Agent based technologies for flexible automated manufacturing systems (AbaMS)

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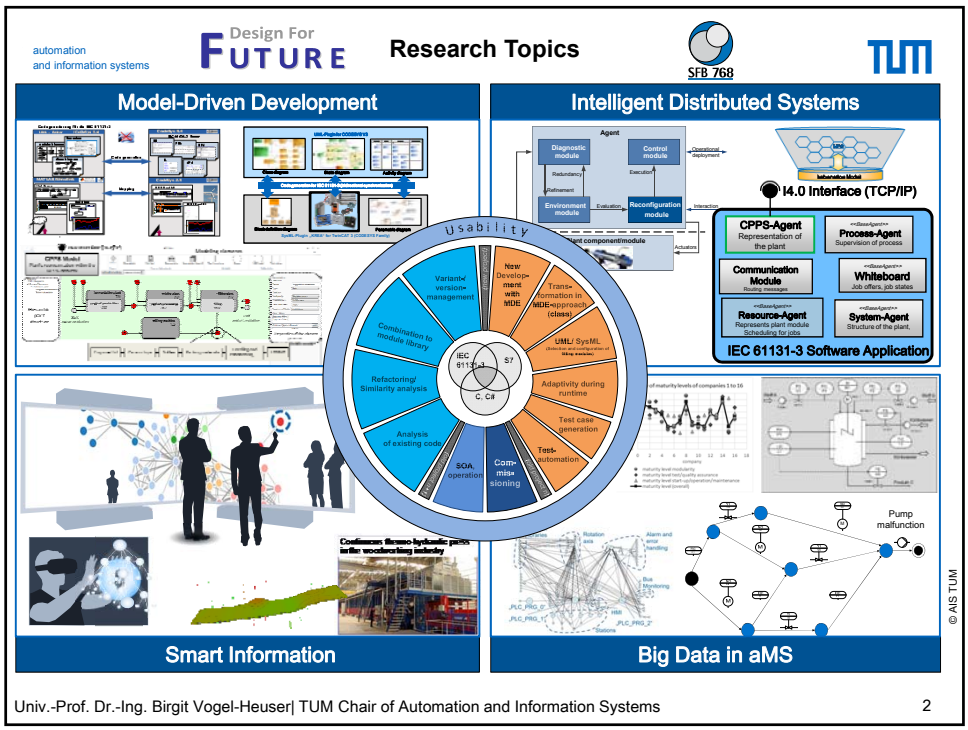
The Digital Transformation of Manufacturing Industries – Revolution or Evolution?
November 22-24



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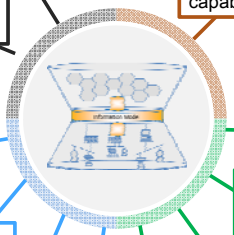
Cyber-Physical Production Systems (CPPS) – Industrie 4.0

Data processing for humans

- **Assistance systems for Engineering**
- **Data processing and integration for humans**

Architecture models (reference architecture) for a category of aggregation/modules related to properties, capabilities, interfaces…



Communication and data consistency

- **Appropriation of necessary data** for configuration, production, negotiation
- **World wide distribution** of data, **high availability, access protection**
- **Data consistency** about different „stakeholders" in different engineering phases and crafts
- **Digital networks** and interfaces for communication (between machine, human and plant, plant and plant)

Intelligent products and production units

- Production units with **inherent capabilities**
- **Data analysis** of process and alarm data and connection with engineering data
- **Flexible production units**, **adaptable** to modified product requirements, allow also structural changes
- **Description of product and operating resources**, e.g. ontology, for independent analysis, presentation, organisation and execution of a production process

Source: B. Vogel-Heuser, G. Bayrak, U. Frank: Forschungsfragen in "Produktautomatisierung der Zukunft". acatech Materialien. 2012.

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Challenges in automated Manufacturing systems (aMS)

Challenges

- Increased Overall Equipment Effectiveness (OEE)
- Individualization of products and short product life-cycles
- in contrast „Long-Living" aMS
- Global competition

Availability

Degree to which a system or component is operational and accessible when required for use. (IEEE glossary)

Means

Reconfiguration, Recovery and Restartability

Flexibility

The ease with which a system or component can be modified for use in applications or environments (IEEE glossary)

Weaknesses of today's software engineering in aMS

software development for automation systems: Function-oriented, process-oriented, state-oriented, object-oriented

Engineering of system structure and behavior pre runtime, static software model

High dependency components
Failure of an element → downtime of aMS

Aim: Software systems that can react to situations that are not specifically provided during design phase => agents

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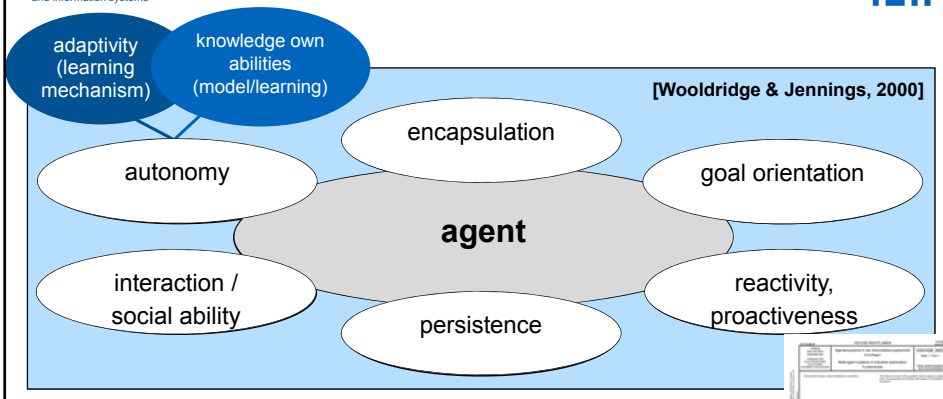
Properties of technical agents



A **technical agent** is an **encapsulated** (hardware/software) entity with **specified objectives**. An agent endeavours to reach these objectives through its **autonomous behaviour**, in **interacting** with its **environment** and with **other agents**.

Source: VDI-Standard 2653 Sheet 1, 2010

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Cyber-Physical Production Systems (CPPS) – Industrie 4.0

Data processing for humans

Assistance systems for Engineering

Prequisite for Industrie 4.0
- Reusable modular application software
- Variant and version management
- Enabling flexibility and availability

Architecture models (reference architecture) for a category of aggregation/modules related to properties, capabilities, interfaces…

Intelligent products and production units

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Flexible production units, **adaptable** to modified product requirements, allow also structural changes

Description of product and operating resources, e.g. ontology, for independent analysis, presentation, organisation and execution of a production process

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Source: B. Vogel-Heuser, G. Bayrak, U. Frank: Forschungsfragen in "Produktautomatisierung der Zukunft". acatech Materialien. 2012.

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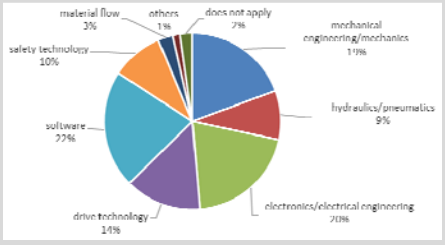
Modular software structures in aMS

Maturity level for
Procedures during development
Software and Reuse
Quality assurance
Handover to the customer
etc.

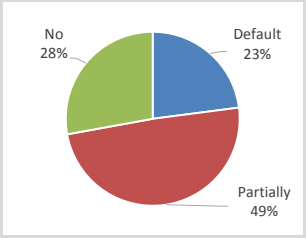
Classification of companies
Mechanical engineering companies (very broad field)
- Plant engineering companies
- Special-purpose engineering companies
- Others

Currently 71 leading german companies involved!

Modularization in different disciplines



Usage of mechatronic modules



Source: B. Vogel-Heuser: Status und Nutzen von Smart Data und Industrie 4.0. In: Automation Symposium, 2016.

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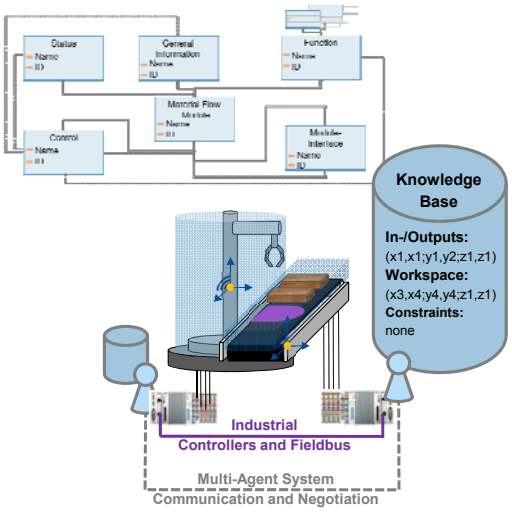
iSiKon – Software Agents for Intralogistic applications

Self-aware Module Agents



Research concept

- **Objectives:** Enable self-(re)configuration of intralogistics systems' modules
- **Challenges**: Model-based description of required module information, hard- and software constraints for plug&play
- **Approach:** Implementation of software agents (knowledge base) and multi-agent systems' (MAS) communication protocols
- **Results:** Software-agent design and implementation of distributed multi-agent systems based on IEC 61131-3 (PLC)
- **Benefit of agents:** Automatic synthesis of automation software out of existing intralogistic components

https://www.ais.mw.tum.de/en/research/current-research-projects/isikon/

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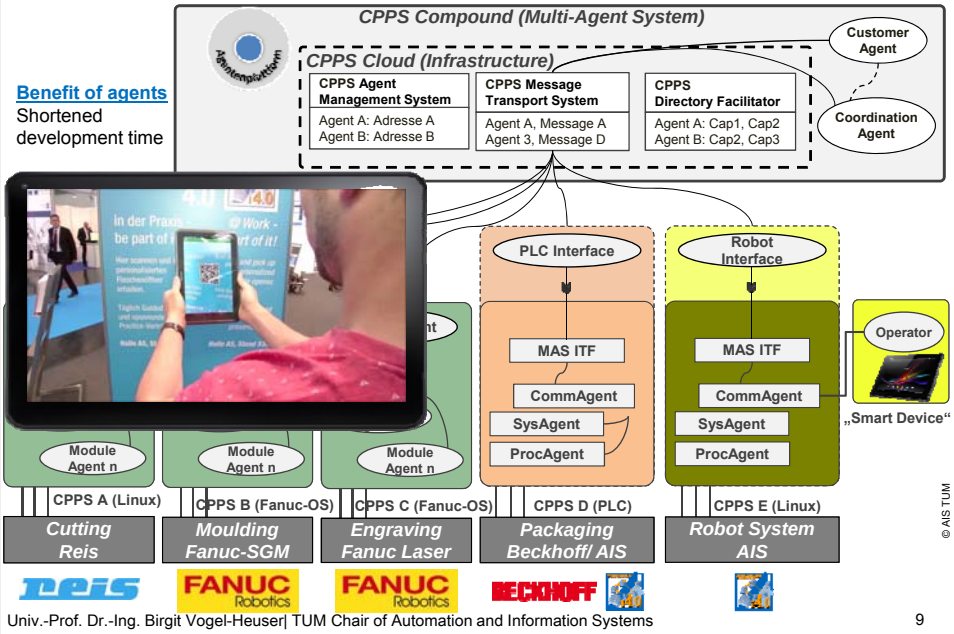
MAS based architecture- cooperation of heterogenous robots

Benefit of agents
Shortened development time



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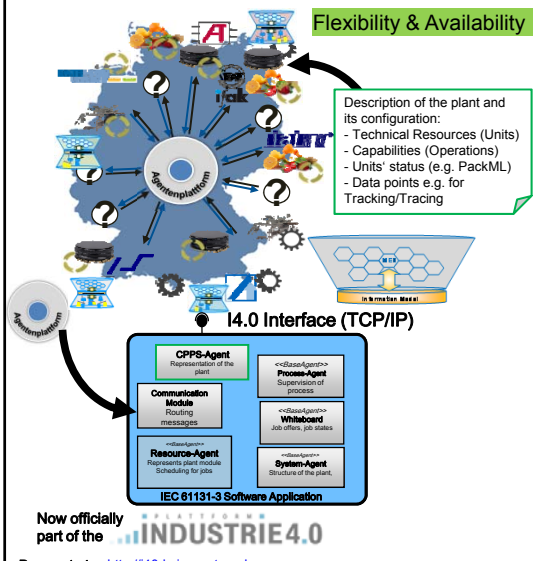
MyJoghurt – Established Demonstrator for Industrie 4.0
Agend based cooperation of heterogeneous machines



Now officially part of the PLATTFORM INDUSTRIE 4.0

Demonstrator: http://i40d.ais.mw.tum.de
Roadmap: http://www.plattform-i40.de/I40/Navigation/DE/In-der-Praxis/Karte/karte.html

Research concept

- **Objectives:** Improve flexibility and reliability of machines and plants
- **Challenges**: Reconfiguration during runtime to adapt to new products
- **Approach:** Model based approach with agents and product, process and resource description (ecl@ss, AutomationML, OPC-UA)
- **Results:** reconfiguration in case of a failure in between different plants run by different labs at german universities has been shown, concept for automatic adaption for new products based on ontologies is working
- **Benefit of agents:** Flexible network and communication structure of MAS for interaction between plants

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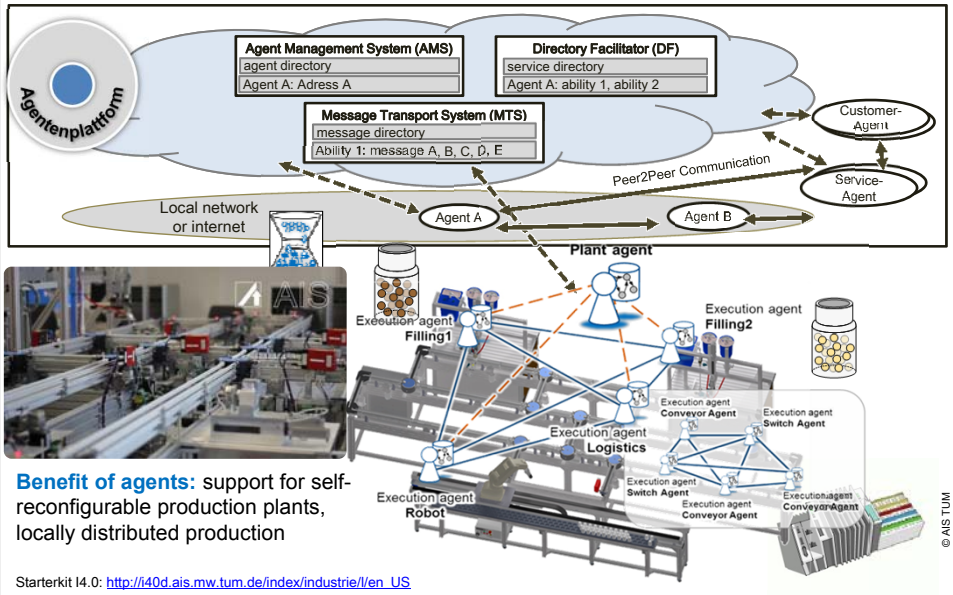
Flexibility based on SysML / OCL Model



Benefit of agents: support for self-reconfigurable production plants, locally distributed production

Starterkit I4.0: http://i40d.ais.mw.tum.de/index/industrie/l/en_US

Source: B. Vogel-Heuser: Herausforderungen und Anforderungen aus Sicht der IT und der Automatisierungstechnik. In: Industrie 4.0 in Produktion, Automatisierung und Logistik, Springer, 2014.

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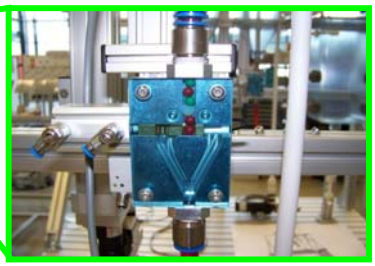
Flexibility – Ressource Model

- SystemUnitClassLib
  - Filling station {**Class:**}
    - Tank {**Class: Role:**}
    - Pellet dispenser {**Class: Role:**}
      - Pneumatic cylinder {**Class: Role:**}
        - Interfaces
          - Input Air Extend {**Class:** PortConnector}
          - Input Air Retract {**Class:** PortConnector}
          - Behaviour {**Class:** PLCopenXMLInterface}
      - Case {**Class: Role:**}
        - Interfaces
          - Geometry {**Class:** COLLADAInterface}



<AutomationML/>

- CAEX for structural desciption
- PLCOpenXML for behavioral description
- Collada for geometric description

Input Diameter	
Name	Input Diameter
Description	
Value	8
Default Value	
Unit	mm
DataType	xs:string
Attribute1	
Output 1 Diameter	
Name	Output 1 Diameter
Description	
Value	8
Default Value	
Unit	mm
DataType	xs:string
Attribute1	
Attribute2	
Output 2 Diameter	
Name	Output 2 Diameter
Description	
Value	5
Default Value	
Unit	mm
DataType	xs:string

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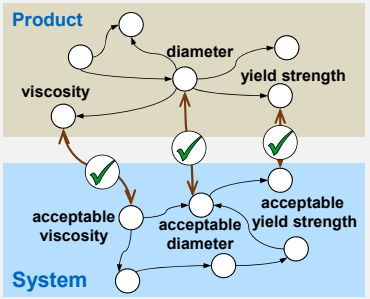
Flexibility – Matching Resource Model and Product Model with ontologies

Product description
- **Name**: White chocolate balls
- **Viscosity**: 2.5 Pa*s
- **Yield strength**: 20 Pa
- **Diameter**: 0.5 cm
- **Aggregation state**: solid

Ontology
- Formal knowledge representation
- Provides the means to flexibly process knowledge

→ Basis to identify whether **filler** can manufacture yoghurts with **white chocolate balls**

Ressource description
- **Name**: Filler
- **Acceptable viscosity**: 1..3 Pa*s
- **Acceptable yield strength**: 10..30 Pa
- **Acceptable diameter**: 0.2..1 cm
- **Functionality**: separate single solid



Mapping of **technical system**'s characteristics with **requirements from product** and **production process** by means of ontologies

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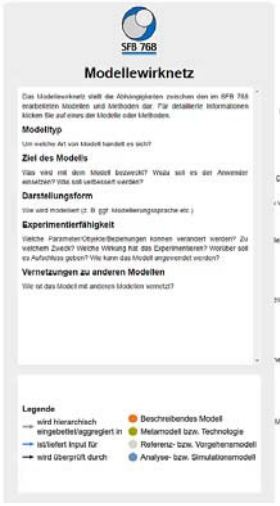
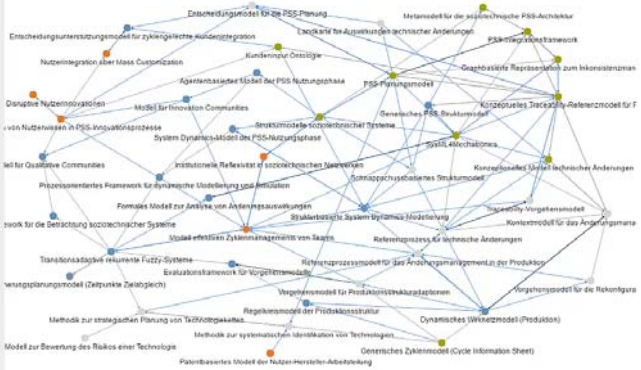
Overview on the CRC 768 Model Network

SFB 768





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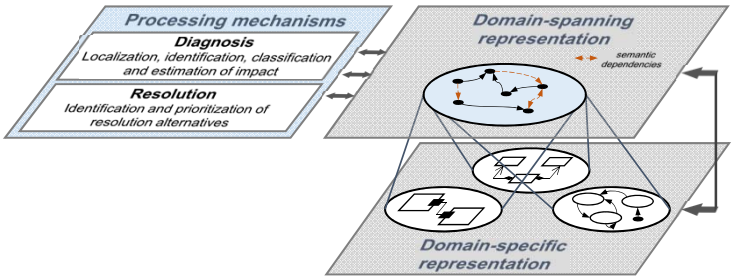
Diagnosis and resolution of inconsistencies between disparate domain models

SFB 768

Approach and Expected Results of Funding Period 3



Connect
Experience
Comprehend
Visual Computing Laboratory

- Basis for development of the approach
  - **Heterogeneous model landscape** of CRC 768
  - **Prioritization of types of models and inconsistencies** together with application and cooperation partners in industry
- Evaluation by means of use cases, empirical evaluation as well as focus groups at the hand of a prototypical realization

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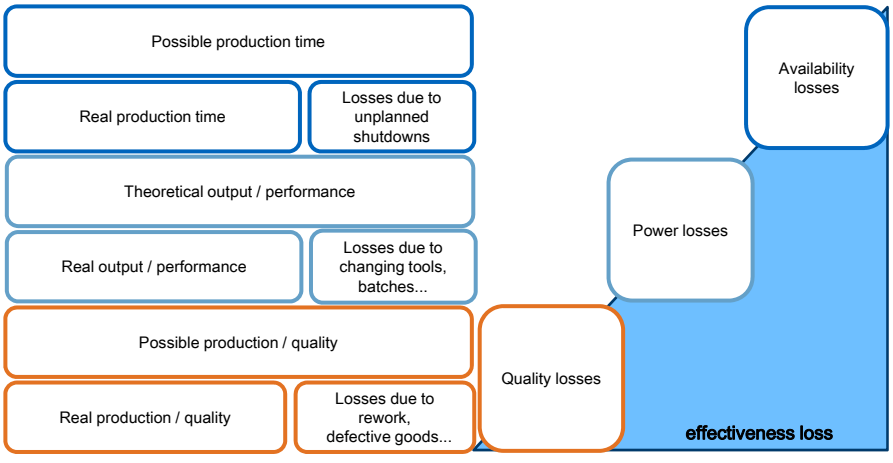
Overall equipment effectiveness (OEE)



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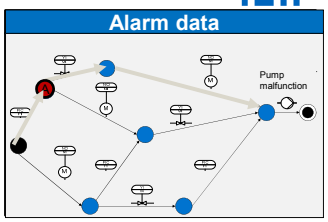
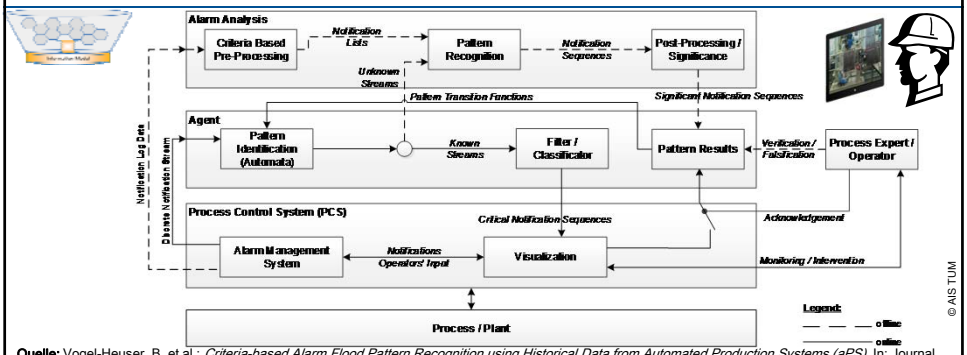
Availability- Identification of causal message patterns

Benefit of agents:
- Modular functionality and defined interfaces
- Step-wise increasing agents knowledge by verification/ falsification by experts (during runtime)
- Decision making in action by the agents based on the knowledge based





Quelle: Vogel-Heuser, B. et al.: *Criteria-based Alarm Flood Pattern Recognition using Historical Data from Automated Production Systems (aPS).* In: Journal Mechatronics, 1-12, 2015.

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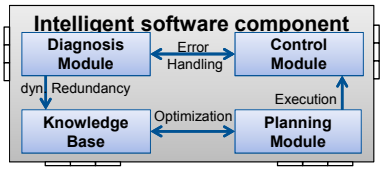
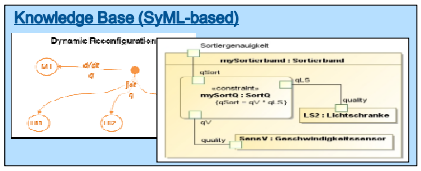
Increased availability by sensor reconfiguration (sensor fault)

Application in process control





Boundaries of the array

<type><ARRAY[*]*/]1..[realSens->size()/],0..[softSens->size() + 1/][*]*/] OF POINTER TO Sens /></type>

Classification real sensors

arrRedList[*]*/][ag.realSens->indexOf(sens)/],1[*]*/] := ADR([ag.controlledBlock.name/].[sens.name/].stSens;

Classification virtual sensors

[ag.realSens->indexOf(sens)/] : [ag.controlledBlock.name/].[sens.name/].setSoft(stSw:=pBestSens);

Templates referred to the MOFM2T-standard

PLC (IEC 61131-3)

ADR(A1.out)	ADR(A2.out)	ADR(B1.out)	ADR(B2.out)
	ADR(VA2.out)		
		ADR(VB1.out)	
			ADR(VB2.out)

Implementation of redundancy matrix

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Benefit of agents: Compensation of sensor breakdowns and higher availability

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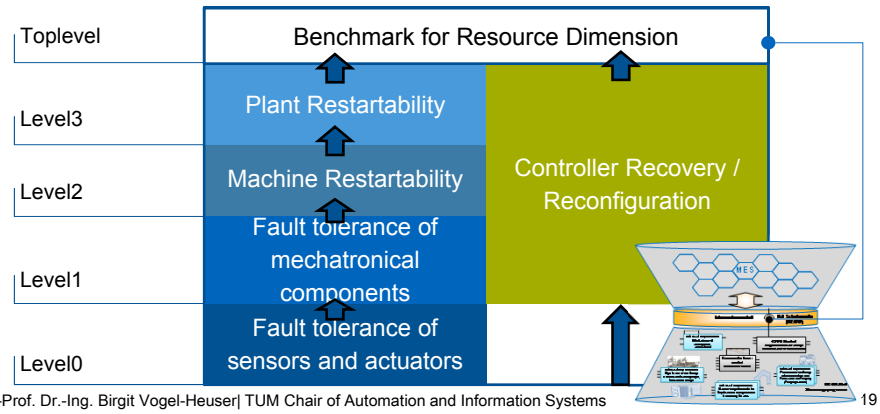
Restartability, Recovery, Reconfiguration of hierarchical aMS

Restart(ability): To cause a computer program to resume execution after a failure, using status and results recorded at a checkpoint. (***source**: IEEE glossary*)

Recovery: Recovery typically includes two phases, error correction and restart, where correction is the process of removing the original problem (the fault) and correct its manifestation (the error), and restart is the process of moving the system to a normal state. (***source**: Andersson et al. 2010*)

Reconfiguration: The arrangement of parts or elements in a different form, figure, or combination: 'software reconfiguration'. (***source**: Oxford dictionaries*)



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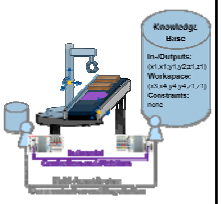
Benefits of agents - Conclusion and Future Work

✓ **Engineering Support**

- Automatic synthesis of automation software (manufacturing)
- Support systems for (re-)engineering and optimization

✓ **Availability**

- Support for self-reconfigurable aPS, Compensation of hardware (sensor) failures on different levels
- Breakdowns and local knowledge are incorporated into decision-making to increase availability



✓ **Flexibility**

- Flexible MAS for interaction between heterogeneous robots or plants; locally distributed production of customized products

➢ **Renaissance of agent technology due to Industrie 4.0/CPPS and integrating smart data algorithm**

➢ **Modularity is the key**

➢ Metrics are required to compare and benchmark approaches (TC IES and GMA FA 5.15)

Thank you for your attention!

Univ.-Prof. Dr.-Ing. Birgit Vogel-Heuser

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