž Bertalanič, Carolina Fortuna, Shih-Kai Chou, Matjaž B. Jurič, Ramon Sanchez-Iborra, Jernej Hribar, IEEE CLOUD: 7-12 July 2025

OPERATIONAL AND ENERGY ASPECTS

NAOMI

- A new MLOps solution for democratizing AI workflows at the edge
- It’s like a factory, assembly line included, for AI models
- NAOMI architecture shows a flow of operations and data artifacts inside the AI/ML workflow.

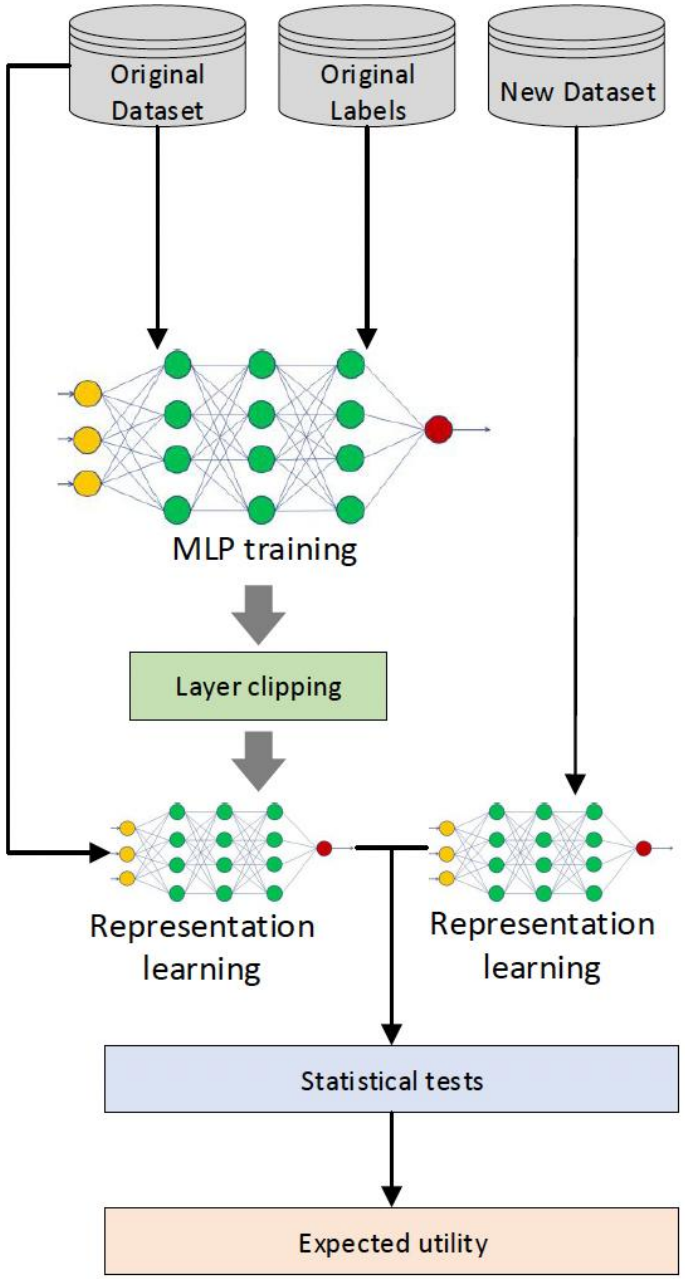


An Overview and Solution for Democratizing AI Workflows at the Network Edge. Andrej Čop, Blaž Bertalanič, Carolina Fortuna, Journal of Network and Computer Applications, 2025.

Self-Evolving Models

- Regular, scheduled
- On monitored metrics (NAOMI)
- **Feature Drift: ALERT**
- Concept Drift
- Dataset drift

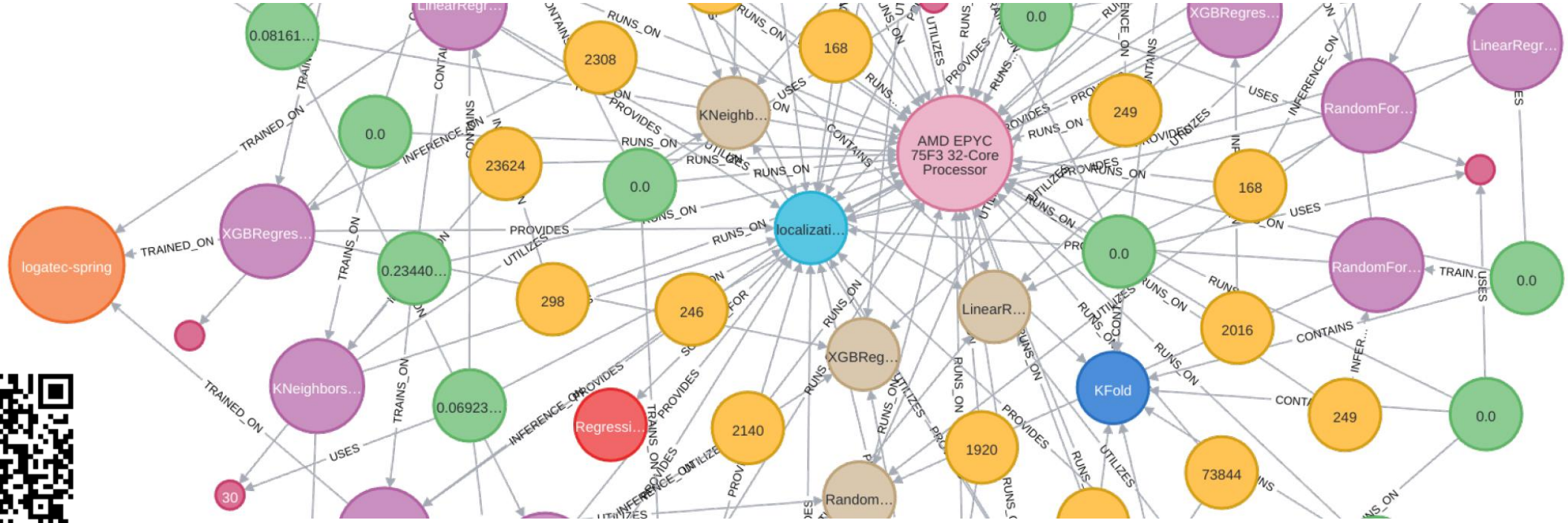
$$U = \frac{U_{KS} + U_{PSI}}{2}$$



A Representation Learning Approach to Feature Drift Detection in Wireless Networks
Athanasios Tziouvaras, Blaz Bertalanic, George Floros, Kostas Kolomvatsos, Panagiotis Sarigiannidis, Carolina Fortuna, 2025, https://doi.org/10.48550/arXiv.2505.10325

MRM3: Machine Readable ML Model Metadata

- Enables more expressive model description in the model repository
- Support for better informed and/or multi-objective model selection



MRM3: Machine Readable ML Model Metadata, Andrej Čop, Blaž Bertalanič, Marko Grobelnik, Carolina Fortuna, MobiSys '25: Proceedings of the 23st [I. E. 23rd] ACM International Conference on Mobile Systems, Applications, and Services, 2025

eCAL - the Energy Cost of Artificial Intelligence Lifecycle

- Considering the OSI model and the MLOps components, we propose a new metric, eCAL:

$$eCAL = \frac{\text{Total energy of data manipulation } [J]}{\text{Total manipulated app. level data } [b]}$$

- An open source, modular and extensible simulator for eCAL: https://github.com/sensorlab/eCAL

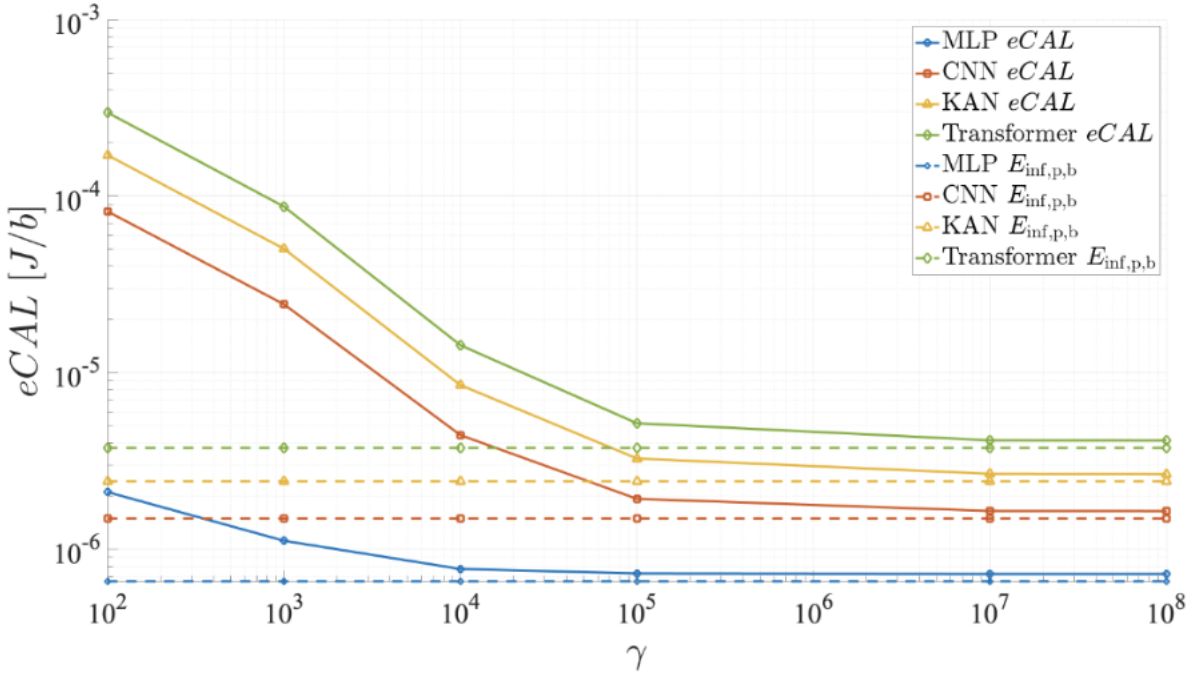


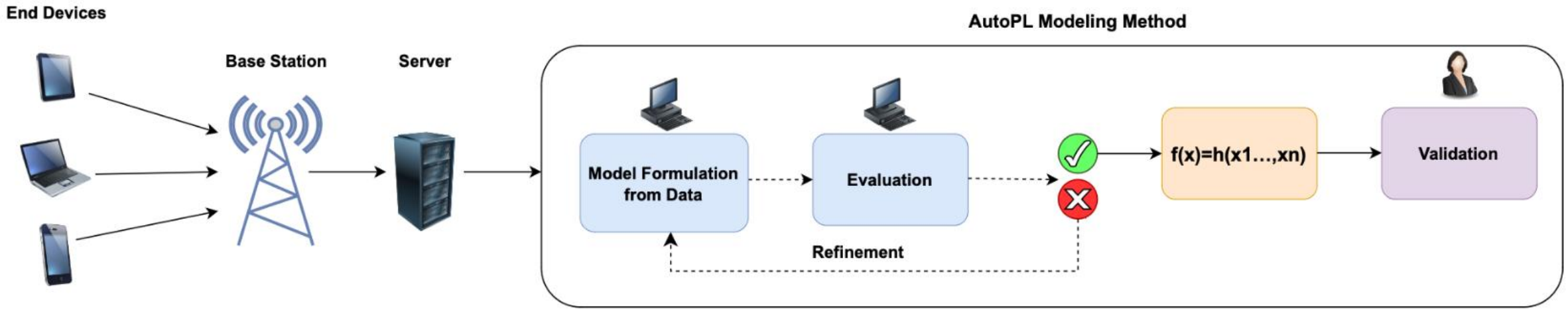
Fig. 13: Energy cost of AI model lifecycle ($eCAL$) for different models over the number of inferences (γ), log scale on both axes.

Chou, S.-K., Hribar, J., Hanžel, V., Mohorčič, M., & Fortuna, C. (2024). *The Energy Cost of Artificial Intelligence Lifecycle in Communication Networks*. Under review. https://arxiv.org/abs/2408.00540

AUTOMATING SCIENTIFIC DISCOVERY

Automated Scientific Discovery

- A method gaining popularity recently in various communities (physics, chemistry, etc.)



Towards Automated and Interpretable Pathloss Approximation Methods, Ahmad Anaqreh, Shih-Kai Chou, Irina Barašin, Carolina Fortuna, AAAI 2025 Workshop on Artificial Intelligence for Wireless Communications and Networking: Philadelphia, Pennsylvania, USA, Mar 03, 2024.

Automated Modeling Method for Pathloss Model Discovery, Ahmad Anaqreh, Shih-Kai Chou, Mihael Mohorčič, Thomas Lagkas, Carolina Fortuna, 2025, https://arxiv.org/abs/2505.23383v2

SABER: Symbolic Regression-Based Angle of Arrival and Beam Pattern Estimator, Shih-Kai Chou, Mengran Zhao, Cheng-Nan Hu, Kuang-Chung Chou, Carolina Fortuna, Jernej Hribar, 2025, https://arxiv.org/abs/2510.26340v1



Thank you!

Email: carolina.fortuna@ijs.si