Industrial Examples of Graph Applications

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CINTI 2023 Conference

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Personal Intro

@Bosch Budapest since 2015

- Bosch Scientist – Academic Relations team
- Automotive communications and security testing background
- Knowledge management – Product cybersecurity

- PhD in Physics (experimental particle physics, ELTE, Budapest, Postdoc at CERN, Geneva) – photon structure measurements
- MBA in international management (University of Geneva)
- 20 years in industry:
  - Embedded systems, real-time control applications
  - HW-SW codesign & optimization
  - Functional safety and cybersecurity
  - Aerospace and automotive industries

- Family with 3 teens

Knowledge graphs link engineering data across the organization

What we work on
Divisions @ Budapest

Mobility Company

- Automotive Electronics
- Cross-domain Computing Solutions
- Powertrain Solutions
- Electrical Drives
- Automotive Steering
- Chassis System Control
- Bosch eBike Systems
- Automotive Aftermarket

The presence of most Bosch Mobility Company divisions at ECB offers extraordinary synergy possibilities

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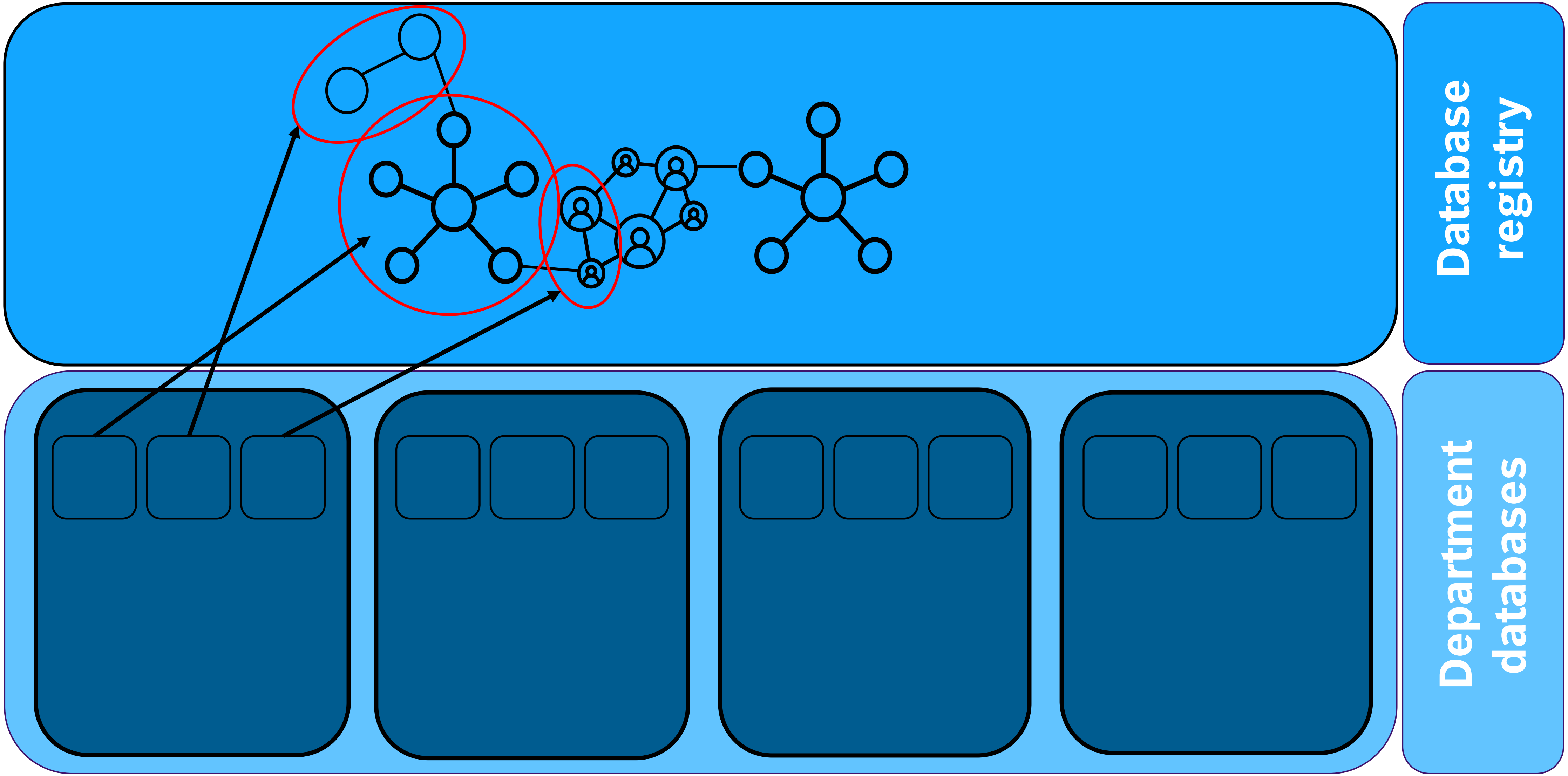
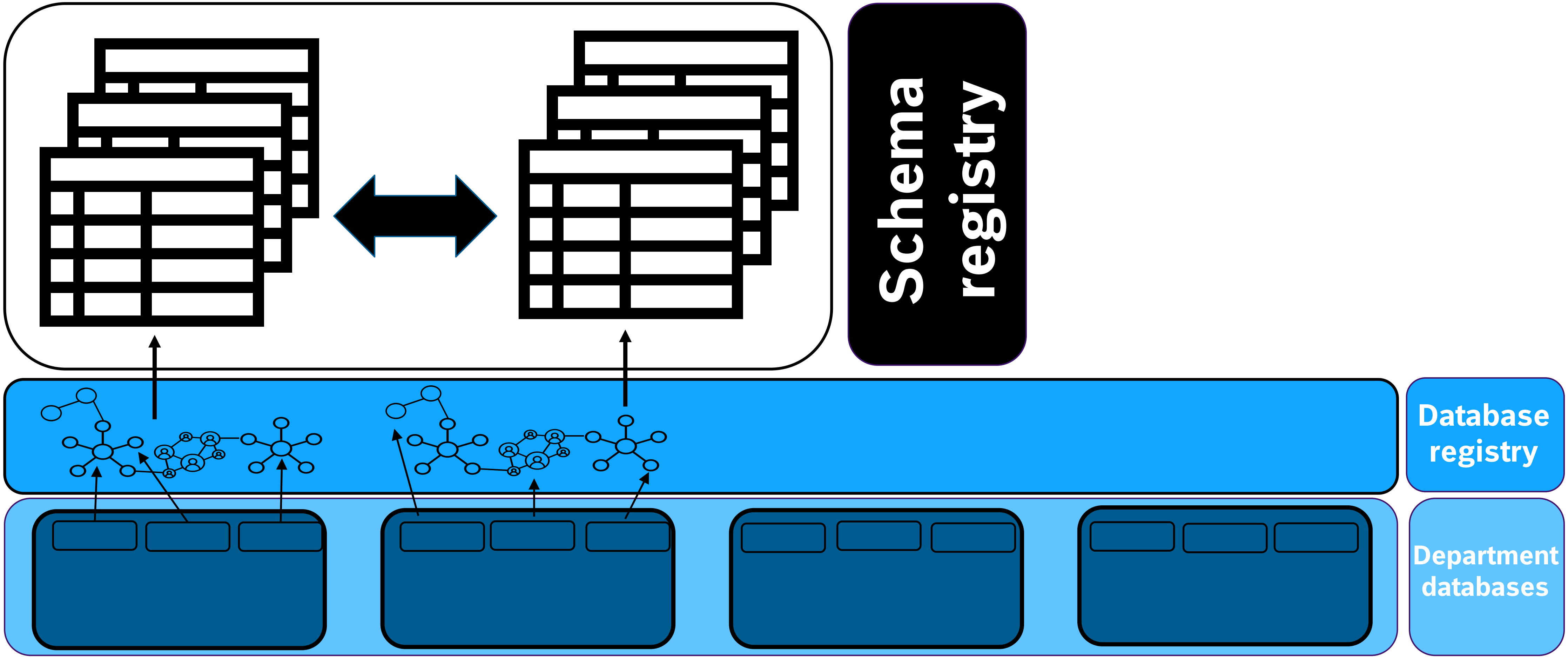

Database registry
Department databases



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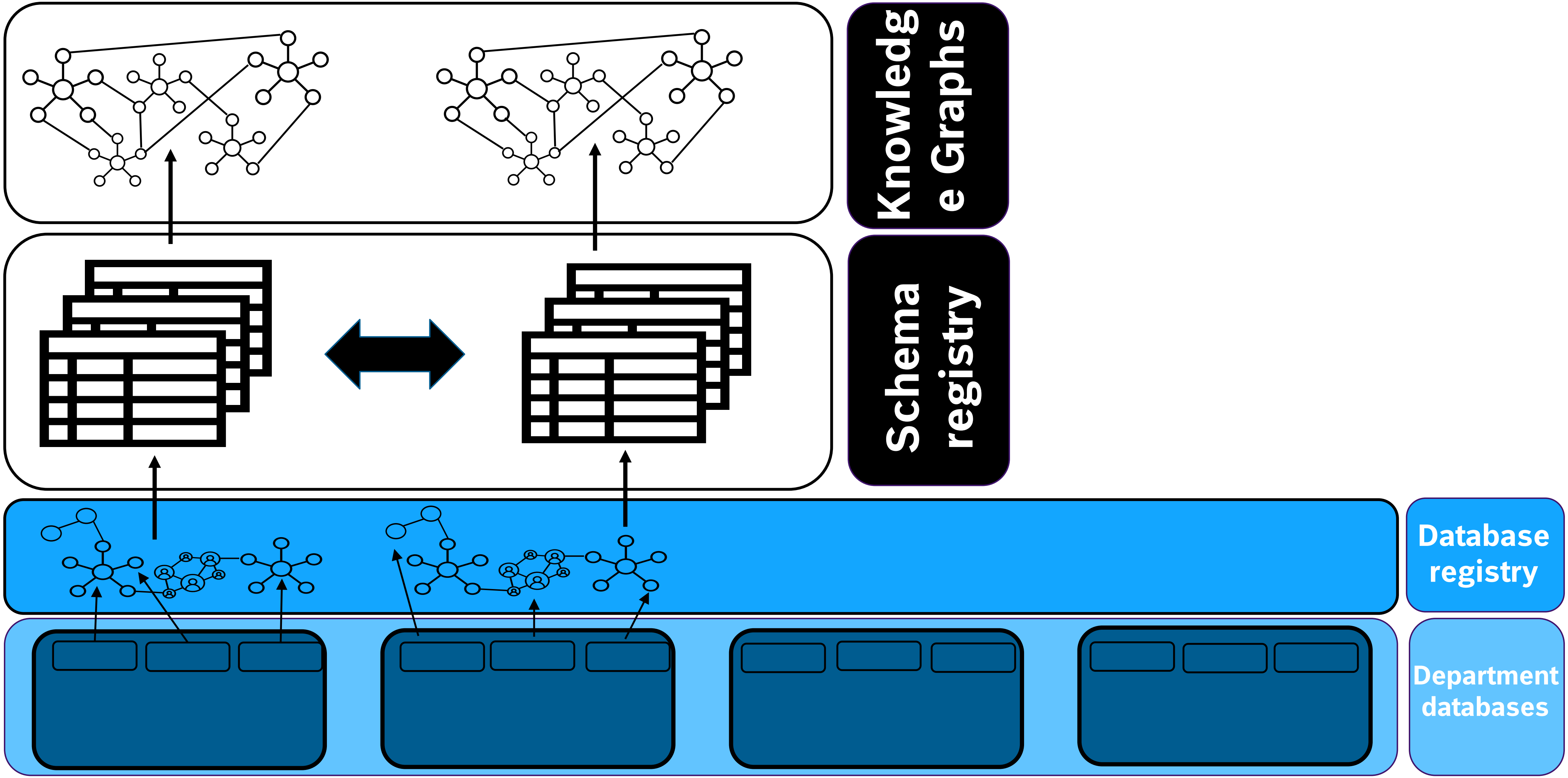
Knowledge Graphs
Schema registry
Database registry
Department databases

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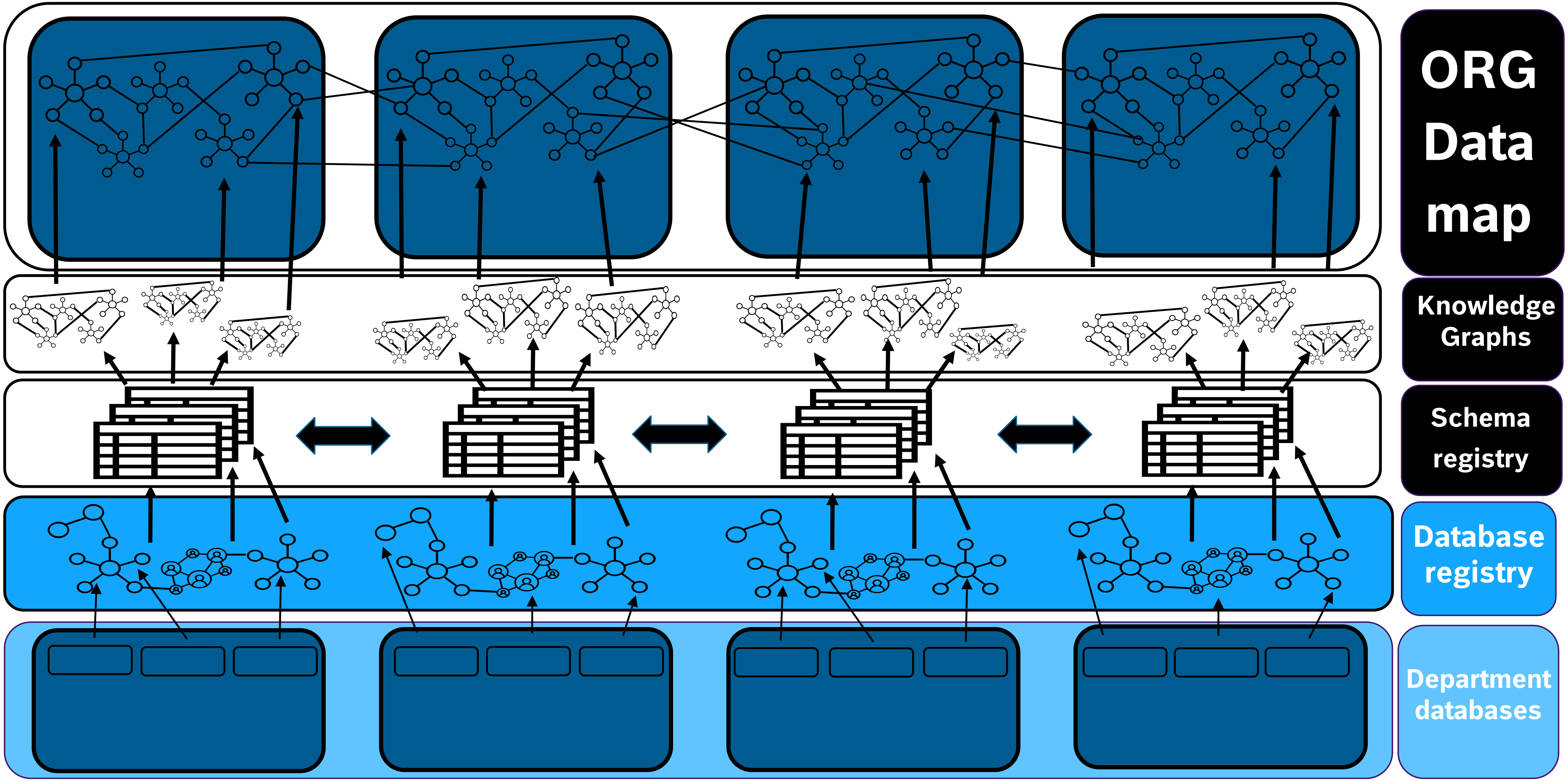

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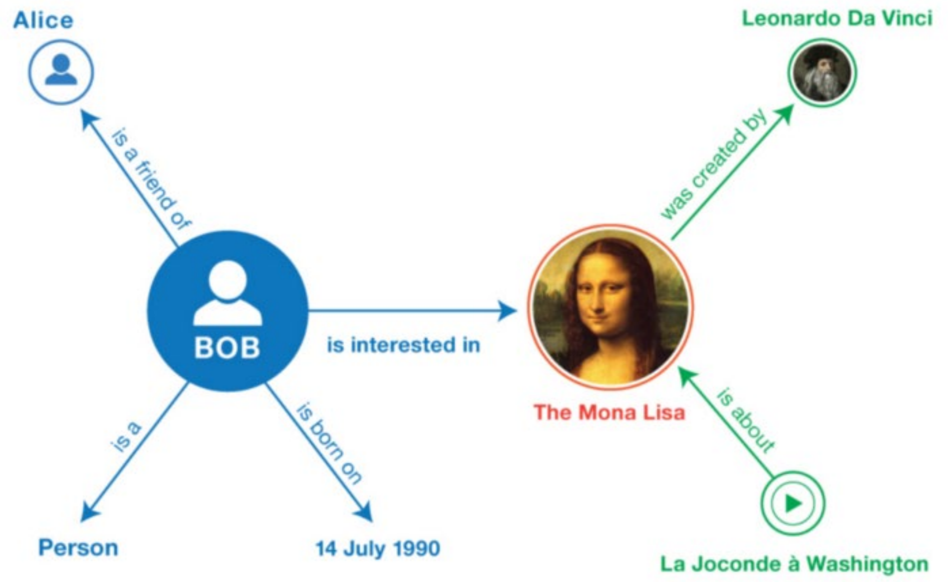
Knowledge Graphs in Engineering
Terms

A **vocabulary** refers to a set of terms and concepts to describe data.

A **taxonomy** is a hierarchical framework of the terms.

An **ontology** is the composition of properties and how they are related, by defining a set of terms and relational expressions that represent the entities.

A **triple** is a statement about semantic data in the form of subject-predicate-object expression.



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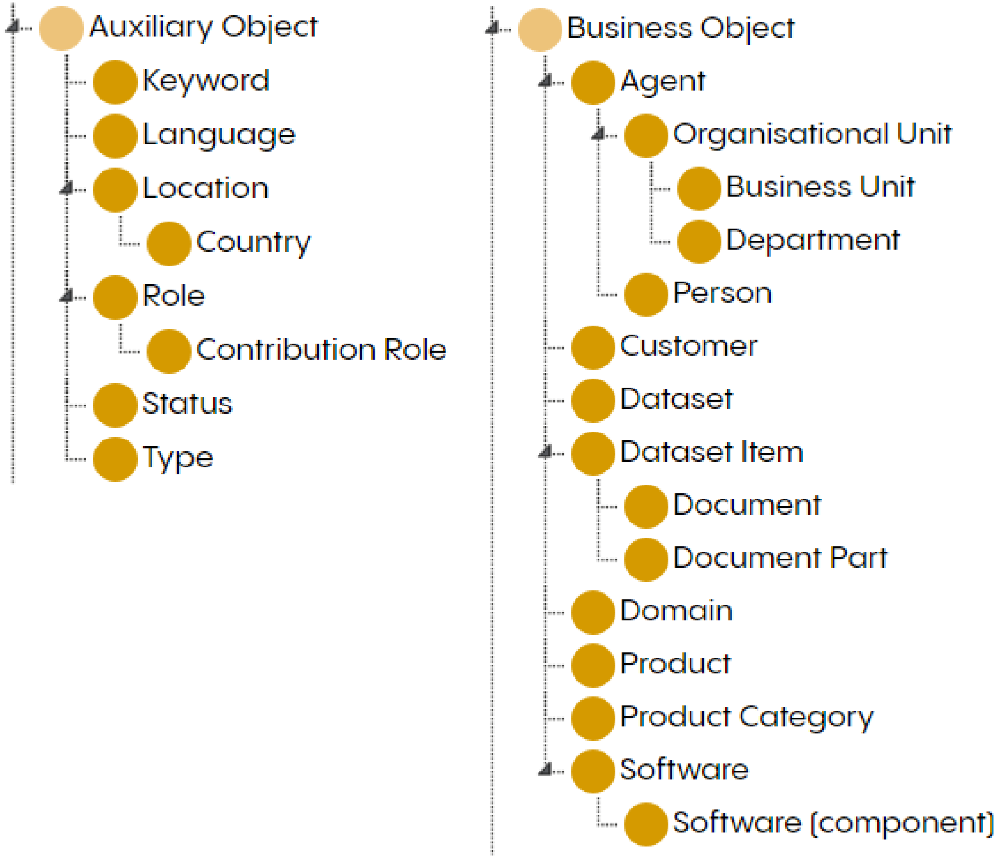
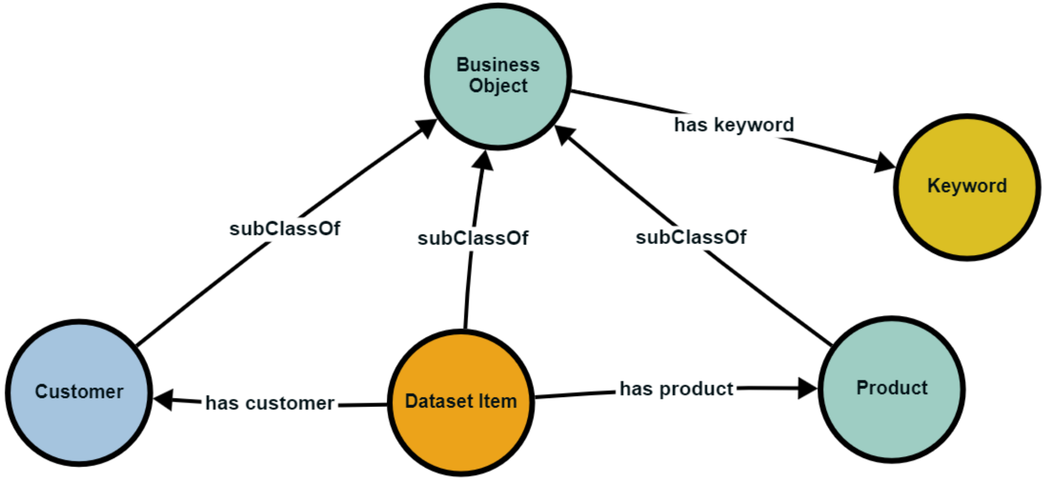
Knowledge Graphs in Engineering
Core data ontology

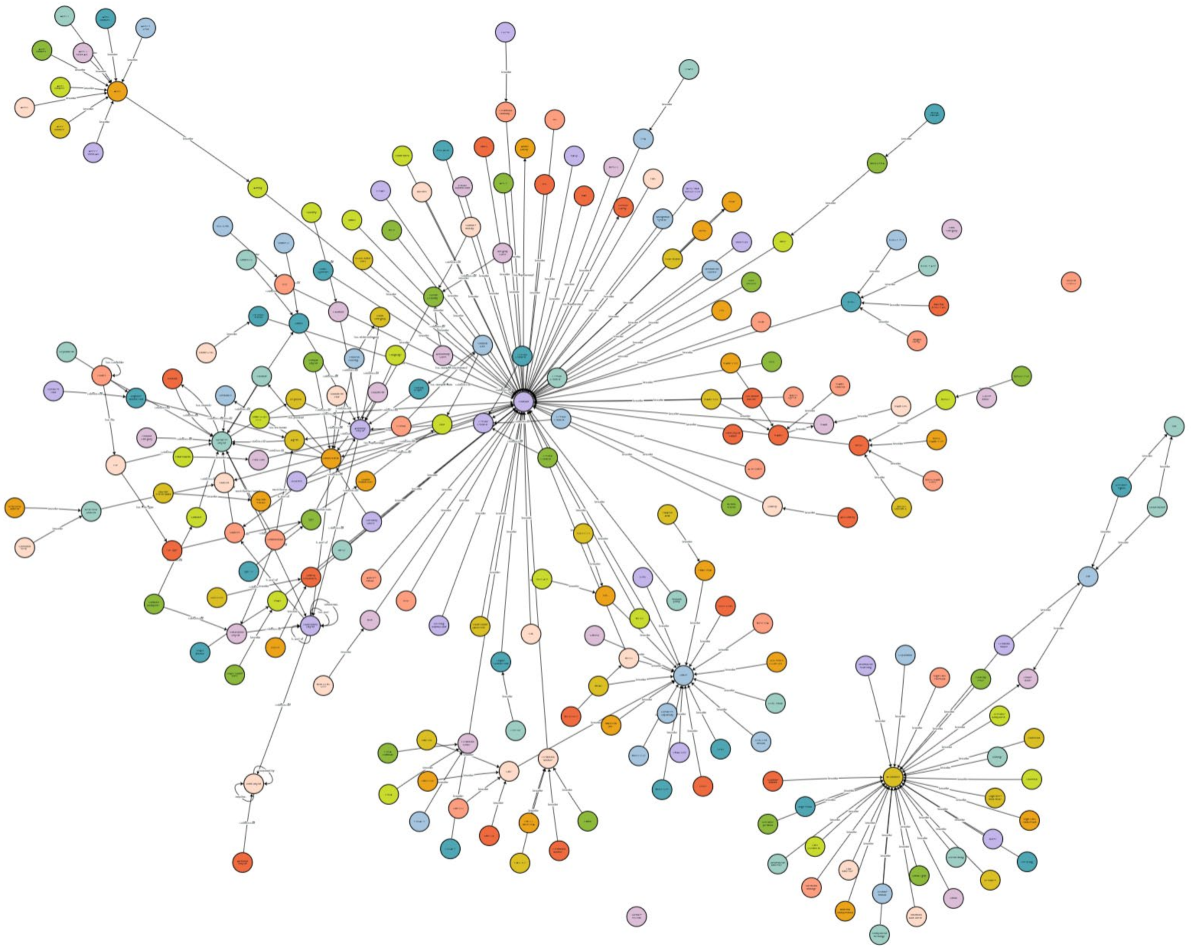


Our **core data ontology** is an abstract description of data assets and related meta-data objects.



Implemented in current ontology
Imported from outer ontology

Knowledge Graphs in Engineering
KG in Stardog Explorer



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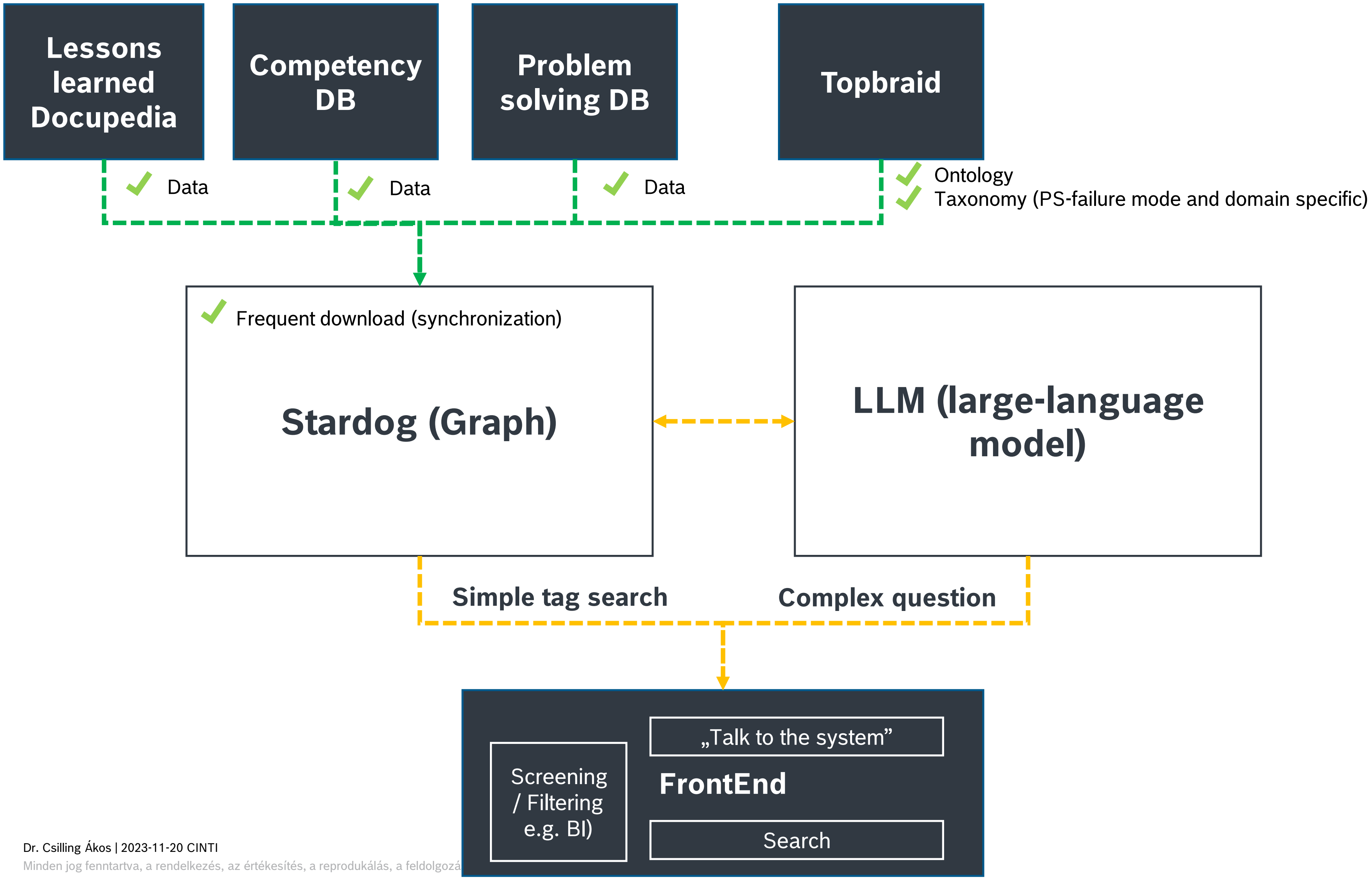

Lessons learned Docupedia
Competency DB
Problem solving DB
Topbraid
Data
Data
Data
Ontology
Taxonomy (PS-failure mode and domain specific)
Frequent download (synchronization)
Stardog (Graph)
LLM (large-language model)
Simple tag search
Complex question
„Talk to the system”
Screening / Filtering e.g. BI)
FrontEnd
Search

Knowledge Graphs in Engineering
Key Take-Aways

Why Knowledge Graphs?

- **Flexible data model,** easier to integrate **new data sources**
- **Dynamic** way to **connect data points**, revealing **intricate relationships**
- **Intuitive** and **efficient exploration** of information

Why Knowledge Graphs **with LLM**?

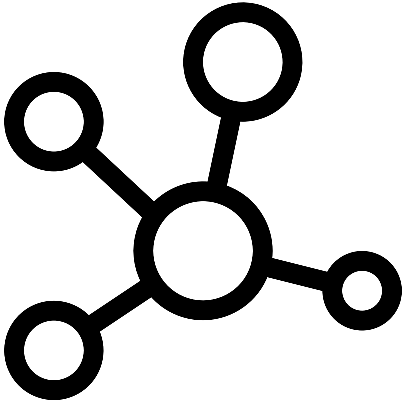
- Enabling more **complex, contextual questions** to retrieve information

Current Status:

- Mapping our data asset ✔
- Competence build up ✔

Next steps:

- Integrating more data assets
- Roll out first use-case (LL and Problem solving)



Behavior Prediction with Graph Neural Networks

Engineering Center Budapest
Our Focus Areas in Budapest

Automation

Prototype vehicle built in ECB for testing of >L3 autonomous functions

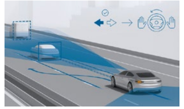
Environment Sensing
Radar, camera and ultrasonic sensors.

Perception, localization
Computer Vision with AI, e.g.:
Road Sign Recognition

Prediction, planning
Predictive driver assistance functions, e.g.:

Automated Emergency Braking

Motion Control Advanced Driver Assistance



Traffic Jam Assist

Adaptive Cruise Control

Power Steering

ESP

We develop elements of key importance for the Bosch Automated Driving System.
Our goal: Deliver turnkey Automated Driving solutions to our customers.

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Behavior Prediction with Graph Neural Networks

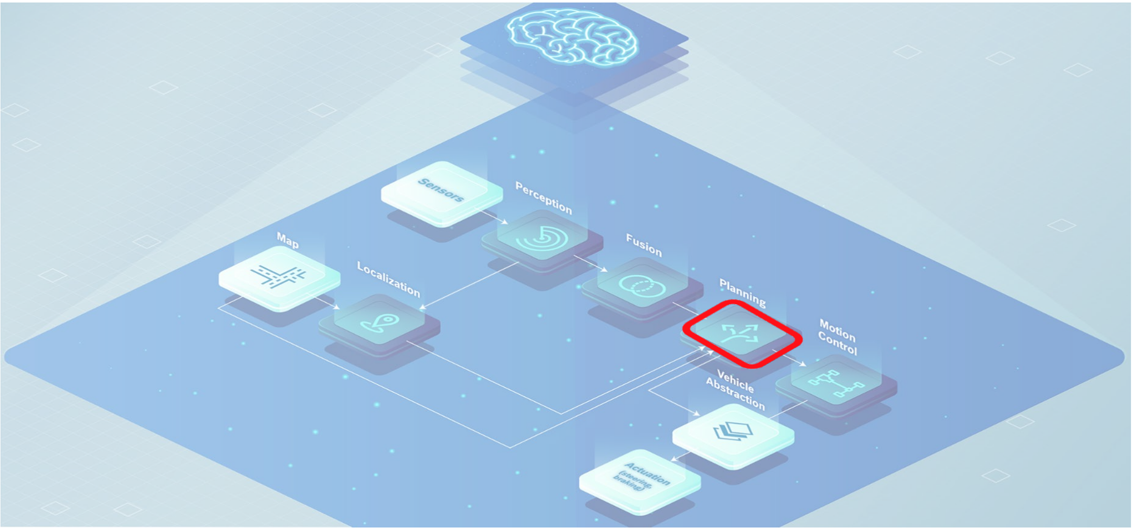
Intro to L4/RB-Stack

- Goal is SAE L4 Automation

- Sensor set

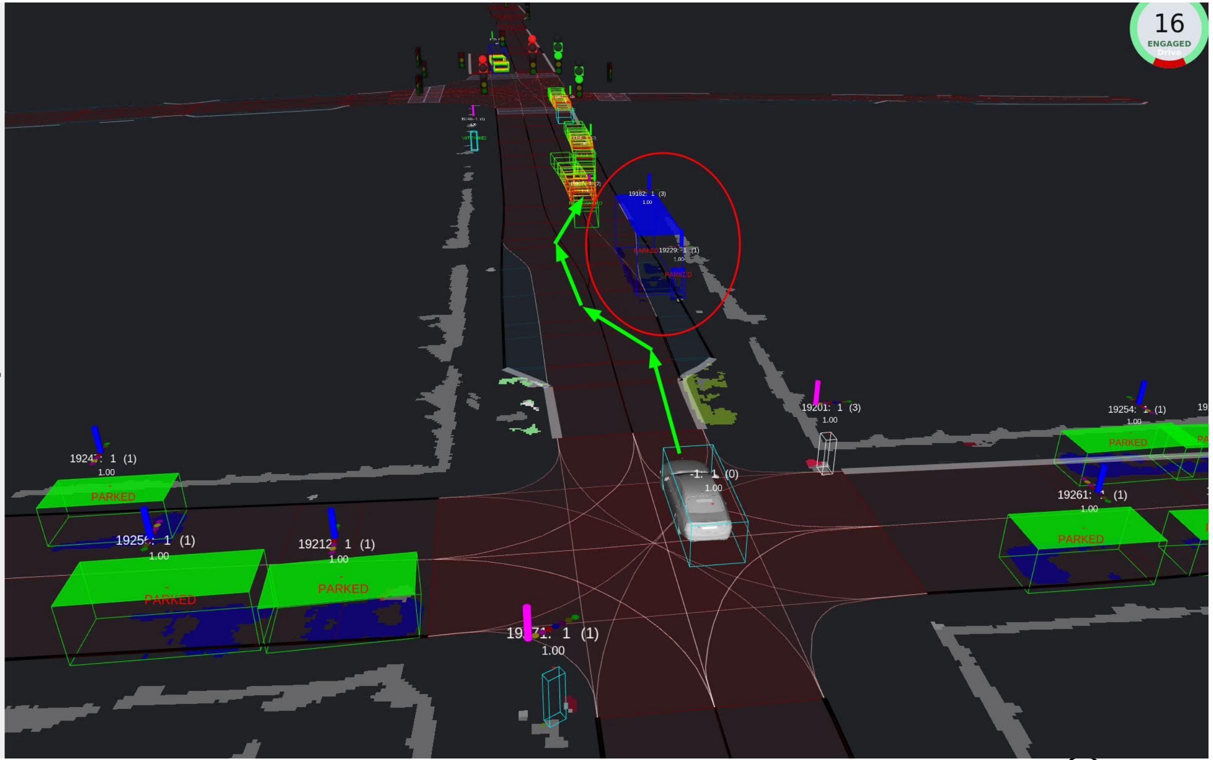
- Planning Machine Learning (PLNML): scope is end-to-end machine learning solutions in prediction and planning

- Planning component in the stack



Behavior Prediction with Graph Neural Networks
Problem Definition (example for parked car classification)

- Aim in L4 is full autonomy, ego vehicle cannot be stuck
- Parked car classification is a surprisingly hard problem



Behavior Prediction with Graph Neural Networks
Problem Definition (example for parked car classification)

- Parked car classification is a surprisingly hard problem

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Behavior Prediction with Graph Neural Networks
Problem Definition

- System limitations for parked cars with Logistic Regression (LR)
  - General performance was not satisfactory for new behavior: nudging
  - No generalization to unseen data (e.g. different routes in Germany)
  - Typical problem clusters (static agents, no state change possible)

- Other system limitations (trajectory, ego lane change success, etc.)

- Proposed solution: Multi-task GNN
  - Modeling of agent-agent, and agent-environment relations and interactions
  - Serving not only parked car classification, but other prediction/planning tasks

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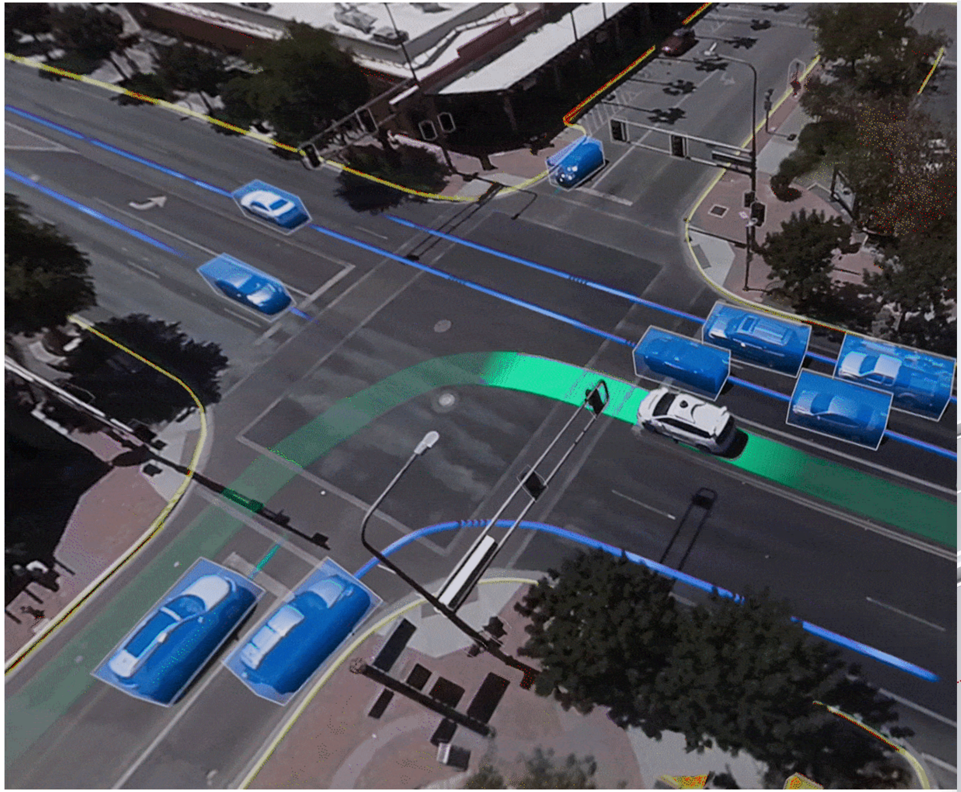
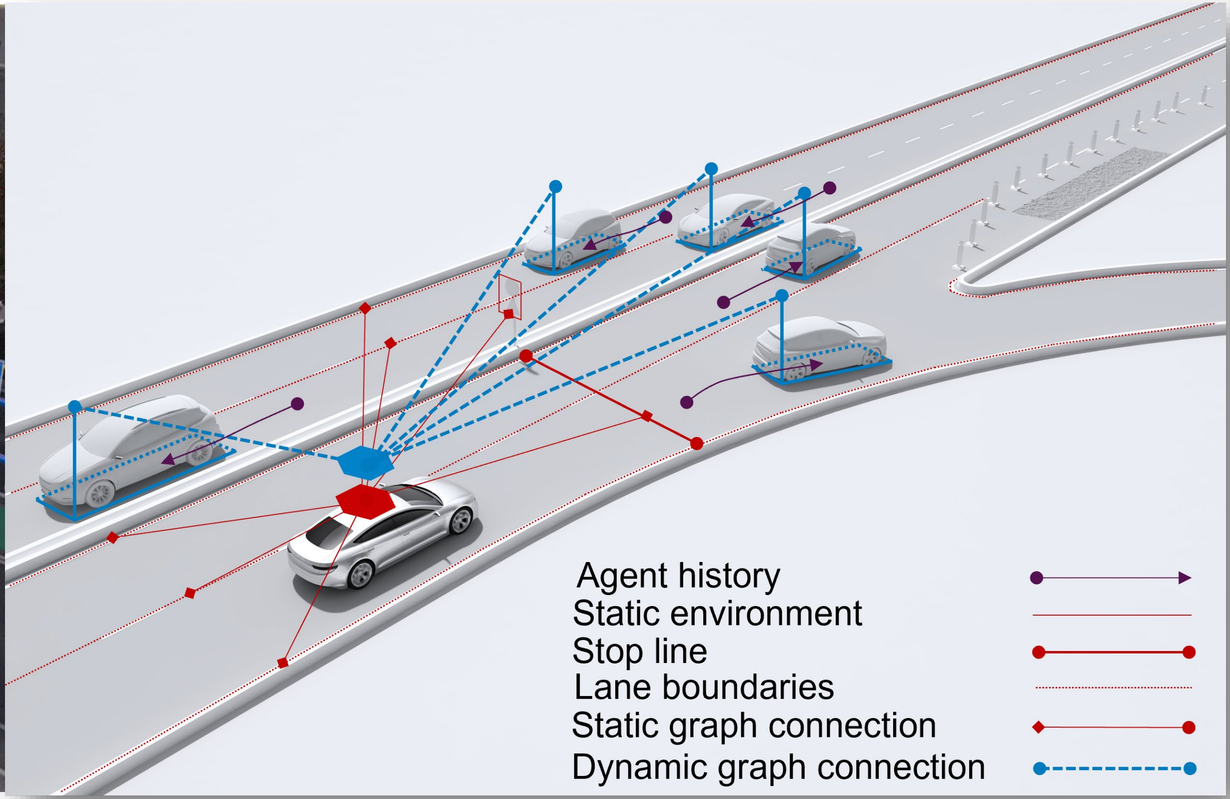
Behavior Prediction with Graph Neural Networks
Solution: Multi-task GNN

- Proposal: vectornet working on graph representation
- Input of the model is a fused, vectorized environment and agents





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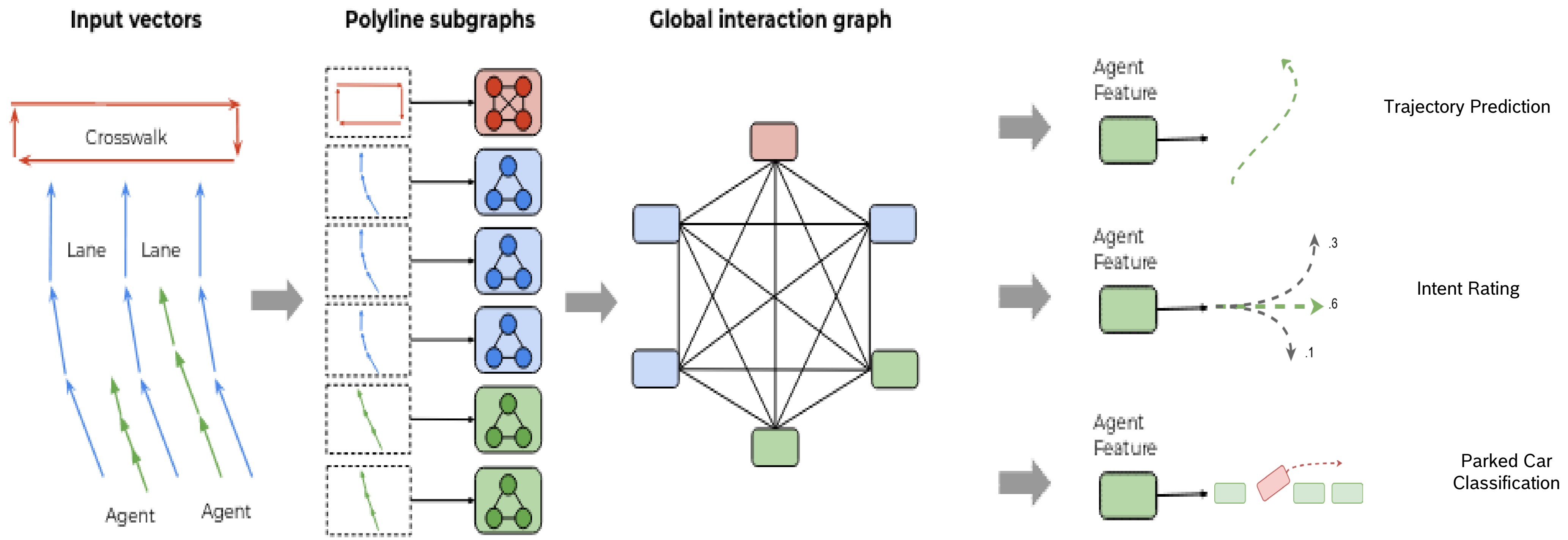
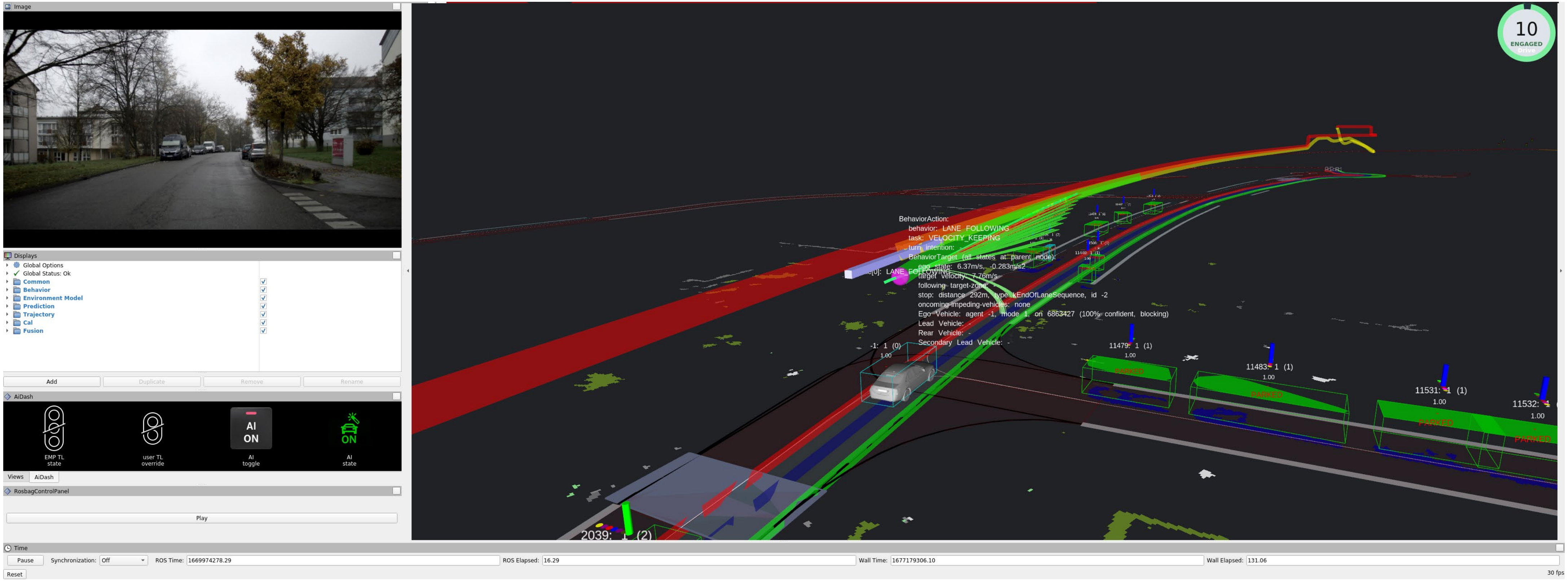
Behavior Prediction with Graph Neural Networks
Solution: Multi-task GNN



Behavior Prediction with Graph Neural Networks
Comparison between LR and GNN

- Example of a static agent at an intersection

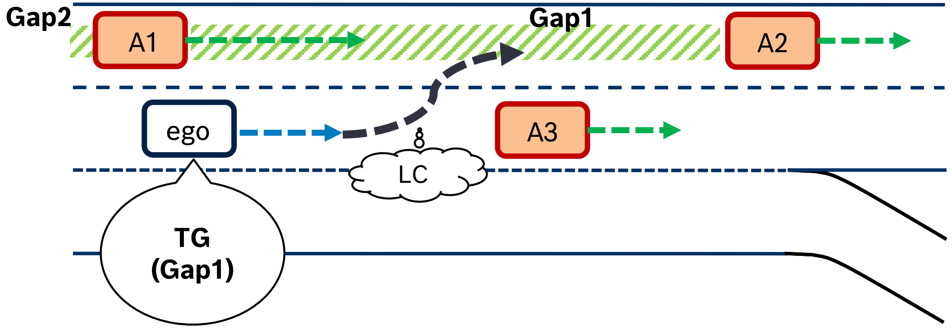


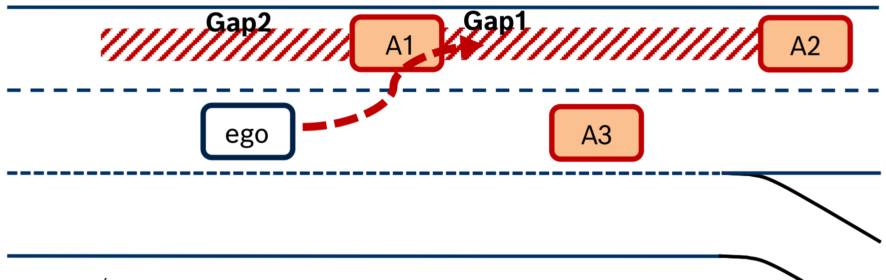
Behavior Prediction with Graph Neural Networks

Outlook to other Planning tasks

Ego Lane Change Success

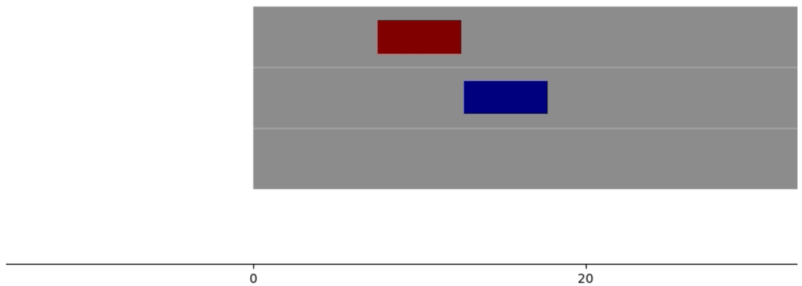
- Veto the possibly unsuccessful lane changes
- Rating the track gaps (Gap1, Gap2)

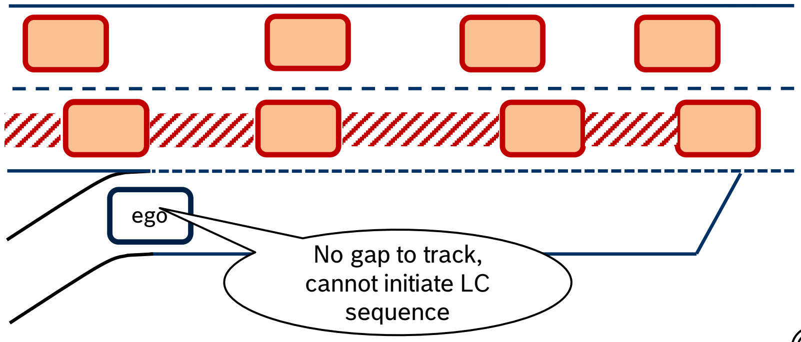




Hybrid Trajectory Prediction

- Take into account interactions for a more assertive lane change
- Useful in merges and dense traffic





Evaluating Cybersecurity with Attack Graphs

Security of Automotive Products

Cybersecurity is Mandatory to Ensure Road Safety

Originally, cars were designed as closed systems. Cyber-security was not an issue.

- Many different! electronic control units (ECUs) on an inhomogeneous network.
- More and more features implemented in SW, including safety-critical drive-by-wire functions.
- External connectivity (Infotainment, SW update, emergency calls, v2x smart services).
- Remote access
  - Lock / unlock
  - Start / stop
  - User devices

- Cybersecurity management and evaluation is mandatory in most markets, ISO 21434 is the standard method.

Autonomous driving (Illustrative). Photo: Shutterstock

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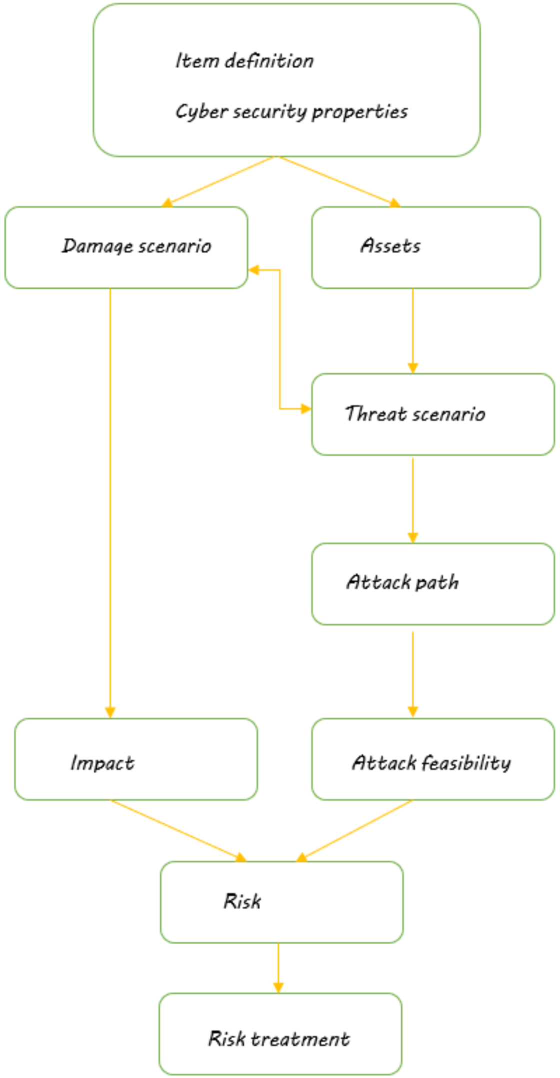
Evaluating Cybersecurity with Attack Graphs
Threat Analysis and Risk Assessment

- ISO/SAE 21434 is the cybersecurity standard for road vehicles
- It mandates full lifecycle cybersecurity management, including the **Threat analysis and risk assessment**
- Systematic process to identify and treat risk
- Cybersecurity attacks can be combined into a “kill chain”
- Manually enumerating all possible attack paths in a complex system is practically impossible

We need automation in the threat analysis



ISO/SAE 21434

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Evaluating Cybersecurity with Attack Graphs

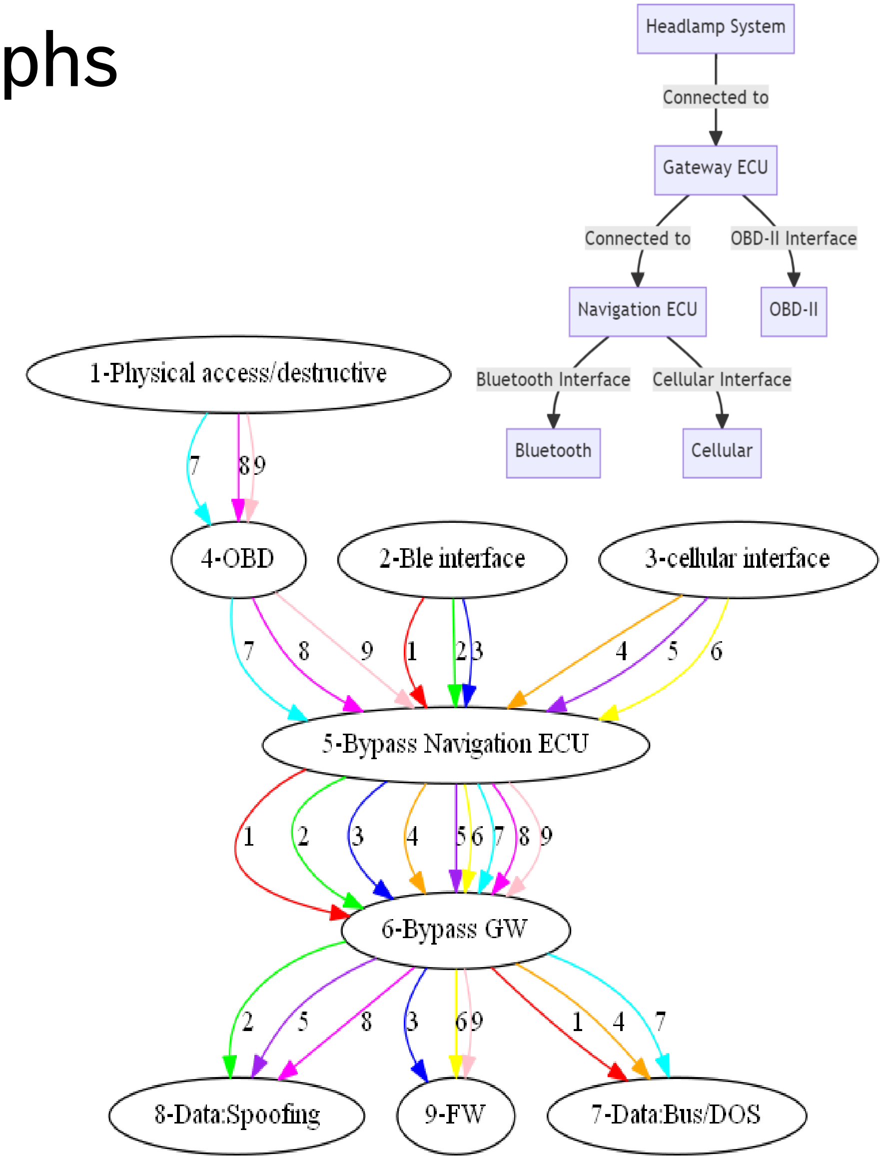
Attack Graphs for TARA

- Understand the system composition
- Construct asset inventory
- Define external and internal interfaces
- Evaluate each attack step separately, in immediate context

- **Construct attack graph** and generate all possible paths

- Rank each path according to combined feasibility (likelihood)
- Consider security measures to reduce feasibility

- Add in damage scenarios to evaluate impact
- Risk is a combination of the impact with the feasibility



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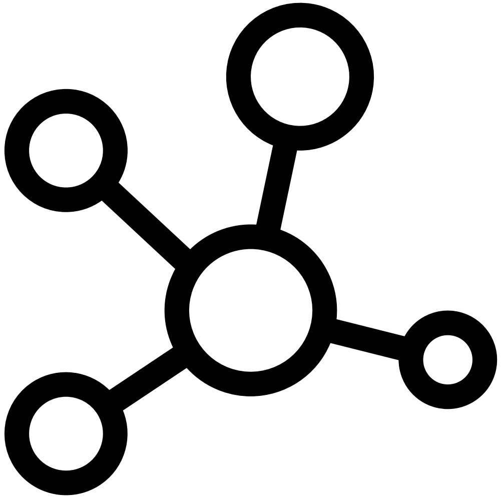
Industrial Examples of Graph Applications
Conclusions

- Graph computation methods are well suited to many industrial applications
- The basic concepts are available and accessible
- The challenge is to reformulate industrial questions into graph language and find the right model for the specific application



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