Universität Stuttgart
Institute of Industrial Automation and Software Engineering (IAS)

Faculty V - Computer Science, Electrical Engineering and Information Technology of the University of Stuttgart

Research and Teaching at IAS

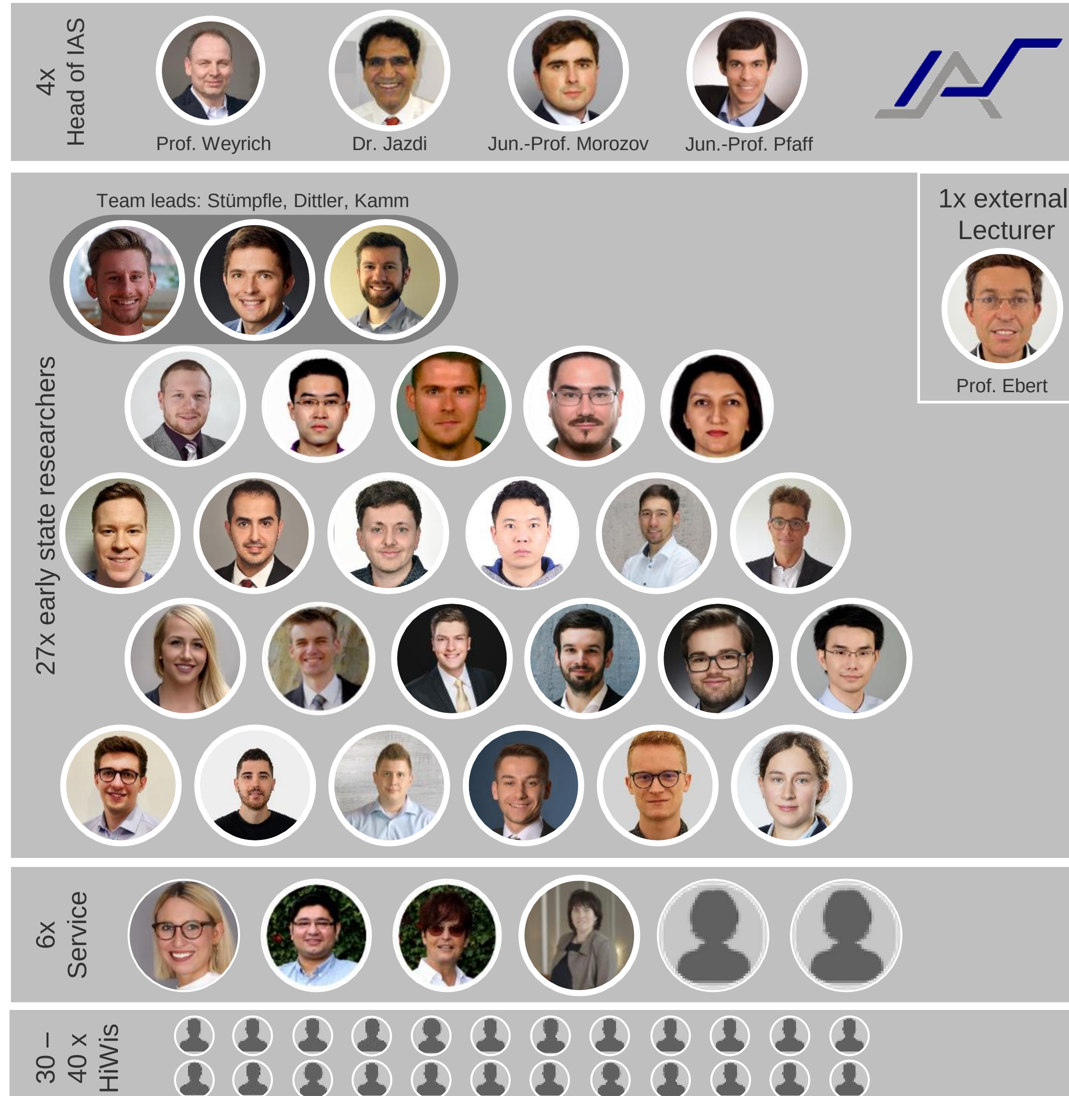
University of Stuttgart,
Institute of Industrial Automation and Software Engineering (IAS)

Institute of Industrial Automation and Software Engineering (IAS)

Research and teaching at the Institute focuses on the topic of **Software Systems for Automation Engineering**.

We see ourselves as **bridgehead to Product and Industry Automation** in the research disciplines of **Information Technology, Software Technology and Electronics**.

For this purpose, we **collaborate with research institutions and companies** from the Stuttgart region, from Europe and worldwide.



Institute of Industrial Automation and Software Engineering (IAS)

Faculty of Computer Science, Electrical Engineering and Information Technology of the University of Stuttgart

85 years of Tradition and Progress

since 2024

Jun.-Prof. F. Pfaff

Cognitive Sensors

since 2020

Jun.-Prof. A. Morozov

Networked Automation Systems

since 2013

Institute of Industrial Automation and Software Engineering

Professor M. Weyrich

1995 – 2015

Institute for Automation and Software Engineering

Professor P. Göhner

1970 – 1995

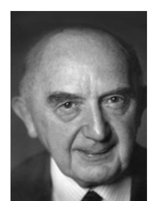
Institute for Control Engineering and Process Automation

Professor R. Lauber

1935 – 1970

Institute for Electrical Plants

Professor A. Leonhard



Teaching

The institute conducts about 1000 exams per year.

Lectures

- Industrial Automation I & II
- Technologies and Methodologies of Software Systems I & II
- Software Engineering for Real-Time Systems
- Industrial Automation Systems

- Basics of Software Systems
- Lecture Series: Software and Automation
- Lecture Series: Aspects of Autonomous Systems
- Reliability of intelligent distributed Automation Systems
- Modeling and Analysis of Automation Systems
- Seminar Intelligent Cyber-Physical Systems
- Risk Assessment for Robotic Systems

- Laboratory Course Software Engineering
- Laboratory Course Industrial Automation
- Laboratory Introduction in Microcontroller Programming

Study programs

- Electrical Engineering department:
  - B. Sc. & M. Sc. Elektrotechnik und Informationstechnik
  - B. Sc. Erneuerbare Energien
  - M. Sc. Nachhaltige Elektrische Energieversorgung,
  - M. Sc. Elektromobilität
  - M. Sc. Information Technology
- Exports to other departments
  - Mechatronik, Technische Kybernetik, Informatik, Medizin-technik, Technikpädagogik, Verkehrsingenieurwesen
- Interdisciplinary
  - M. Sc. Autonome Systeme (Dean of Studies Office)

Research at IAS

We focus on automation systems, especially their software in connection with control systems.

Digital Twin for automation systems

- Digital Twin for autonomous systems control and support of teleoperation
- Automatic reconfiguration management

Complexity control in automation technology

- Test-driven developement of software-defined systems
- Continous integration, developement and deployment of automated products
- Training and validation of autonomous systems based on synthetic data

Intelligent and learning automation systems

- Generative AI: Large Language Models, Generative Adversarial Networks
- Federated machine learning for privacy preserving automation

Risk analysis and anomaly detection for networked automation systems

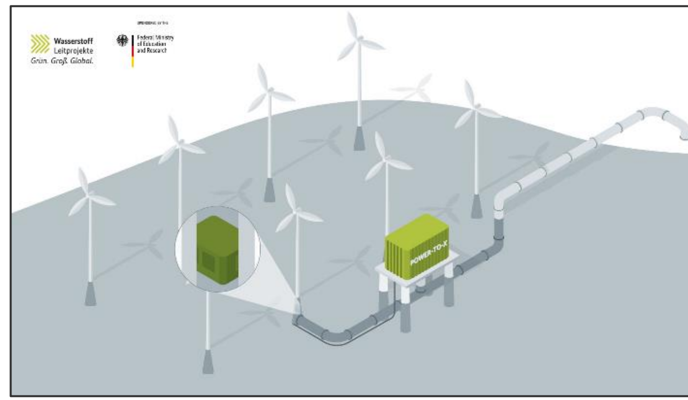
- Deep learning-based anomaly detection techniques
- Reliability analysis for networked automation systems

Research Area: Digital Twin for automation systems

How can the digital twin help to master the complexity of cyber-physical systems in engineering and operation?

Research topics at the IAS

- 5G-based Intelligent Digital Twin
- Autonomous reconfiguration management of software-defined systems
- Digital Twin for autonomous systems control using automatic adaptation and execution of simulation models
- Fallback teleoperation for offsite autonomous systems



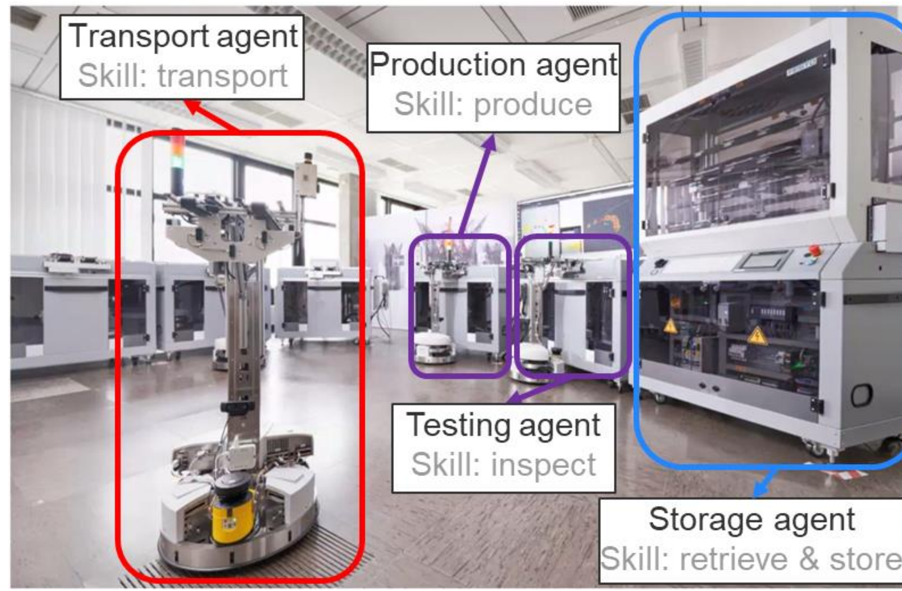
New

Research Area: Intelligent Automation and Autonomous Systems

Can GenAI and federation transform automation by extracting insights while safeguarding privacy?

Research topics at the IAS

- Knowledge discovery in heterogeneous and unstructured data
- Generative AI:
  - Large Language Models for controlling automation systems
  - Generative Adversarial Networks for synthetic training data
- Federated machine learning for privacy preserving automation

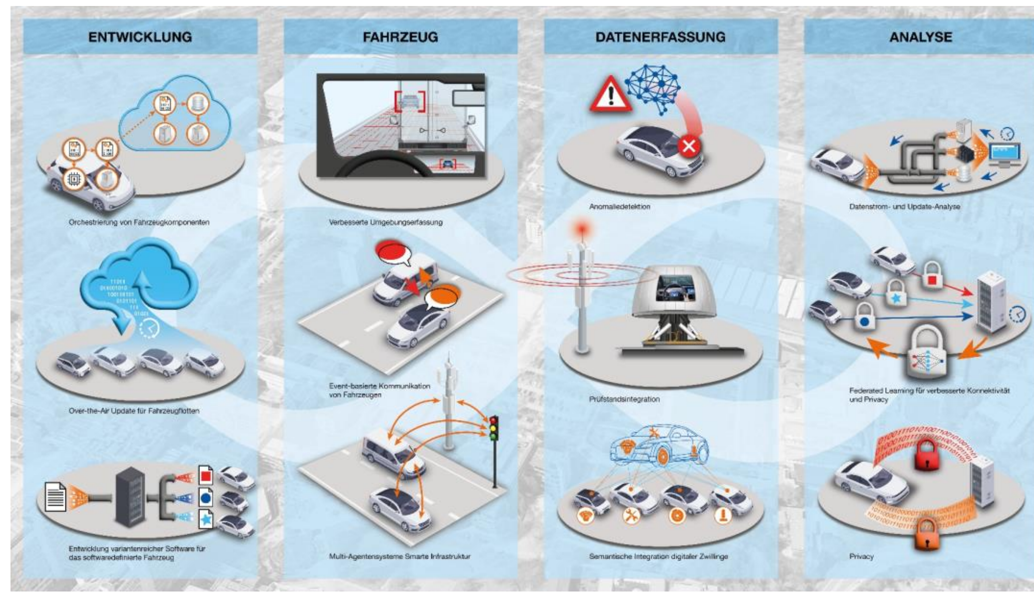


Research Area: Complexity control in automation technology

How can the complexity of software-defined systems be made manageable in engineering and operation?

Research topics at the IAS

- Training and validation of autonomous systems based on synthetic data
- Software-Product-Line-based variant management
- Test-driven development of software-defined mechatronic systems
- Continuous integration, development and deployment for automated systems (CI/CD)

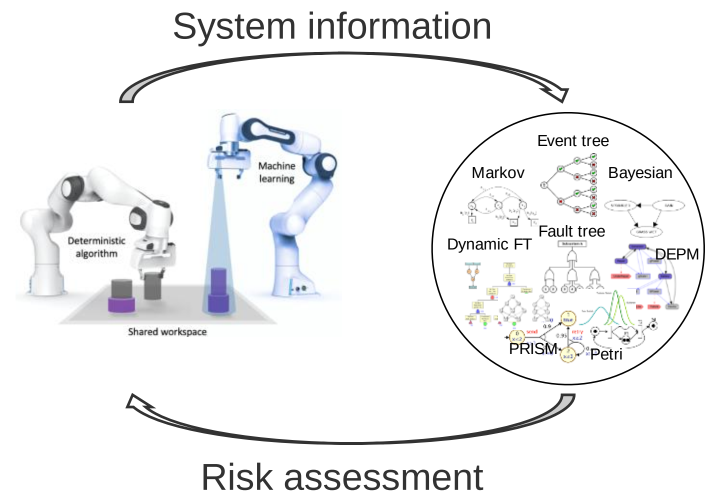


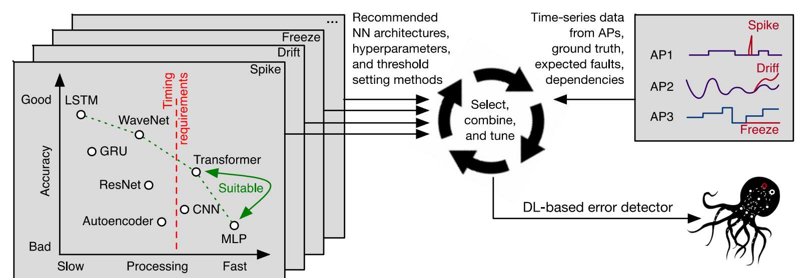
Research Area: Risk analysis and anomaly detection for networked automation systems

How to analyze risk of flexible manufacturing systems and how to exploit the deep learning method to efficiently detect anomalies of Industrial Cyber-Physical Systems?

Research topics at the IAS

- Combination of risk anlysis models.
- Automated, model-based generation of risk models each time the system is repurposed.
- Skill-based approach to risk analysis.
- Evaluation of DL architectures
- Deployment of anomaly detectors on special purpose embedded boards.





IAS in the Research Environment of Stuttgart

Universität Stuttgart

The Institute follows the mission statement "**Intelligent Systems for a Sustainable Society**" and is part of the **Excellence Strategy of the University of Stuttgart**.

Our flag ship projects:

- Leading Univ. of Stuttgart Team of 8PIs in the BMWi flagship project

SofDCar
SofDCar Consortium
We are paving the way for the software-defined vehicle.

- BMBF flagship initiative: H2Mare

We are part of the profile areas and emerging fields of the excellence strategy

- Associated in:

University of Stuttgart
Cluster of Excellence Integrative Computational Design and Construction for Architecture (IntCDC)

We are active in the following organizations:

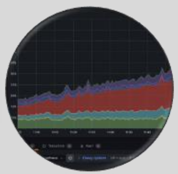
ARENA2036	Research Factory
Technologie Transfer Initiative	Technology Transfer Initiative
INNOVATIONCAMPUS FUTURE MOBILITY	Innovation Campus Future Mobility
GS-IMTR	Graduate School Intelligent Methods for Test and Reliability
GSaME	Graduate School of Excellence advanced Manufacturing Engineering

Model Processes at IAS

The model processes are used to represent special automation technology and to demonstrate the capabilities of software systems.

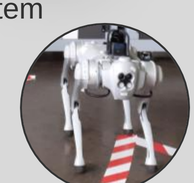
Intelligent Automation & Autonomous Systems

CI/CD OTA Update Deployment

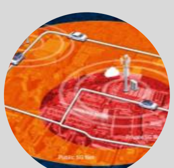


Vehicle Backend Diagnosis

Cyber-physical production system



Robotics AI - RobotDog

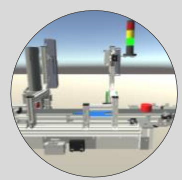


Function orchestration in 5G Networks

Intelligent Digital Twins for Automation Applications

Digital Twin of Offshore-PtX-Plattforms

Digital twin of a modular production system



Automatic Creation and Adaption of Simulation models

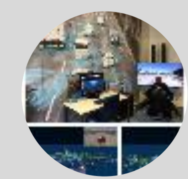
Digital Truck Twin

Reliability of Automation Systems

Intelligent Test of autonomous systems

Franka Emika Robots

SafeLegs: Safe exoskeleton



Scenario-based testing of autonomous driving functions

Cooperation with the following Companies

- CompWare Medical GmbH
- Mercedes-Benz AG
- NAiSE GmbH
- Festo AG & Co. KG
- Hirschvogel Umformtechnik GmbH
- iss (Innovative Software Services GmbH)
- OTTO FUCHS KG
- Robert Bosch GmbH
- Siemens AG
- SMS group GmbH
- Vector Consulting GmbH
- Vector Informatik GmbH
- Infineon Technologies AG
- ZF Friedrichshafen AG
- ETAS GmbH
- Nokia Corporation
- T-Systems
- Tyssenkrupp AG
- Siemens Energy

- Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V.
- INERATEC GmbH
- Astra Zeneca
- EKU Powerdrives

Maker Space

IAS supports various start-up companies and cooperates in research projects

synthavo	Machine parts detection application for higher product quality	since 2021 – Dez. 2023	**EXIST**
RoboTest	Validation and verification of highly automated and autonomous systems	since 2021	**VC**
NAiSE INDOOR NAVIGATION SYSTEMS	Indoor Navigation Systems	Jan. 2017 – Dez. 2017 Aug. 2019 – Juli 2022	**EXIST** **EUREKA-Projekt**
truphysics	Simulation and commissioning of robots in virtual reality	Apr. 2014 – März 2015 März 2016 – Feb. 2018	**EXIST** **Junge Innovatoren**
EKU	Create technologies that combine power generation with efficient control systems.	Juni 2014 – Mai 2015 Juni 2015 – Mai 2016	**EXIST** **Junge Innovatoren**

Prof. Weyrich is also the faculty's start-up officer and thus the first point of contact for those interested in starting a business.

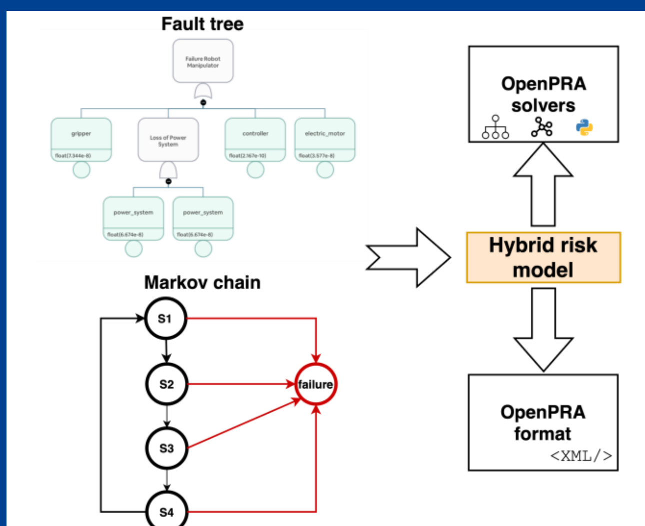
- **Research Activities**

OpenPRA: Probabilistisches Risiko Analyse Framework

Kombination von PRA-Methoden zur Analyse von vernetzten Automatisierungssystemen

Features:

- Holistic, easy-to-use and highly adaptable framework
- User-friendly web interface
- Collection of risk models, solvers and transformers
- OpenPRA format



How can we effectively combine PRA methods and integrate them into a framework?

International Community

- University of Stuttgart (DE),
- North Carolina State University (US)

PRA

https://openpra.org

Deep Learning basierte Anomalieerkennung

Dynamische Anomalieerkennung für vernetzten Automatisierungssystemen

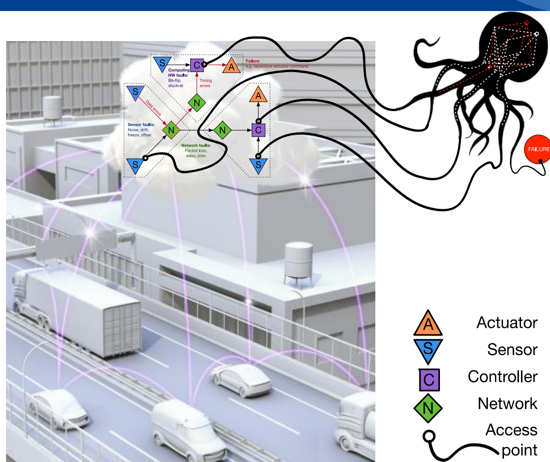
Requirements:

- Intelligent configuration of DLAD methods for networked automation systems

Core technologies:

- Deep Learning based anomaly detection
- Statistical features represent the context
- Model-based system analysis

How is anomaly detection intelligently applied in different system context?



Approach

- Evaluation of the most common types of errors.
- Evaluation of suitable DL architectures and hyperparameters.
- Combination of different DL architectures for efficient anomaly detection.
- Analysis of data flow, identification of access points.
- Integration into the SofDCar demonstrator.

SafeLegs Demonstrator: Safe Exoskeleton

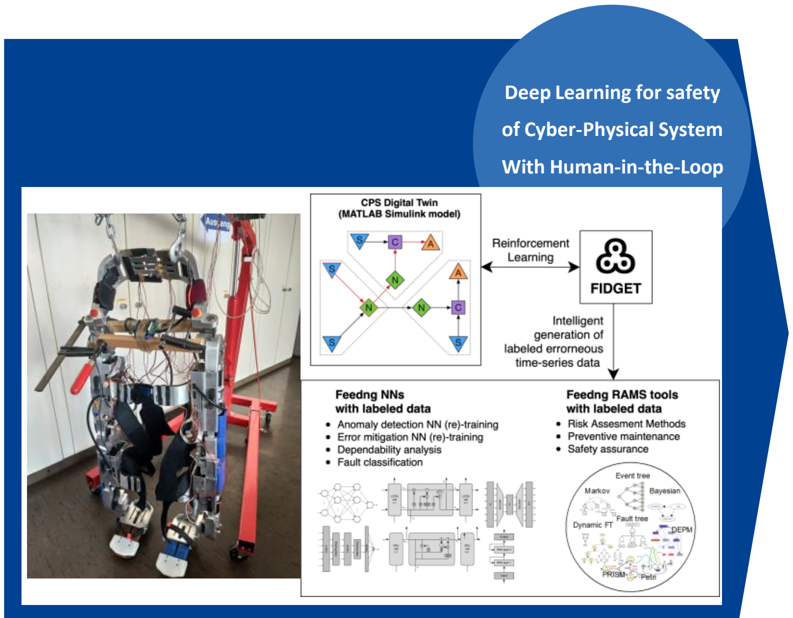
Safety-Critical Demonstrator for Cyber-Physical Systems with Human-in-the-Loop

Requirements:

- Portable robotic systems have their own hardware limitations and human safety challenges that are perfect for safety tool testing

Core technologies:

- Hardware-based fault detection and mitigation through transfer learning
- Biomechanics of wearable robotics
- Model-based fault injection controlled by reinforcement learning



Motivation

- A safety-critical system for the development and testing of Deep Learning-based safety methods

Approach

- MATLAB Simulink model of SafeLegs for model-based safety tools
- Hardware SafeLegs demonstrator for tests in real application scenarios

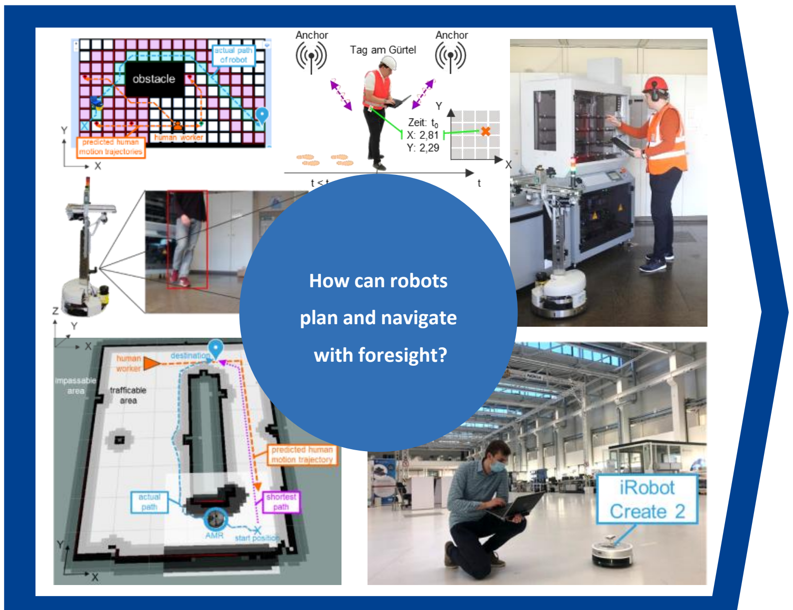
Trajectory predictions for AGV and AMR
Mobile robots act with foresight in dynamic environments

Requirements:

- Acquisition of dynamics in the environment
- Provision of trajectory predictions
- Enhancement of navigation algorithms of mobile robots

Core technologies:

- Ultra-Wideband Real-Time Locating System (RTLS)
- Pattern- and Planning-based trajectory prediction
- D*-pathfinding, ROS Navigation Stack



Motivation

- AGV and AMR are easy to integrate and extremely flexible, BUT thus certainly always slow and therefore inefficient

Approach

- Detecting the environment via RTLS sensor technology
- Prediction of the trajectory of dynamic obstacles by LSTM, 2D-CNN and knowledge-based methods
- ➢ Optimization AGV, AMR by understanding the environment

Safeguarding autonomous systems in operation

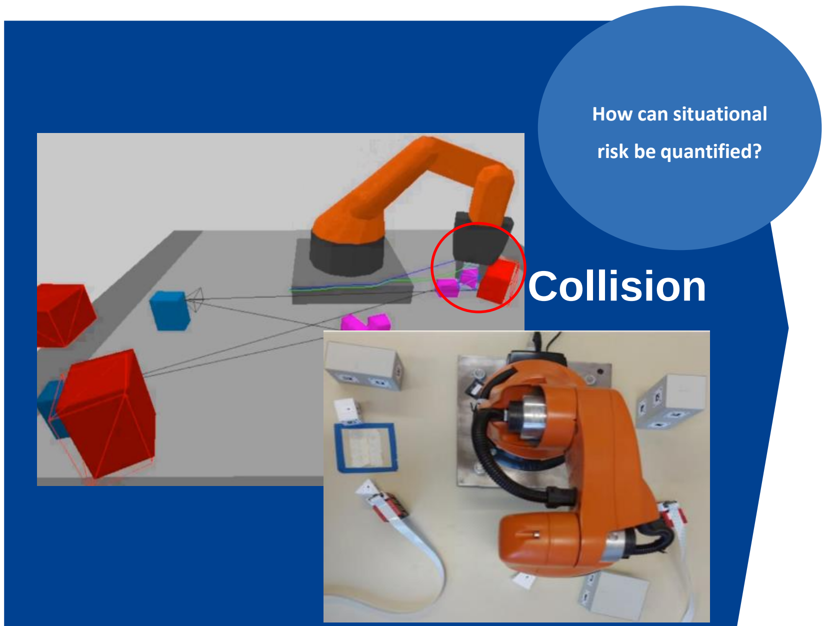
interpretable safety assessment of dynamic decision processes at runtime

Requirements:

- Analysis of trajectories in terms of their risk at runtime.
- Consideration of the situation within the risk assessment

Core technologies:

- Digital Twin
- Multi Agent Adversarial Reinforcement Learning (MAARL)
- Data Analytics



Motivation

- Avoid critical situations proactively
- Operational data contains information about the uncertainties arising from the situation

Approach

- Probability estimation of individual disturbance events
- Search of the most probable scenario, causing a harm with MAARL

➢ Data-driven optimization of the safety margin

Reliability analysis of SDM systems

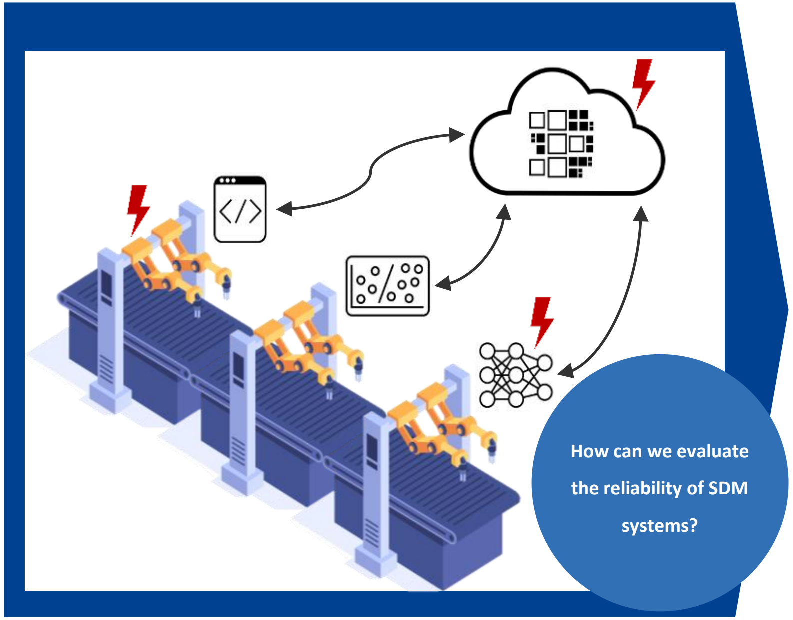
Model-based approach for continuous reliability assessment

Traditional approach:

- Manual risk analysis
- Traditional risk models
- Performed one time prior to commissioning

Core technologies:

- Advanced hybrid risk models
- Model-to-model transformation methods
- Automatic generation of hybrid risk models



SDM Challenges

- Frequent SW Updates
- Changeable production

SDM Approach

- Automated reliability analysis
- Dynamically before each SW update

7PP: 7-Piece Puzzle Robot Demonstrator

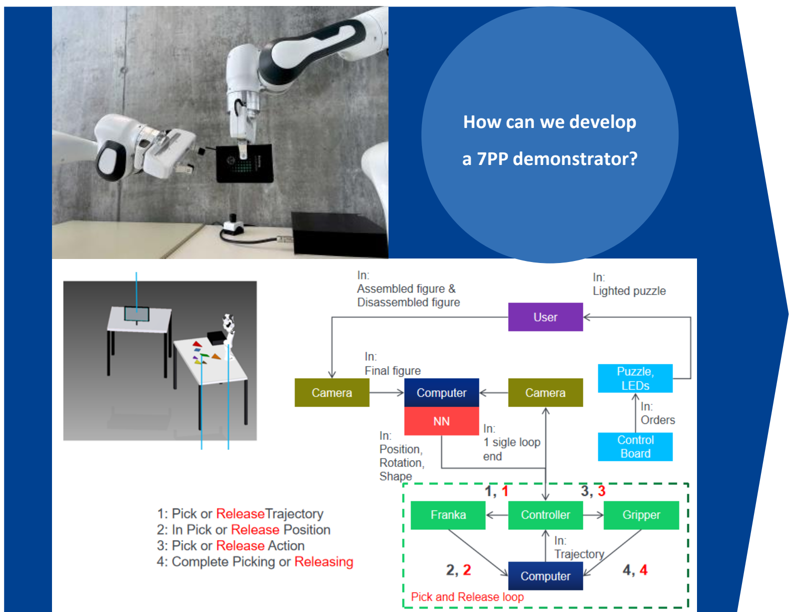
Design & development of concepts for modeling advanced industrial manufacturing

Requirements:

- Design & development of concepts for modeling advanced industrial manufacturing

Core technologies:

- Object recognition with the help of computer vision
- Trajectory planning for the manipulators



Approach

- With the 7-piece puzzle (tangrams) over 1600 figures can be created.
- Object detection to determine the position, angle and shape of each puzzle piece.
- Trajectory planning using the control interface, replication of the given figure.

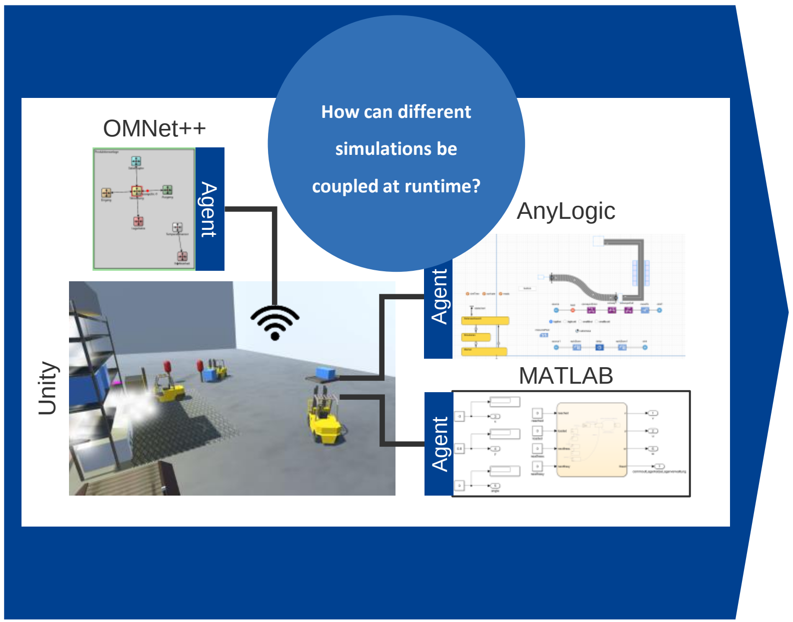
Co-Simulation (Cooperation with Vector Informatik)
Dynamic Co-Simulation of heterogeneous Internet of Things Systems

Requirements:

- „Plug-and-Simulate“-capable Co-Simulation of heterogeneous and dynamically changing IoT systems

Core technologies:

- Agent-based Co-Simulation
- Component- and Process modeling with MATLAB, AnyLogic, Unity, OMNet++, …



Approach

- Framework for coupling simulations via an agent system
- Connection of the simulations via interface adapters
- Service-oriented modeling of communication and physical processes
- Synchronization of the partial simulations via a central clock agent

New

Robust learning based on heterogeneous data

Knowledge generation in automation technology using data diversity

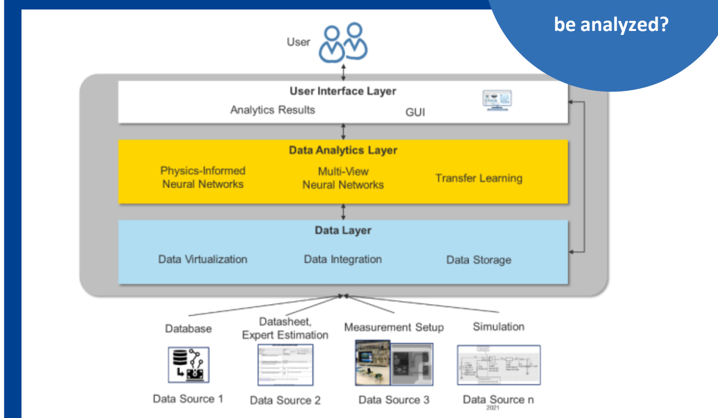
Requirements:

- Integration and uniform semantic description of heterogeneous data
- Analysis of unstructured and heterogeneous data for applications (e.g. failure analysis of electrical components in the FA4.0 project)

Core technologies:

- Data Virtualization
- Recent ML-Methods (Multi-Modal Neural Networks, Transfer Learning, Physics-Informed Neural Networks, Transformer-Based Models)

How can unstructured, heterogeneous data be analyzed?



Motivation

- Leverage existing data richness from disparate, dynamic sources to perform data analytics for applications

Approach

- Intelligent data integration from heterogeneous sources
- Connecting heterogeneous data, artificial intelligence as well as analytical models

➢ AI-based knowledge generation

Software-Defined Vehicles

Software strategies for the connected vehicle of the future

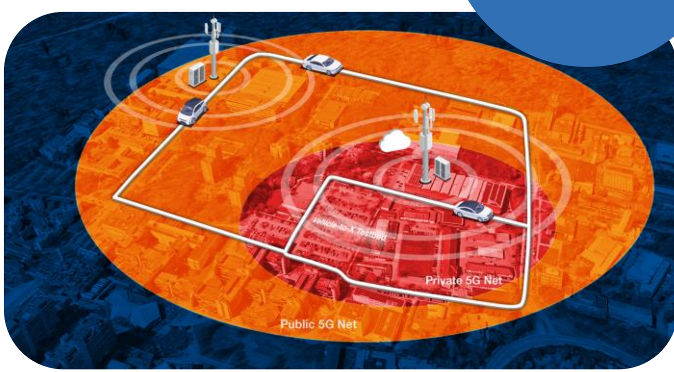
Requirements:

- Realization of short update cycles and robust, dynamic analysis processes
- Optimization of backend and vehicle resources
- Understanding runtime dependencies

Core technologies:

- Intelligent Cloud/Edge Backend
- Data Loop and Data Lake
- Real-time Digital Twin

How can the software-defined vehicle of the future be realized?



Motivation

- The share of software in automobiles and its complexity is increasing
- System participants are increasingly connected, a global exchange of data is strived for

Approach

- Data aggregation and dependency linkage
- Anomaly and causality detection
- Function offloading by runtime orchestration

New

Model Adaption in Digital Twins of Modulare Production Systems

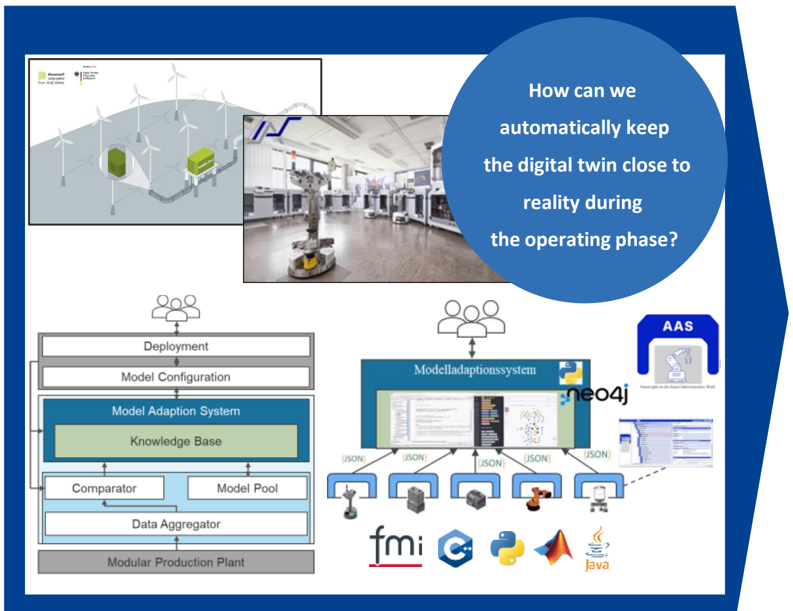
How can the digital twin be kept close to reality during the operating phase?

Requirements:

- Automatic coupling and parameterization of simulation models
- Increasing the use and reusability of digital twins during operation phase

Core technologies:

- Intelligent Digital Twin
- Large-Graph Models, Asset Administration Shell
- Service-oriented model adaption architecture



Motivation

- Changes in the operating phase require an adaption of the digital twin
- Model adaption becomes complex due to the heterogeneous models and lack of knowledge

Approach

- Automatic adaptation and execution of simulation models for the respective use case
- Knowledge-graph modeling for the dynamic query and generation of simulation configurations

New

Synthetic data generation for machine trained models

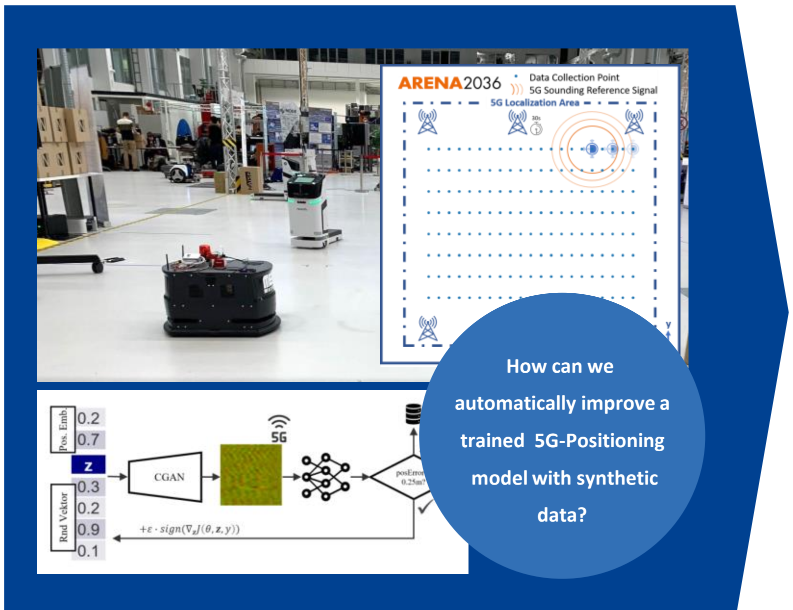
How can industrial machine learning models be trained with less real data?

Requirements:

- Automated generation of synthetic training data for improving trained models
- Generated data is relevant and challenging for the model

Core technologies:

- Generative Adversarial Networks
- Adversarial Attacks
- Large Vision Models



Motivation

- Real labeled training data is scarce and expensive
- Human experts often don‘t know what kind of training data is missing for improving their models

Approach

- Generation of challenging data by generative adversarial networks and Large Vision Models
- Training with the generated data to improve models without collecting more real data

New

CI/CD of Variant-Rich Automotive Softwaresystems

Agile Development of Variant-Rich Software for the Future Automotive

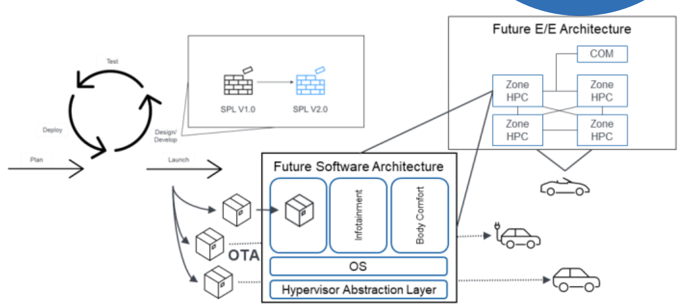
Requirements:

- Fast and Continuous Updates for the Vehicle of the Future
- Mastering Complexity by Managing Software Variance

Core technologies:

- CI/CD Pipelines
- Large Language Models (LLM)
- Software Product Lines

How to continuously develop and deploy variant-rich automotive software?



Motivation

- A Complex Transition Towards a Software-Defined Automotive Industry

Approach

- LLM assisted Software Product Line Engineering
- Over the Air Updates
- Decoupling of Hardware and Software through virtualization and standardized interfaces

Self-organized reconfiguration management

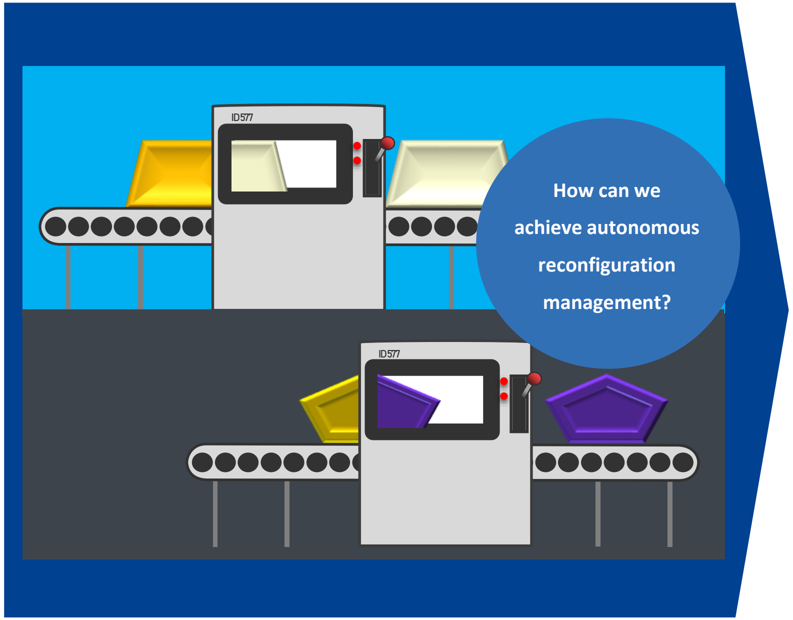
Decentralized, self-organized planning of automation systems

Requirements:

- Support of the planner in the rough planning phase of industrial automation systems

Core technologies:

- Agent technology (Self-organisation)
- Metaheuristics (layout optimization)



Approach

- Planning of an industrial automation system is modelled as a dialog-based process and applied to an agent system
- Agents represent resources and try to integrate them into the planned automation system
- ➢ Determination of possible constellations for the automation system to be planned

Deep Industrial Transfer Learning

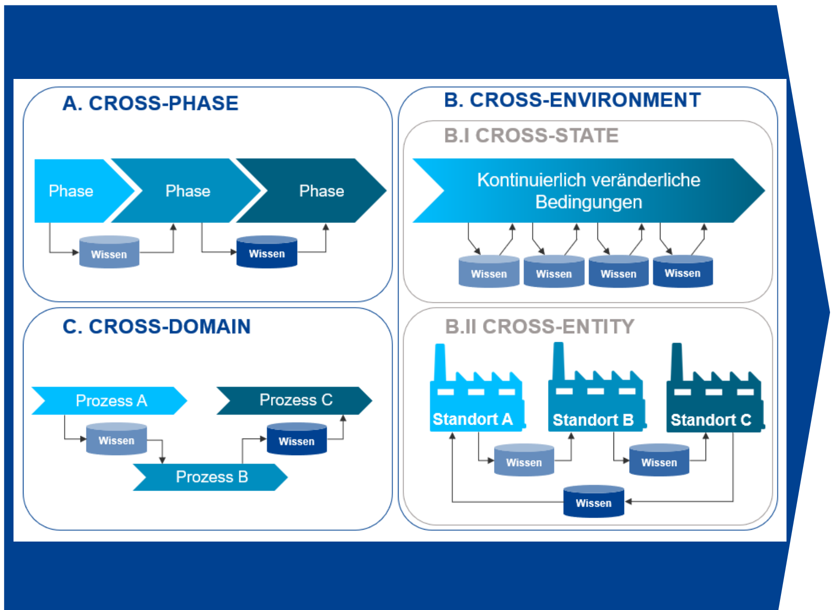
Learning automation systems with dynamic knowledge transfer

Requirements:

- Handling of input data (usually time series data) of different dimensions
- Solution of regression and classification problems

Core technologies:

- Two-stage deep neural network algorithm
- Representation database for storing and exchanging characteristic feature sets
- Client-to-client communication architecture



Motivation

Efficient learning despite

- data sets that are often small in everyday industrial life
- dynamic processes that require continuous updates of the learning model.

Approach

- Transfer of knowledge between algorithms that are able to learn

Requirements-based testing of autonomous systems

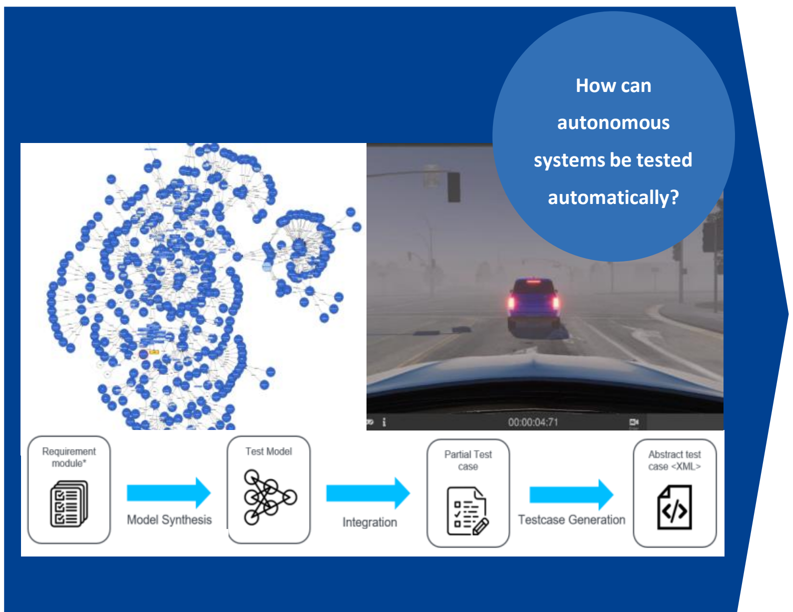
Automated validation and verification of autonomous systems

Requirements:

- Manufacturers announce concepts for autonomous systems, but tools are needed to secure them

Core technologies:

- Ontologies
- Synthetic data
- Data Analysis



Approach

- Ontologies for structuring requirements
- Derive relevant test cases from requirements
- Evaluate results based on KPIs

Autonomous System: Digital Twins and Large Language Models

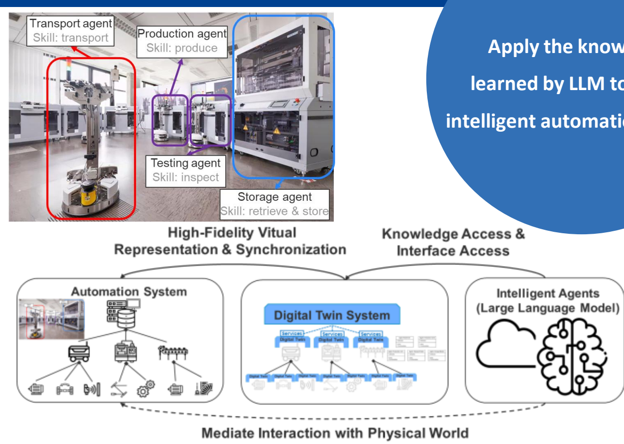
Integration and adaptation of LLM into automation systems

Requirements:

- Save human efforts in searching, interpreting information, and solving tasks.
- Higher degree of automation requires intelligence

Core technology stacks:

- Large Language Models
- Digital Twins
- Automation Systems
- Domain Knowledge in Production Technology



- Interacting with physical world

- Information models
- Service interfaces
  - Query
  - Control

- **Interpreting semantics**
- Reasoning
- Knowledge

Apply the knowledge learned by LLM to enable intelligent automation system.

Motivation

- Develop a dedicated LLM-System to solve complex tasks in the domain of industrial automation
- Intuitive human machine interaction

Approach

- Prompting, Retrieval Augmented Generation, Fine-tuning
- Different design paradigms to create LLM-powered software system for knowledge management, planning & control, reasoning & diagnosis, and HMI

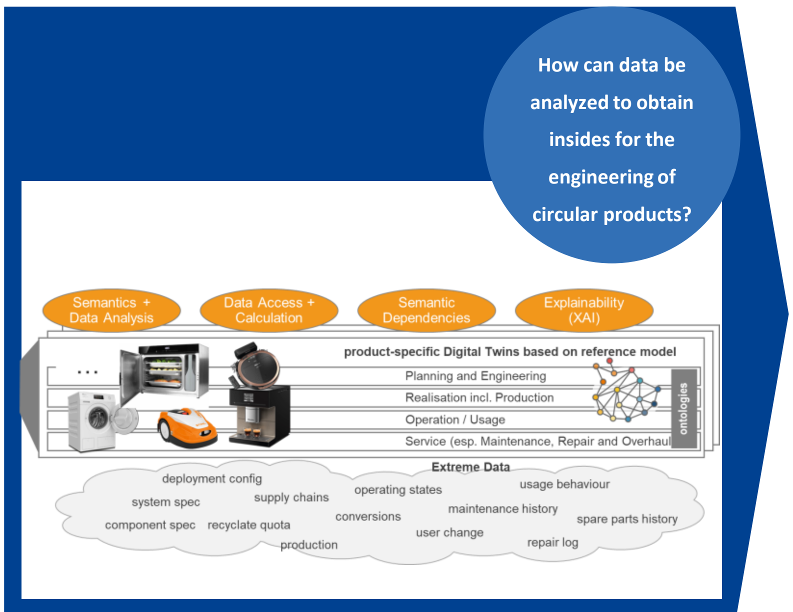
Automatic Assistance Systems for the Circular Economy
How can information circularity be achieved?

Requirements:

- Gathering and structuring data over the lifecycle of a product
- Enrich lifecycle data by means of machine learning

Core technologies:

- Data Models for Lifecycle Data (enhanced Ontologies, Intelligent Digital Twin)
- Large Language Models
- (Physics-Informed) Neural



Motivation

- Enriched Lifecycle Data available in a structured way and allow the user to easily access it

Approach

- Intelligent data integration over the lifecycle by ontologies and intelligent digital twins
- Enriching data by machine learning
- Allow easy interaction with the data model via LLMs
- ➢ AI-based Information Circularity Assistant

University of Stuttgart

Institute of Industrial Automation and Software Engineering

Pfaffenwaldring 47

70550 Stuttgart, Germany

Thank you!

Prof. Dr.-Ing. Dr. h.c.
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