Universität Stuttgart
Institute of Industrial Automation and Software Engineering

Research and Teaching at IAS

2022

Prof. Dr.-Ing. Dr. h. c. Michael Weyrich

Institute of Industrial Automation and Software Engineering (IAS)

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

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

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

Prof Weyrich was appointed to the University of Stuttgart in April 2013.

Jun.-Prof. Morozov (TT) was appointed to the University of Stuttgart in April 2020.

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

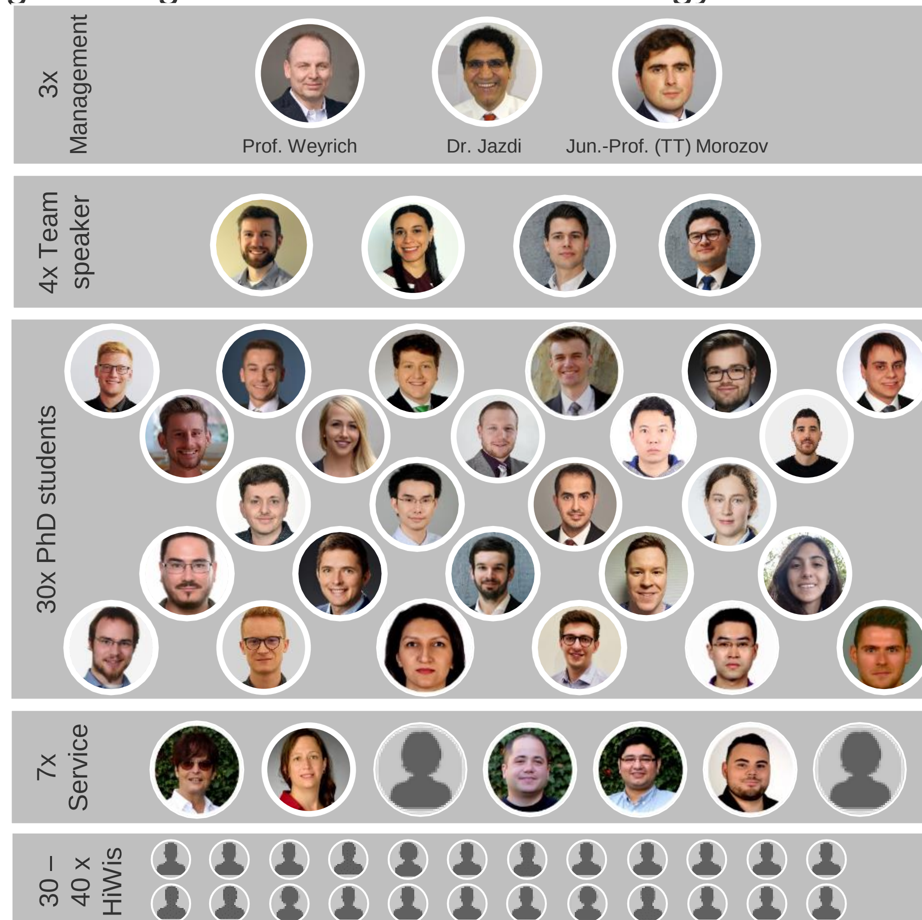
since 2020
Jun.-Prof. A. Morozov
Networked Automation Systems

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

- 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

- Multidimensional Synchronization of Digital Twins
- Automatic reconfiguration management

Complexity control in automation technology

- Co-simulation of software-defined systems
- Variant management in development

Intelligent and learning automation systems

- Artificial intelligence and dynamic reliability
- Decentralized, cooperative machine learning in automation

Safety and assistance systems in automation technology

- Test of distributed components
- Safeguarding autonomous systems

Risk analysis and anomaly detection for networked automation systems

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

Research Area: Complexity control in automation technology

How can the complexity of cyber-physical systems be made manageable in engineering and operation?

Research topics at the IAS

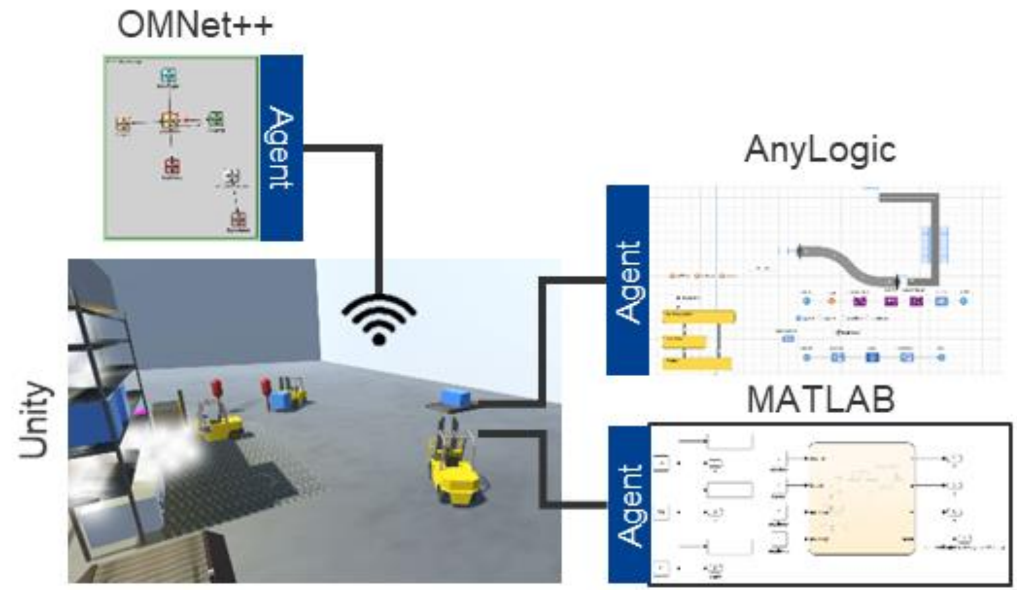
- 5G-based Intelligent Digital Twin
- Co-simulation of software-defined automated systems
- Autonomous reconfiguration management of software-defined systems
- Multidimensional synchronization of digital twins for different applications

Research Area: Complexity control in automation technology

How can the complexity of cyber-physical systems be made manageable in engineering and operation?

Research topics at the IAS

- Co-simulation of software-defined automated systems
- Variant management in development

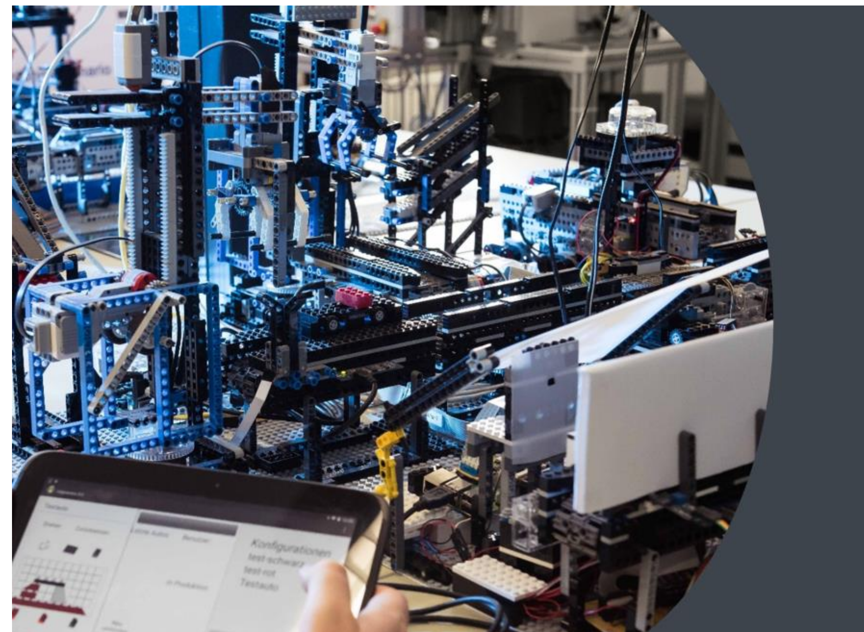


Research Area: Intelligent Automation and Autonomous Systems

Are technical systems of tomorrow going to automate themselves?

Research topics at the IAS

- Dynamic Intelligent Reliability
- Optimization of automation systems using machine learning
- Intelligent automation for user-oriented
- Soft sensors for networked automation architectures
- Decentralized, cooperative machine learning in automation
- Simulation of autonomy concepts

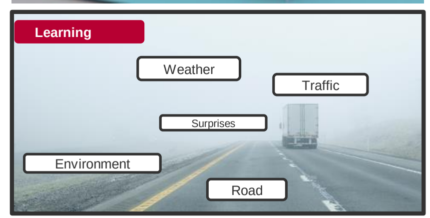


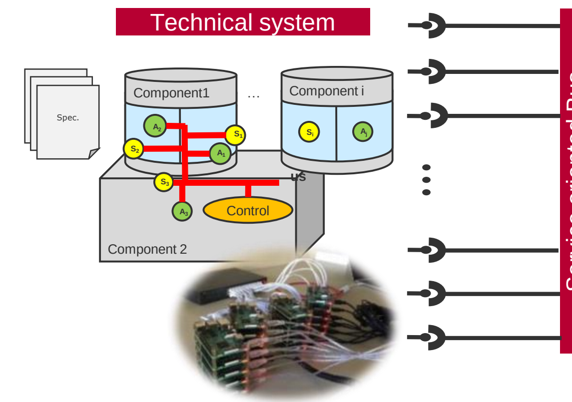
Research Area: Safeguarding of automation systems and components

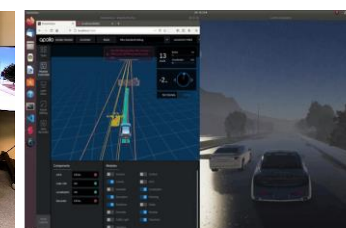
How can we rely on the quality of automated systems in terms of reliability, safety and availability?

Research topics at the IAS

- Dynamic reliability calculation
- Testing of distributed components
- Verification and validation of software updates
- Safeguarding of autonomous systems
- Cognitive sensor networks in safety-relevant systems





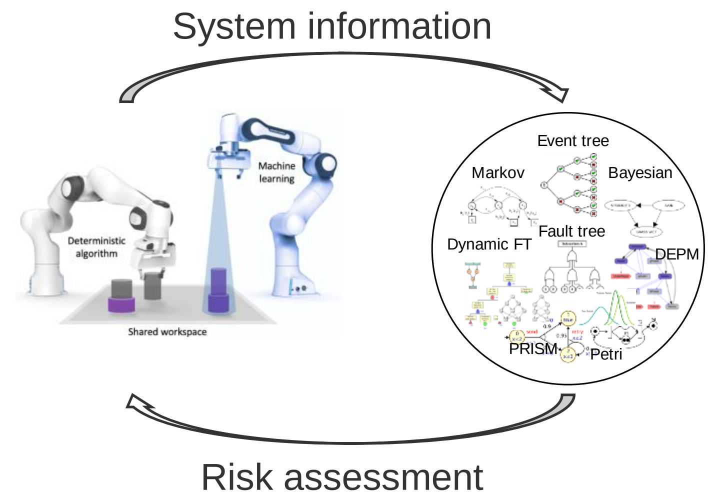


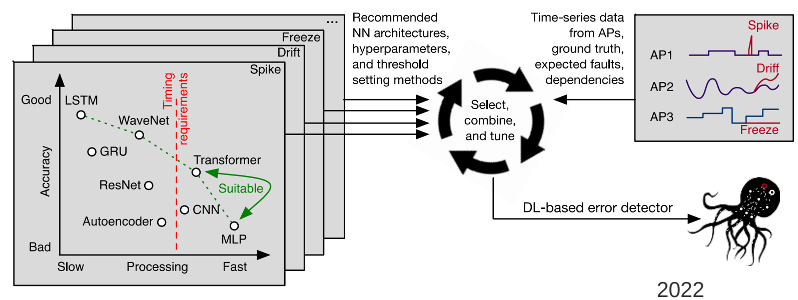
Research Area: Risk analysis and anomaly detection for networked automation systems

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

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

Institute of Industrial Automation and Software Engineering

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

- Autonomous systems
- Architecture and adaptive building
- Production technologies
- BMWi flagship initiative: SofDCar
- BMBF flagship initiative: H_2Mare

Universität Stuttgart

ARENA2036 — Research Factory

CyberValley — Intelligent Systems

Technologie Transfer Initiative — Technology transfer

Model Processes at IAS

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

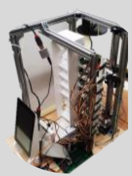
Intelligent Automation & Autonomous Systems

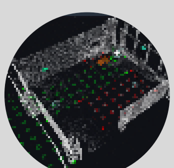
Intelligent Warehouse (ARENA 2036)

Data Analytics in Manufacturing

Cyber-physical production system

Context aware pill dispenser





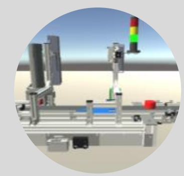
Real-Time Locating System

Complexity control of CPS

Digital Truck Twin

Plug & Simulate

Simulation of plant modernization



Digital twin of a modular production system

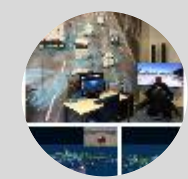
Reliability of Automation Systems

Intelligent Test of autonomous systems

Franka Emika Robots

SafeLegs: Safe exoskeleton

Scenario-based testing of autonomous driving functions



Maker Space

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

synthavo	Machine parts detection application for higher product quality	since 2021	**EXIST (approved)**
RoboTest	Validation and verification of highly automated and autonomous systems	since 2021	**VC (planned)**
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.

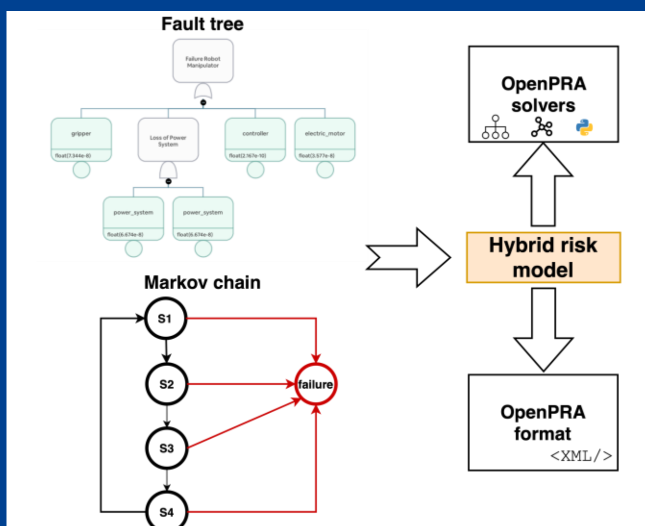
- **Research Activeties**

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

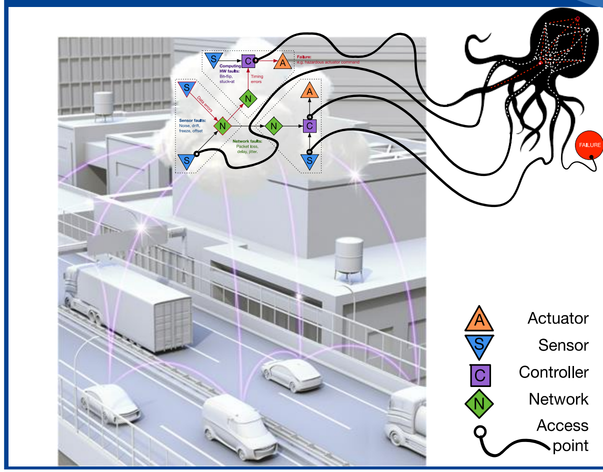
Requirements:

- 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

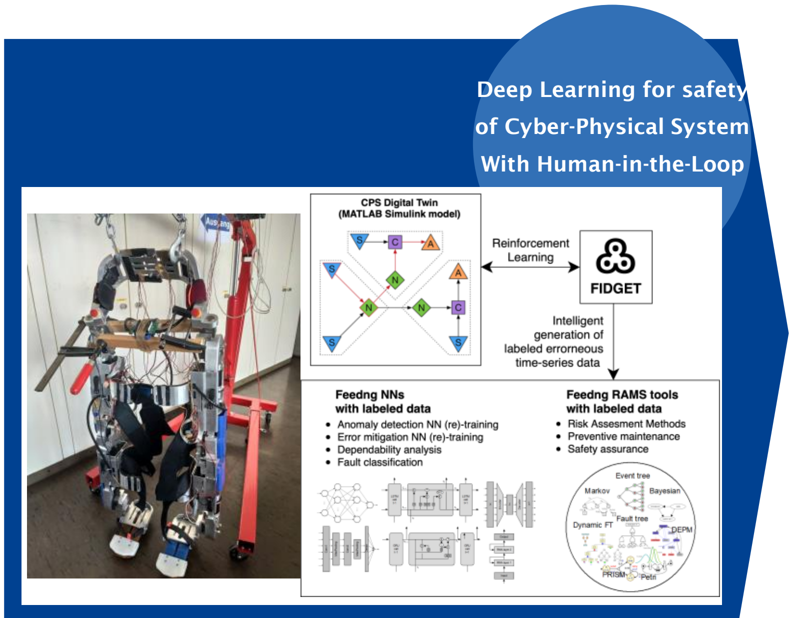
Safety-Critical Demonstrator for Cyber-Physical Systems with Human-in-the-Loop

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

Reliability analysis of SDM systems

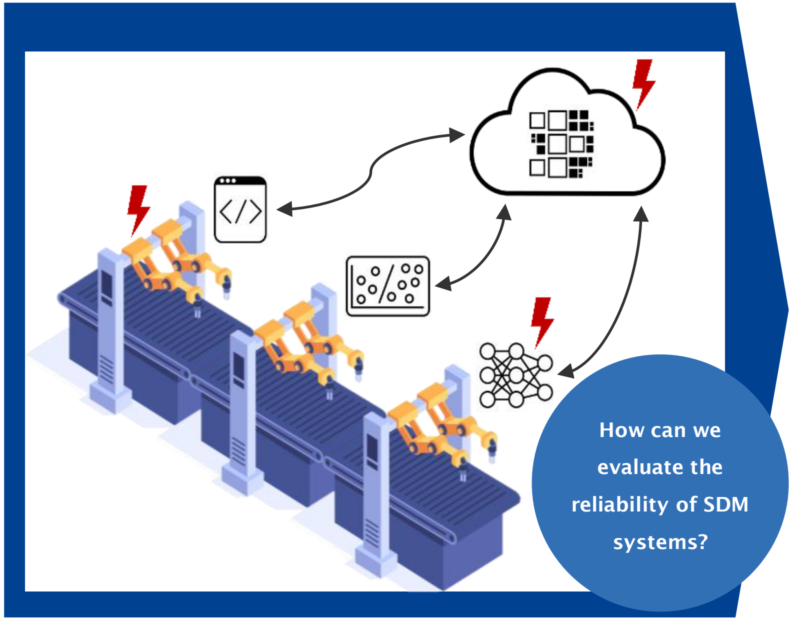
Model-based approach for continuous reliability assessment

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

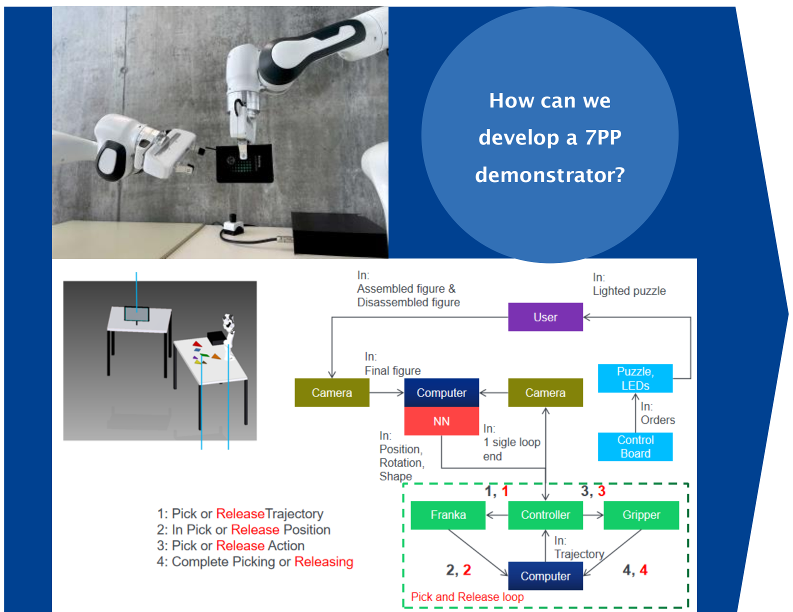
Design & development of concepts for modeling advanced industrial manufacturing

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.

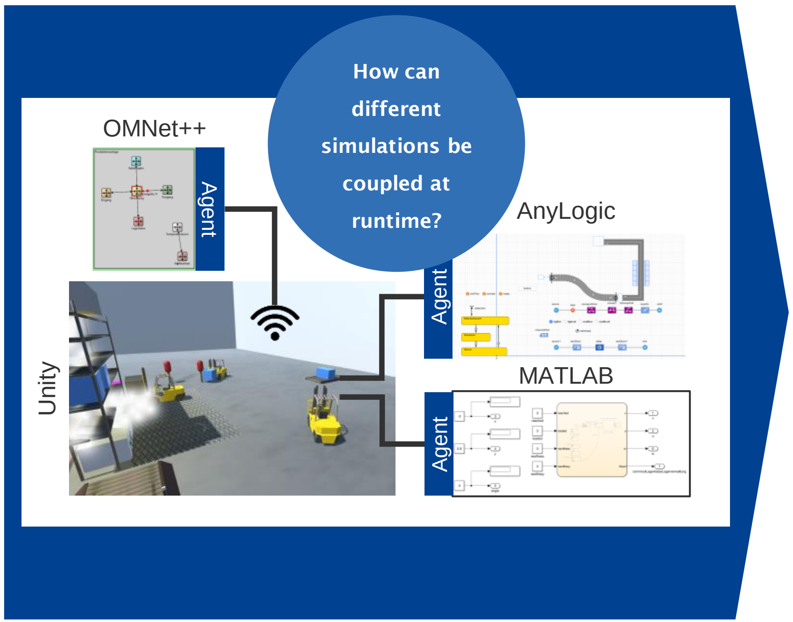
Co-Simulation (Cooperation with Vector Informatik)
Dynamic Co-Simulation of heterogeneous Internet of Things Systems

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

Robust learning based on heterogeneous data

Knowledge generation in automation technology using data diversity

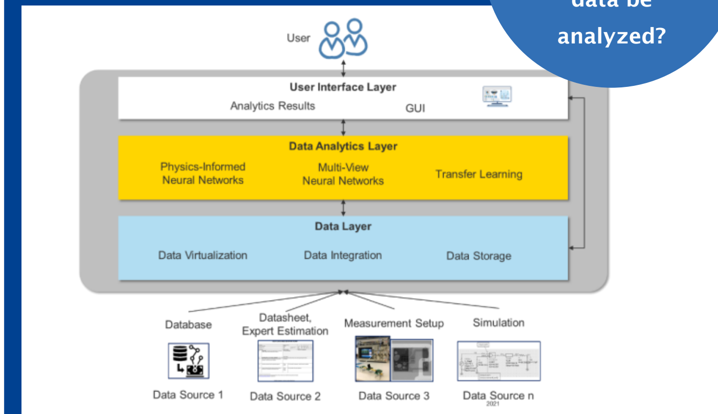
Requirements:

- 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
- ML-Methods (Multi-View Neural Networks, Transfer Learning, Physics-Informed Neural Networks, Graph Analytics)

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 cars

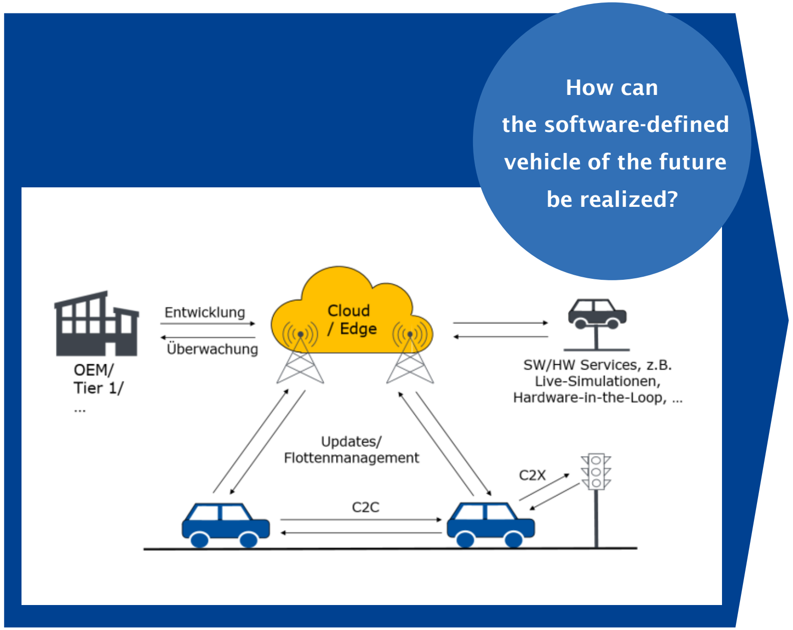
Software strategies for the connected car of the future

Requirements:

- Realization of short update cycles and robust analysis processes
- Reduction of the amount of data required for communication between traffic participants

Core technologies:

- Continuous Integration and Deployment
- Big Data Analytics, Deep Learning
- Decision making



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

- Extensible data aggregation
- Holistic analysis of heterogeneous data
- Automatisierte Fehlerbehebung und Optimierung

Application-optimized model adaptation

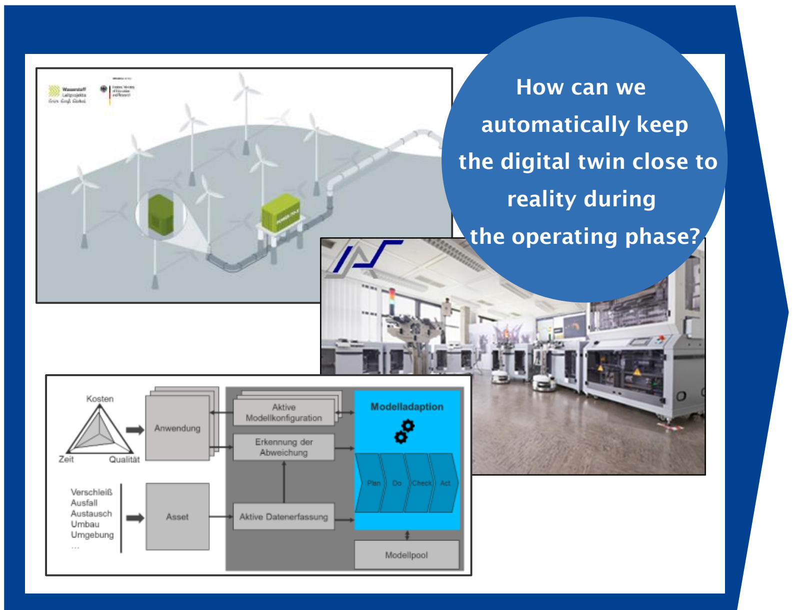
How can the digital twin be kept close to reality during the operating phase?

Requirements:

- Mastering the heterogeneous model landscape of modular plants
- Generation and optimization of application-oriented model configurations

Core technologies:

- PDCA cycle (methodology)
- Agent technology (self-organization)
- Knowledge Graphs (Knowledge Modeling)



Motivation

- Unforeseen changes require model adaptation
- Model adaptation becomes complex due to the heterogeneous model landscape

Approach

- Automatic generation and optimization of application-oriented model configurations
- Suitable knowledge modeling for automatic model adaptation

Synthetic data generation for machine trained models

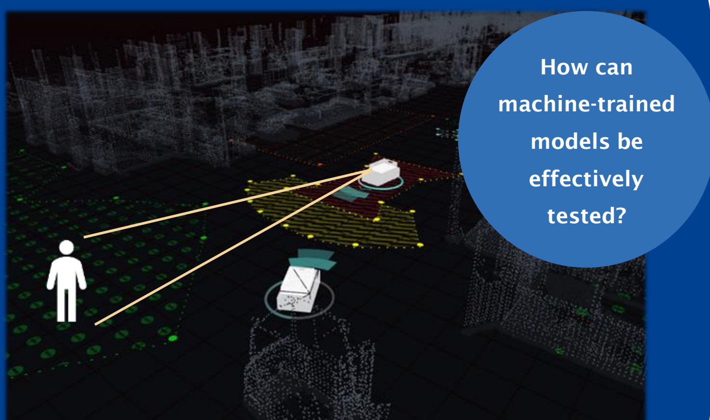
Generation of new challenging data through optimization processes

Requirements:

- Automated generation of data for further training of learning models
- Generated data is relevant and challenging for the model

Core technologies:

- Machine learning
- Generative Adversarial Networks
- Numerical optimization methods



Motivation

- Menschliche Experten können schlecht einschätzen welche konkreten Daten für ein maschinell trainiertes Modell herausfordernd sind

Approach

- Generation of challenging data by generative adversarial networks and numerical optimization methods
- Training with the generated data to close cognition gaps

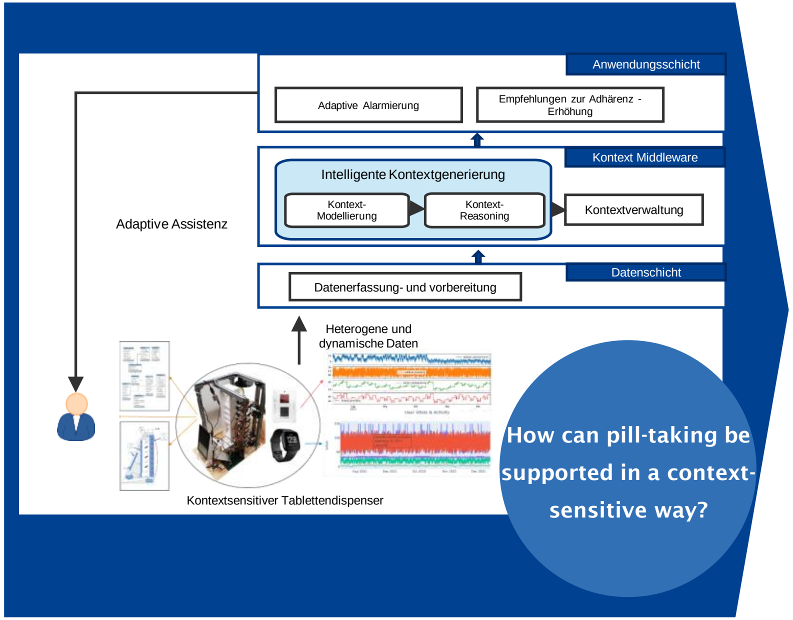
Context-aware cyber-physical systems using the example of adaptive user support in the health sector

Requirements:

- Acquisition, modeling, and analysis of heterogeneous data around a cyber-physical system to derive applicable knowledge.

Core technologies:

- Hybrid context modeling
- Middleware-based architecture
- Graph algorithms for consistency checking of time-based context models



Approach

- Acquisition of heterogeneous and dynamic data for context modeling (system parameters, environment parameters, user data, etc.)
- Middleware-based architecture for scalable reuse of the context model by applications and services.
- Use case: development of a pill dispenser as an IoT approach with context-adaptive user support

Deep Industrial Transfer Learning

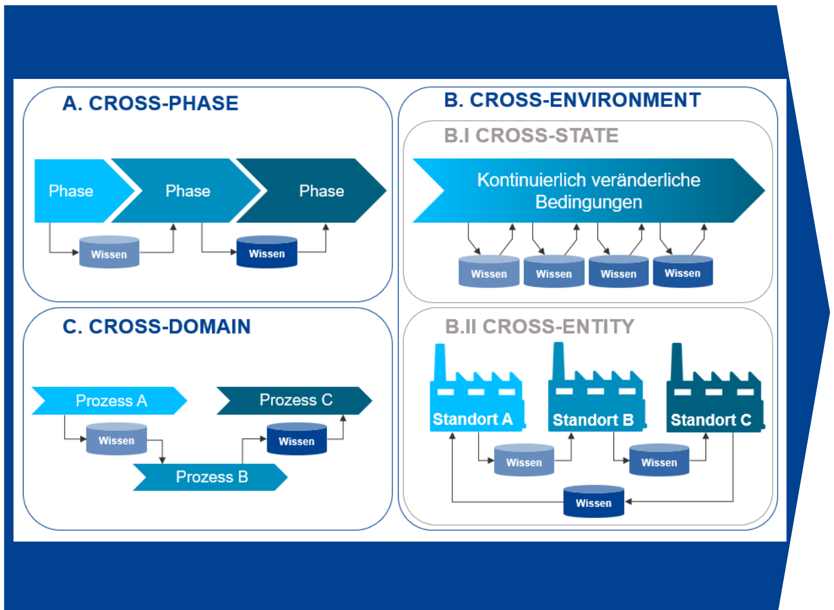
Learning automation systems with dynamic knowledge transfer

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

New

Automated variant management

Generation of system architectures in systems engineering

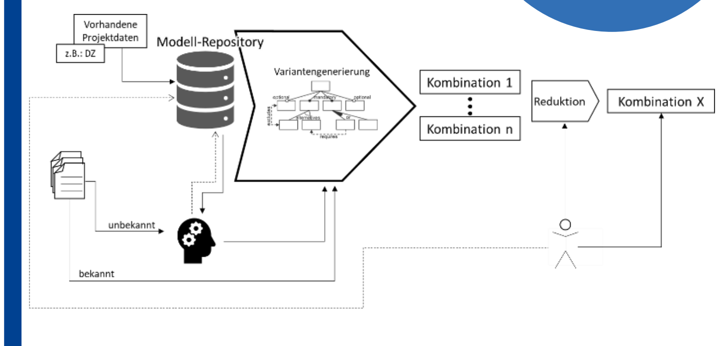
Requirements:

- Complexity control in variant management
- Assistance for the system engineer

Core technologies:

- Feature Oriented Domain Analysis
- 150%-Modell
- Data Analytics

How to create approximately all variants of a system and select one?



Motivation

- As systems become more complex, the solution space for system development becomes unmanageable

Approach

- Model repository for known relationships and patterns
- Use of an appropriate methodology for variant management
- Model and data based variant generation

Trajectory predictions for AGV and AMR

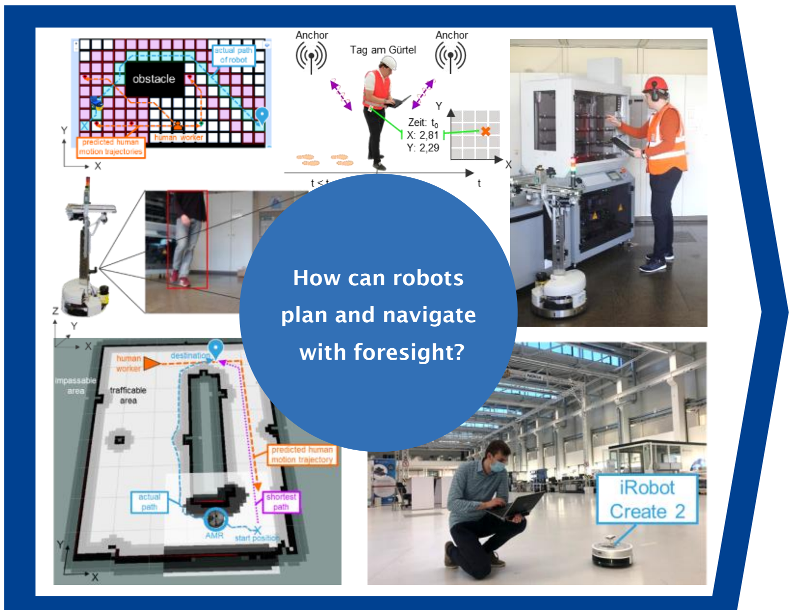
Mobile robots act with foresight in dynamic environments

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

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Thank you!

Prof. Dr.-Ing. Dr. h. c. Michael Weyrich

e-mail michael.weyrich@ias.uni-stuttgart.de
web www.ias.uni-stuttgart.de
phone +49 (0) 711 685-67301
fax +49 (0) 711 685-67302

University of Stuttgart
Institut für Automatisierungstechnik und Softwaresysteme

Pfaffenwaldring 47
70550 Stuttgart