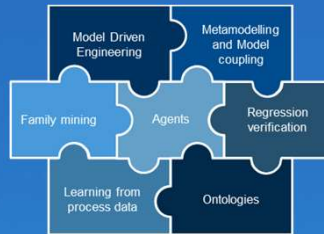


Multi Agent Systems in the context of Industry 4.0 - Reusable pattern for field level control



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Full professor; head of institute
Automation and Information Systems (AIS)
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Summer School on AI for Industry 4.0
27th to 31st of July 2020,
Saint-Étienne, France

Univ.-Prof. Dr.-Ing. Birgit Vogel-Heuser | TUM Chair of Automation and Information Systems



1

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Birgit Vogel-Heuser
Institute of Automation and Information Systems (AIS)



Multi-Agent Systems (MAS) related activities

- Chair of VDI/VDE (Association of German Engineers) TC 5.15 "Multi-Agent Systems in Automation"
- Developing VDI/VDE 2653 "Agent Systems in Automation Systems", Sheet 4: "Multi-agent Systems in Industrial Automation Patterns" (*in process*)
- Chair of IFAC TC 3.1 Computers for Control

Scientific staff from AIS

- About 20 researchers (PhD students and Postdoc)
- 3 technicians, trainees (software engineering)

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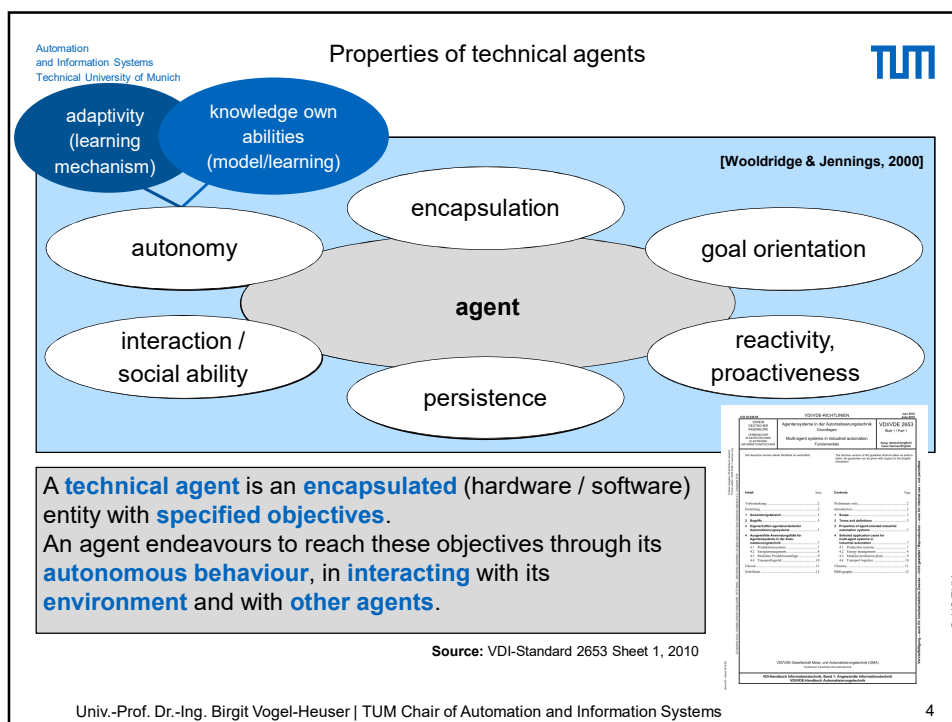
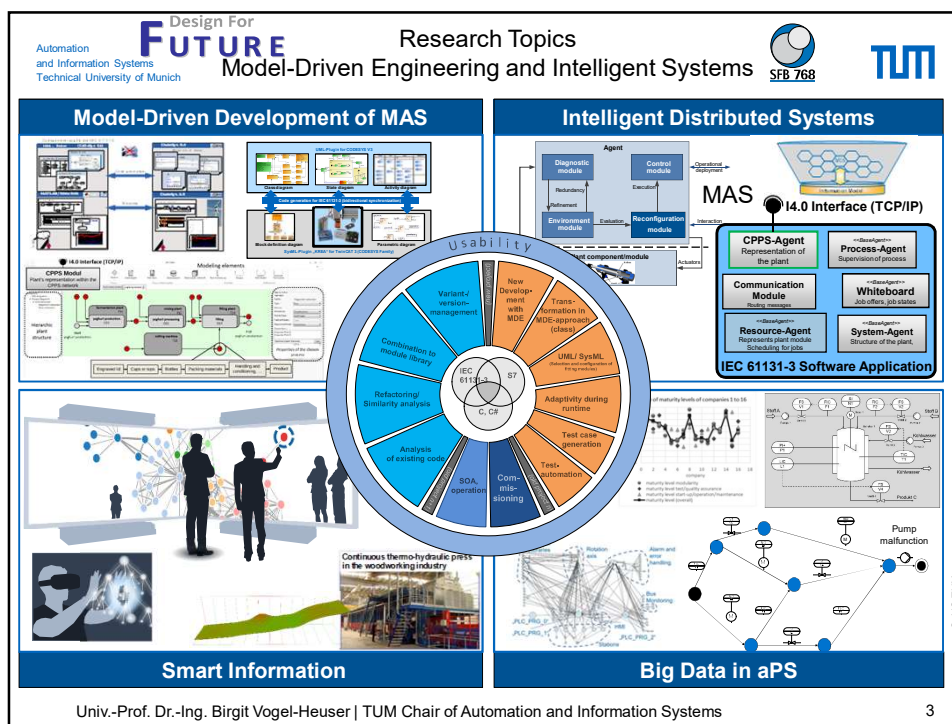
- The leading university in mechanical and electrical engineering in Germany
- Faculty of mechanical engineering
 - 25th at the QS World University Ranking by Subject (1st in Germany), 2020



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2



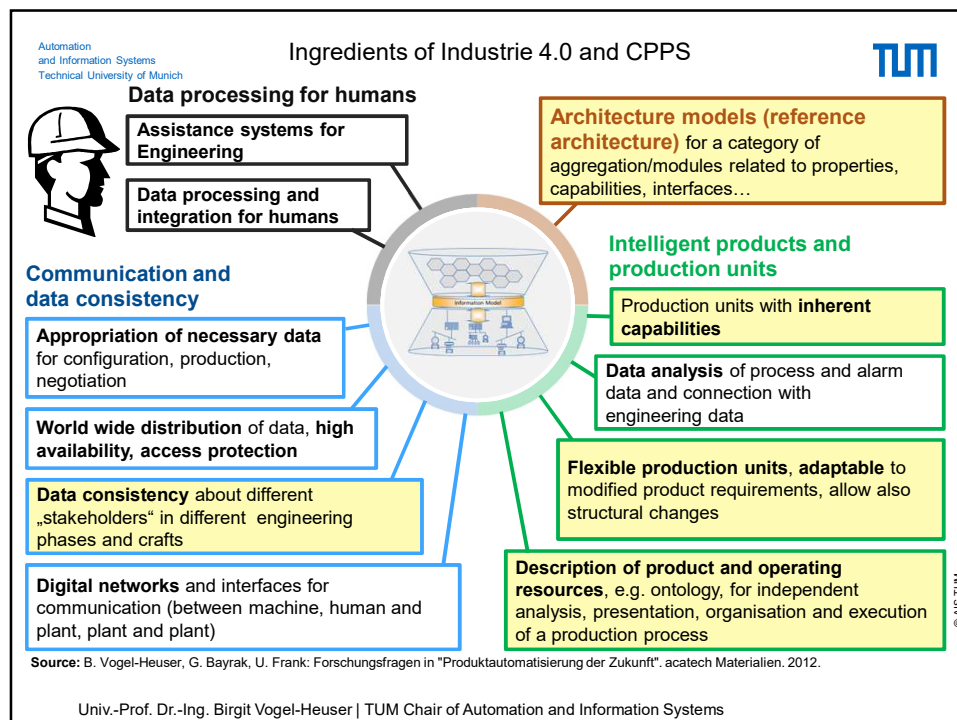
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5



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Software-evolution is the key – engineering as a basis for the software-evolution

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- **Importance of Software in production automation**
 - 9% of a machine is software (cost) (2008)
 - 20% (average) up to 50% of engineering costs for software (2012)
 - 25% (average) engineering costs (forecast 2015) VDMA, 2008

Source: Bayer

Source: Birgit Vogel-Heuser; Jens Folmer; Christoph Legat: Anforderungen an die Softwareevolution in der Automatisierung des Maschinen- und Anlagenbaus. In: at – Automatisierungstechnik, 62(3), 3/2014

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Technical constraints of field level control

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Real-time requirements of automated production systems

- hard real-time for the platform (PLC)
- Cyclic behavior of the platform (1μs – 1s)
- Classical PLC as well as Soft-PLC (PC-based) programmed in IEC 61131-3 Languages
- Increasing amount of IPC and C, C-derivatives
- Online change is mandatory**

IEC 61131-3 Languages

Sequential Function Chart	Ladder Diagram	Function Block Diagram
<pre> graph TD Step1[Step1] -- Transition 1 --> Step2[Step2] Step2 -- Transition 2 --> Step3[Step3] </pre>	<pre> graph LR Var1[Var1] --> Var2[Var2] Var2 --> Var3[Var3] Var3 --> OUT[OUT] </pre>	<pre> graph LR Var1[Var1] --> AND[AND] Var2[Var2] --> AND AND --> OUT[OUT] </pre>
<p>Structured Text</p> <pre> OUT := (Var1 & Var2 & Var3) OR (Var4 & Var5) </pre>	<p>Instruction List</p> <pre> LDN Var1 ANDN Var2 ANDN Var3 ST OUT </pre>	<p>LDN Var1</p> <pre> ANDN Var2 ANDN Var3 ST OUT </pre>

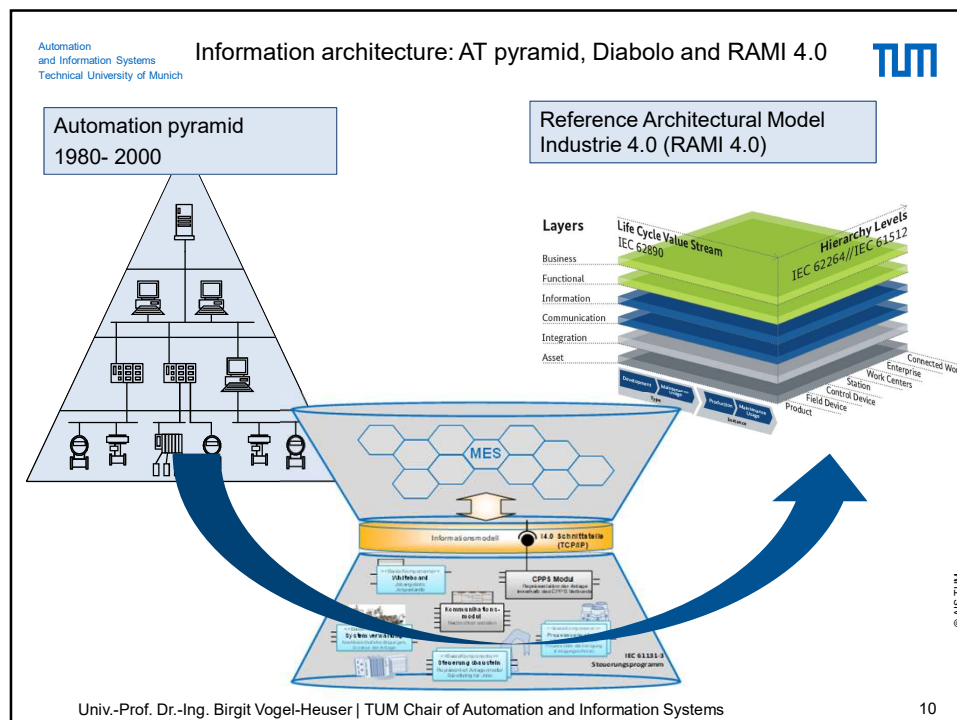
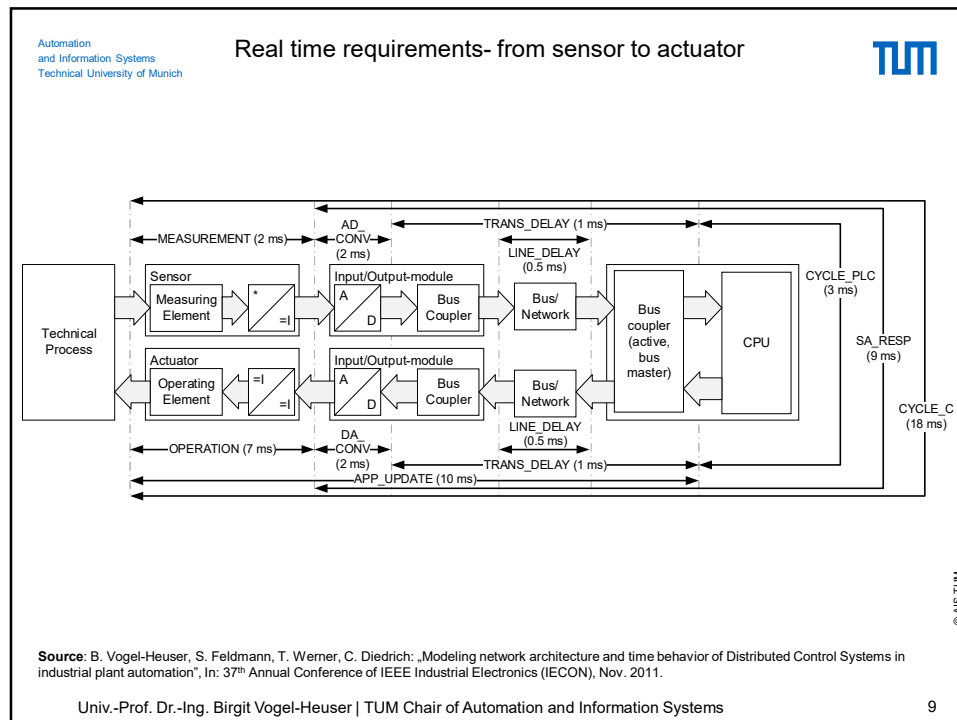
IEC 61131-3 Programming Languages

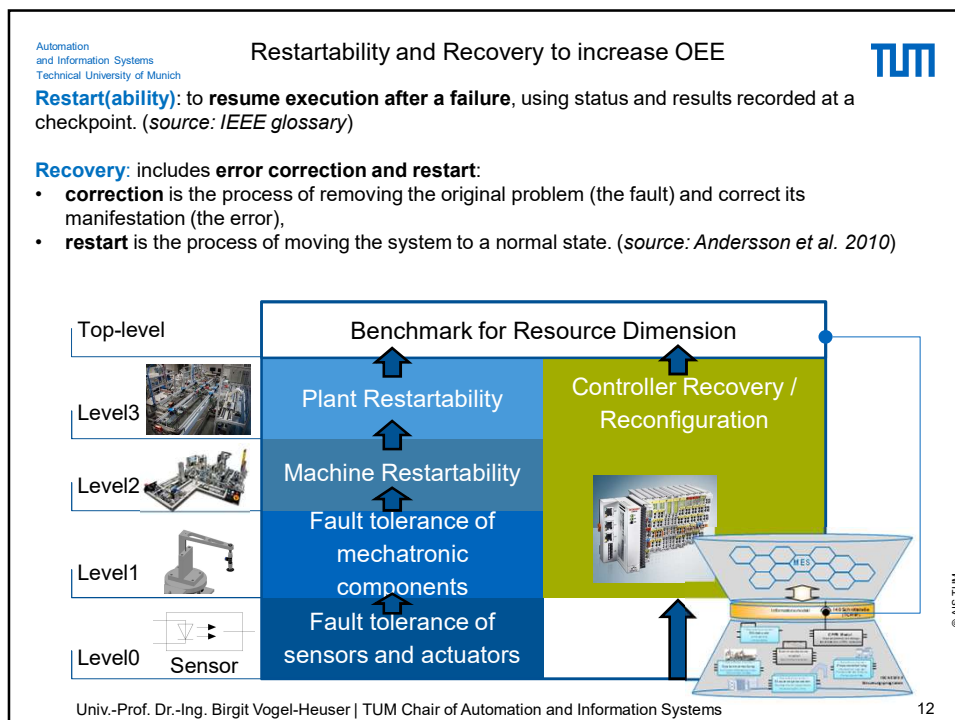
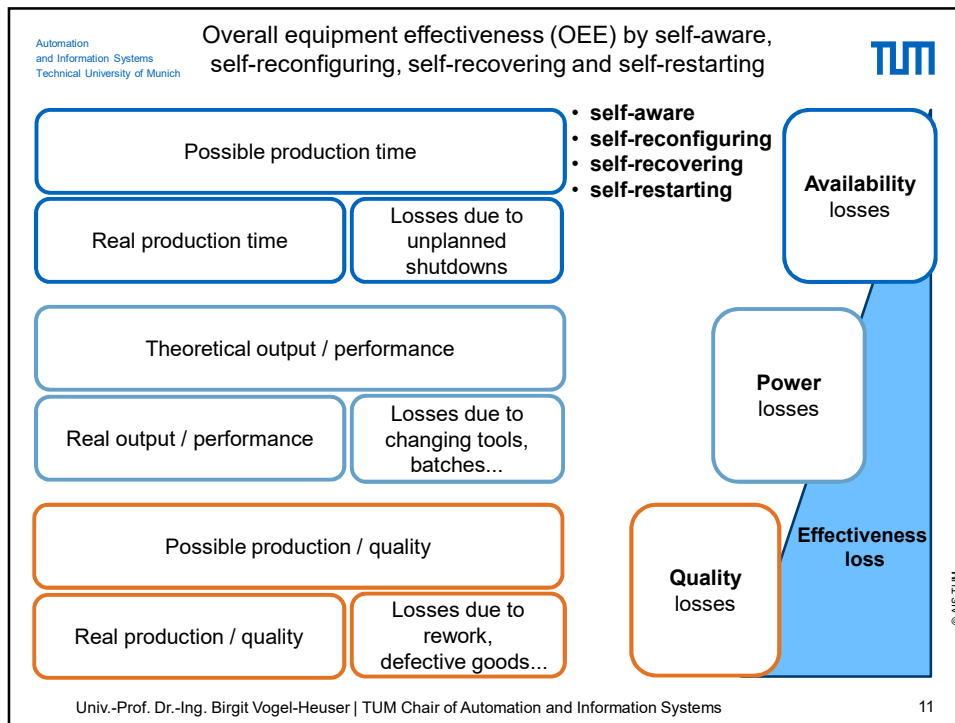
- Proprietary programming languages: Structured Text (ST), Ladder Diagram (LD), Instruction List (IL), Sequential Function Chart (SFC), Function Block Diagram (FBD)
- **Upcoming: C**

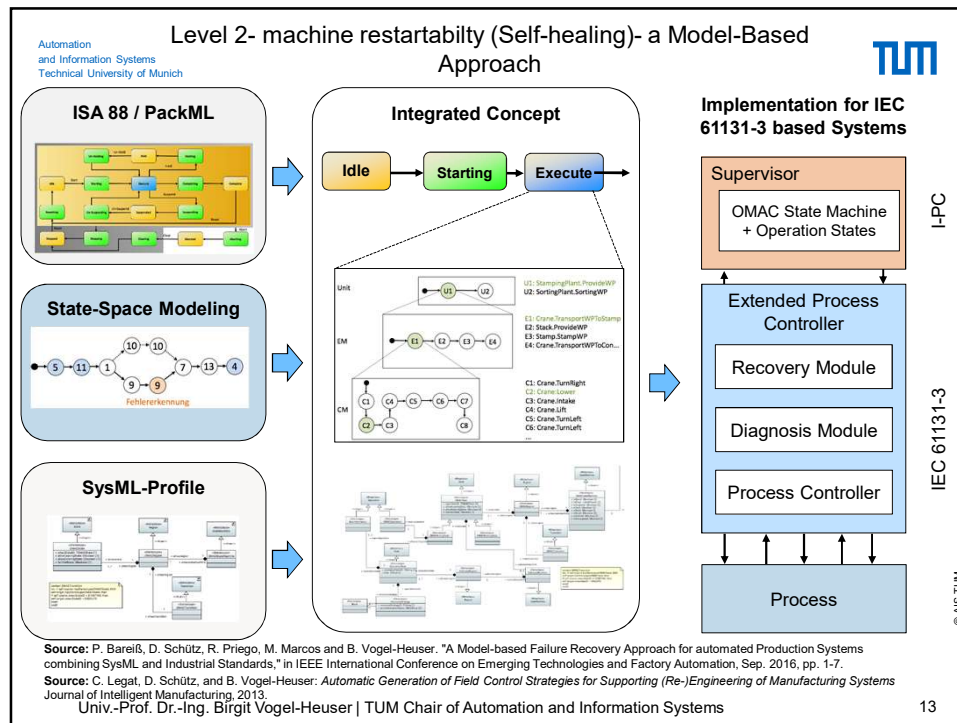
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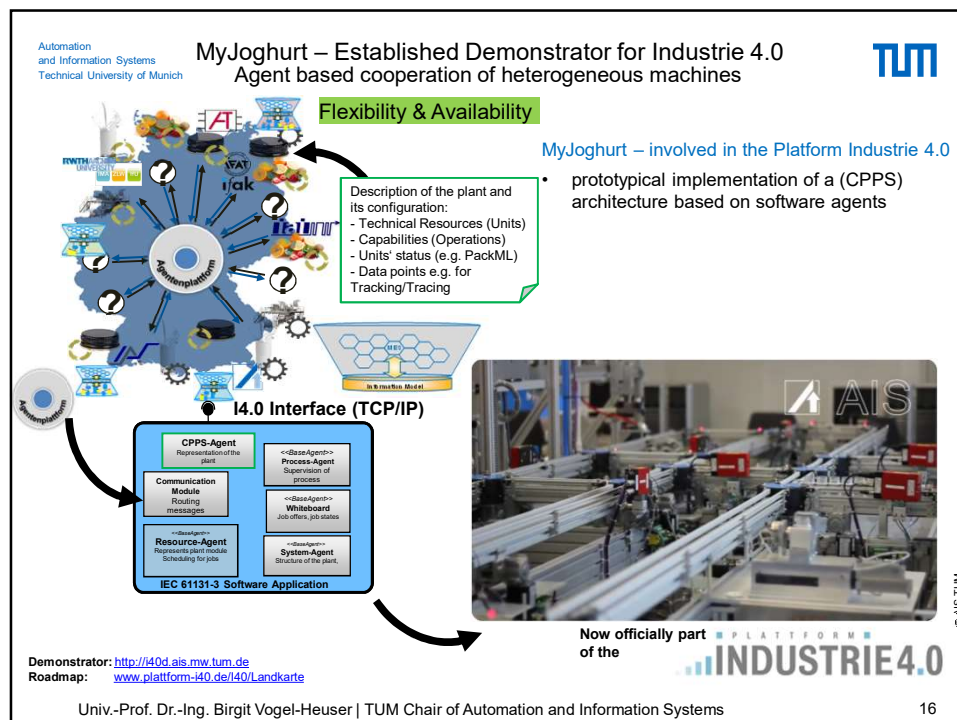
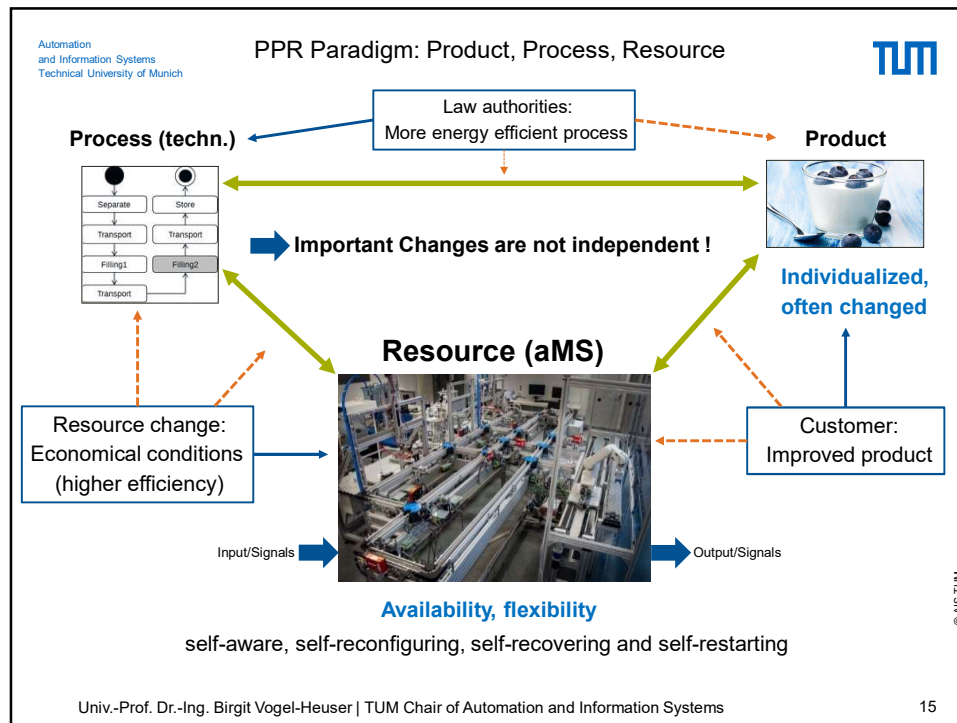


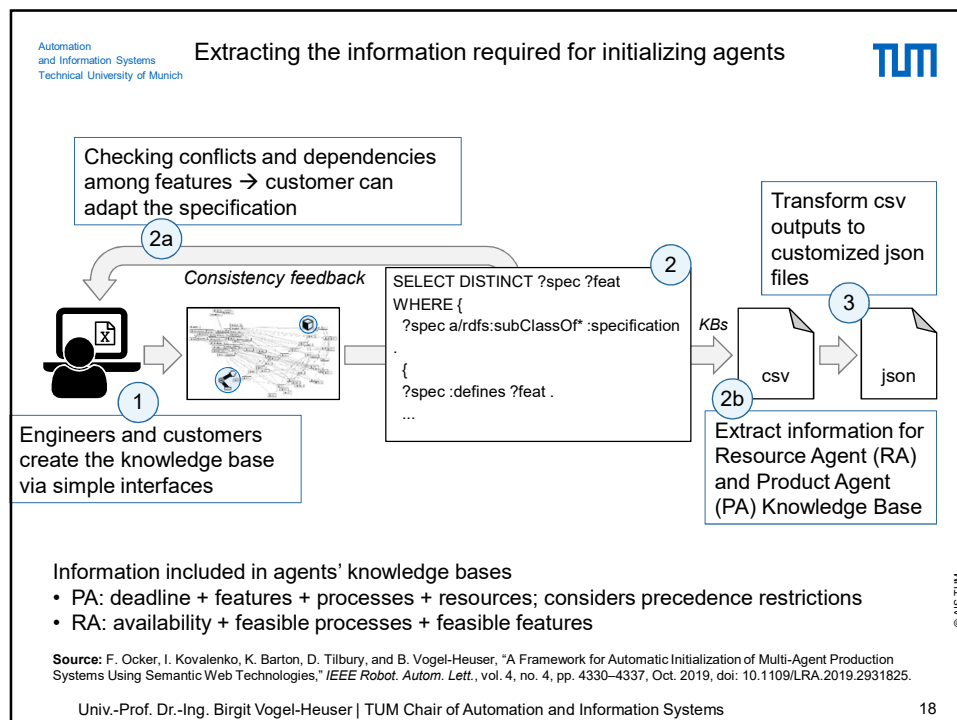
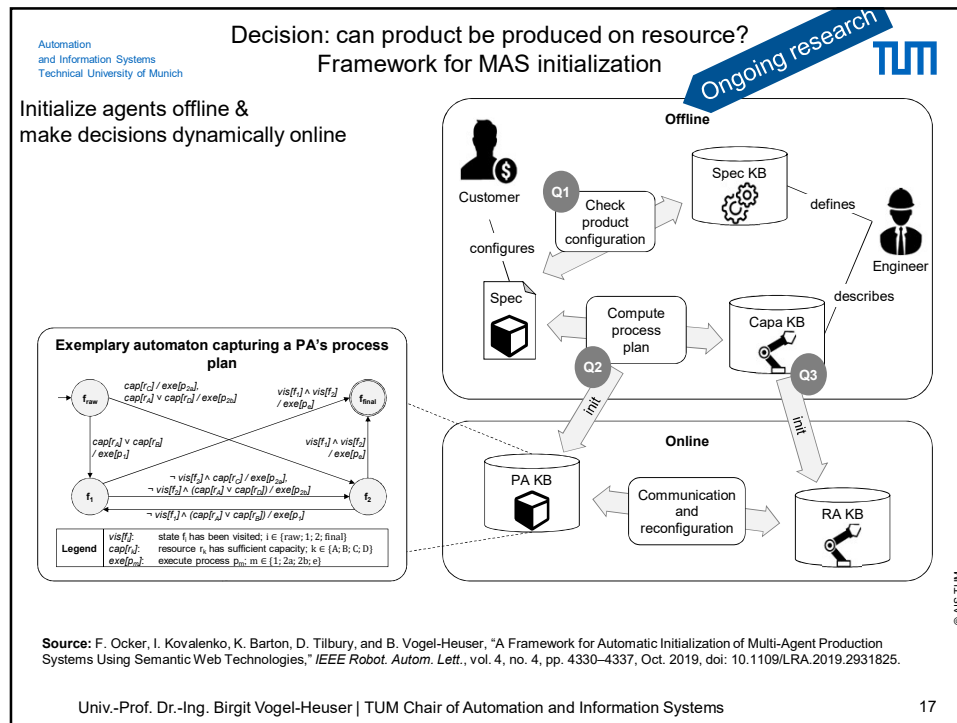


Multi Agent Systems in the context of Industry 4.0 - Reusable pattern for field level control

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Flexibility – Resource 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 description
- PLCOpenXML for behavioral description
- Collada for geometric description

Information goes into the resource agents' KB

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Flexibility – Matching Resource Model and Product Model with ontologies - during operation

Feature-based product description, e.g., json

```
{
  "white_choc_balls": {
    "key": "product",
    "parent": "yogurt",
    "viscosity": {
      "parent": "viscosity",
      "value": "2.5",
      "unit": "Pa*s"
    },
    "yield_strength": {
      "parent": "yield_strength",
      "value": "20",
      "unit": "Pa"
    }
  }
}
```

Resource 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

Ontology

- Formal knowledge representation
- Provides the means to flexibly process knowledge
- Basis to identify whether filler can manufacture yoghurts with white chocolate balls

Product

viscosity → diameter → yield strength

System

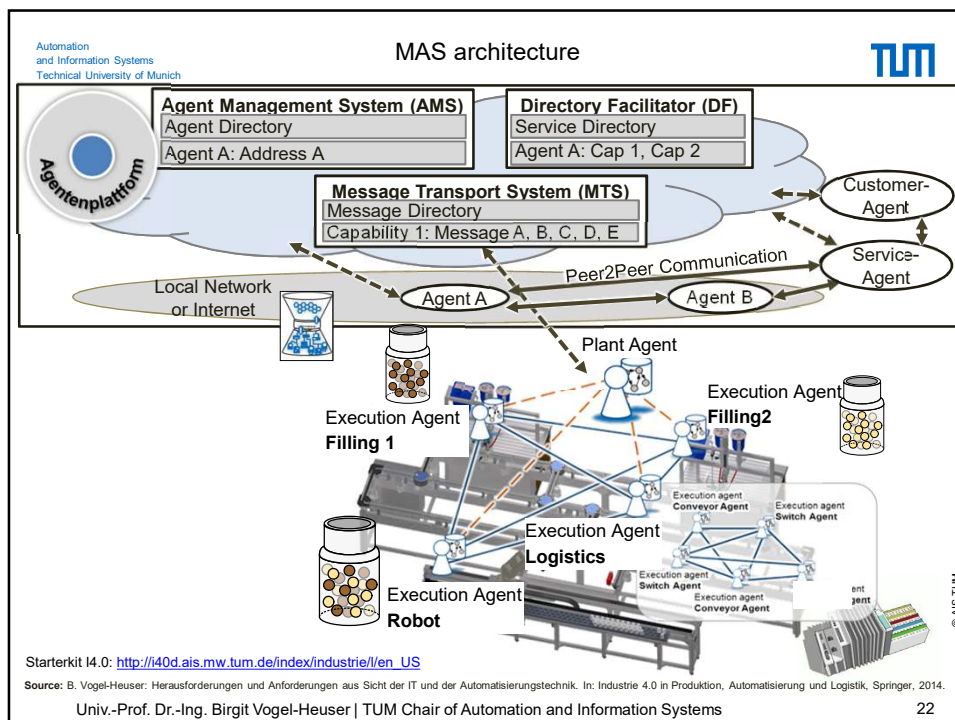
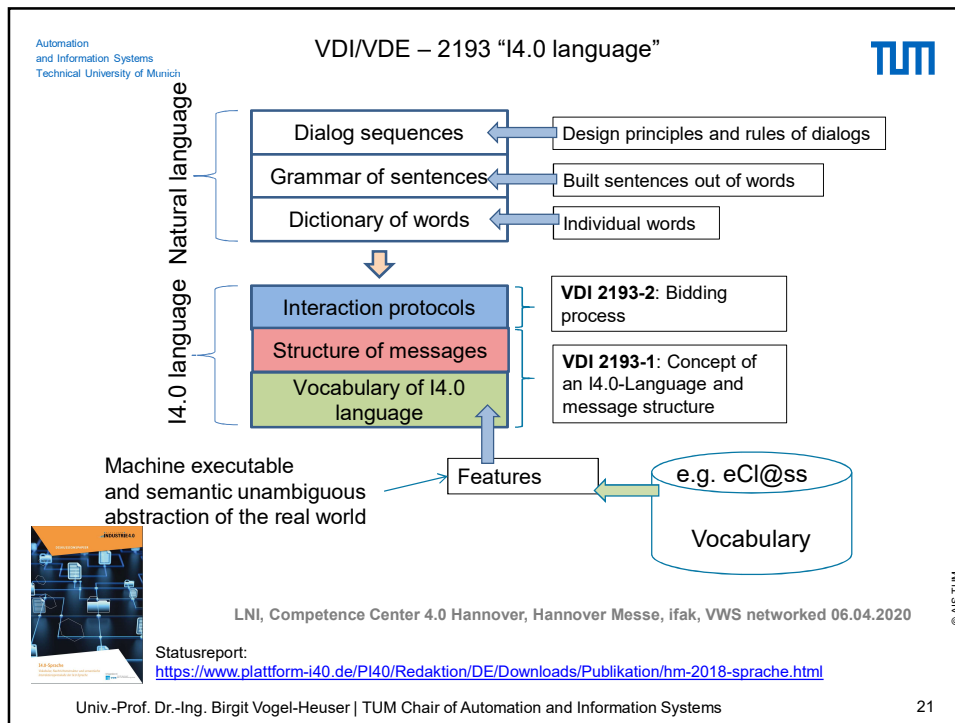
acceptable viscosity → acceptable diameter → acceptable yield strength

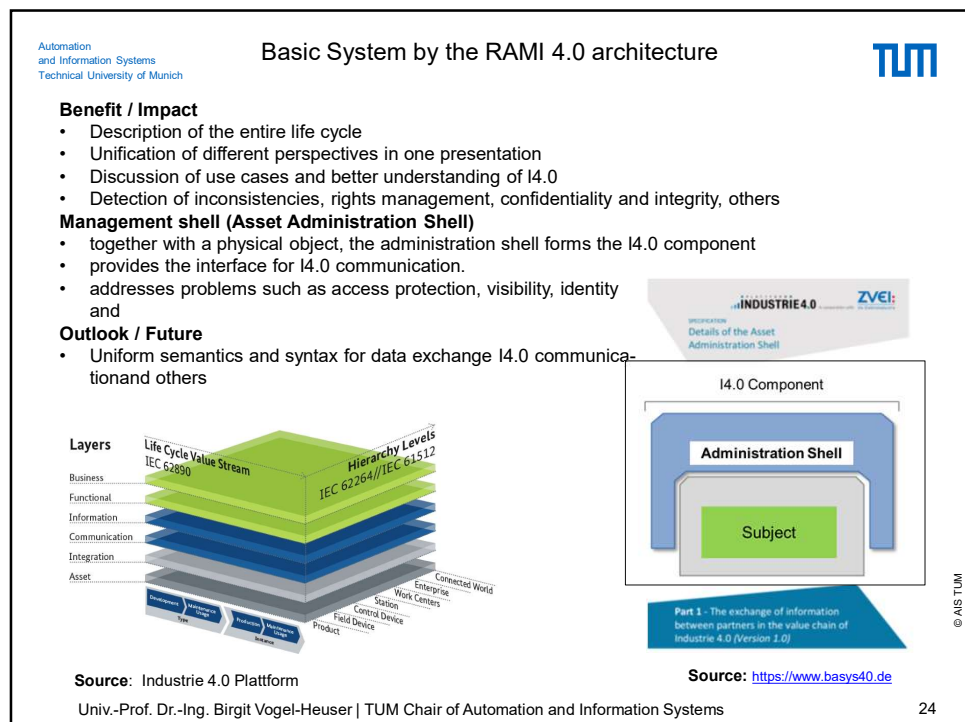
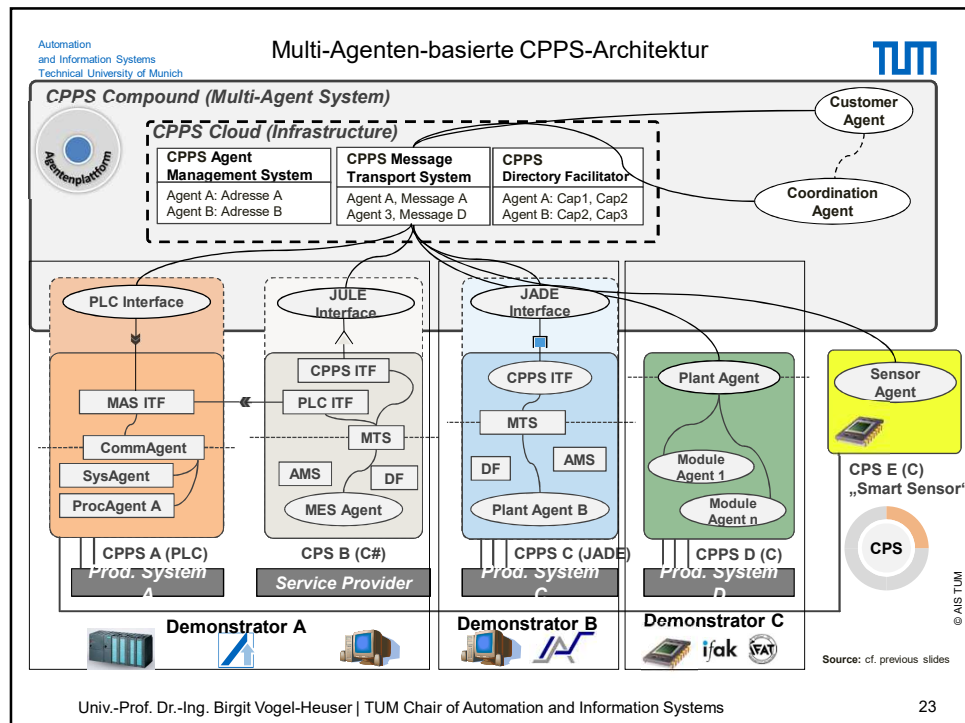
Information goes into the agents' KBs

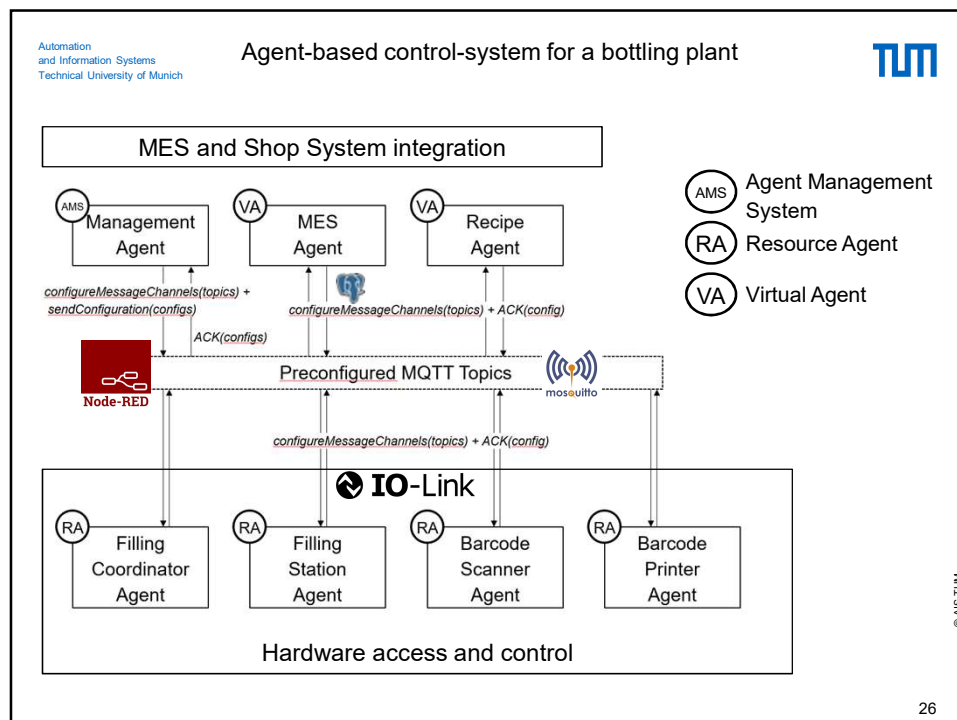
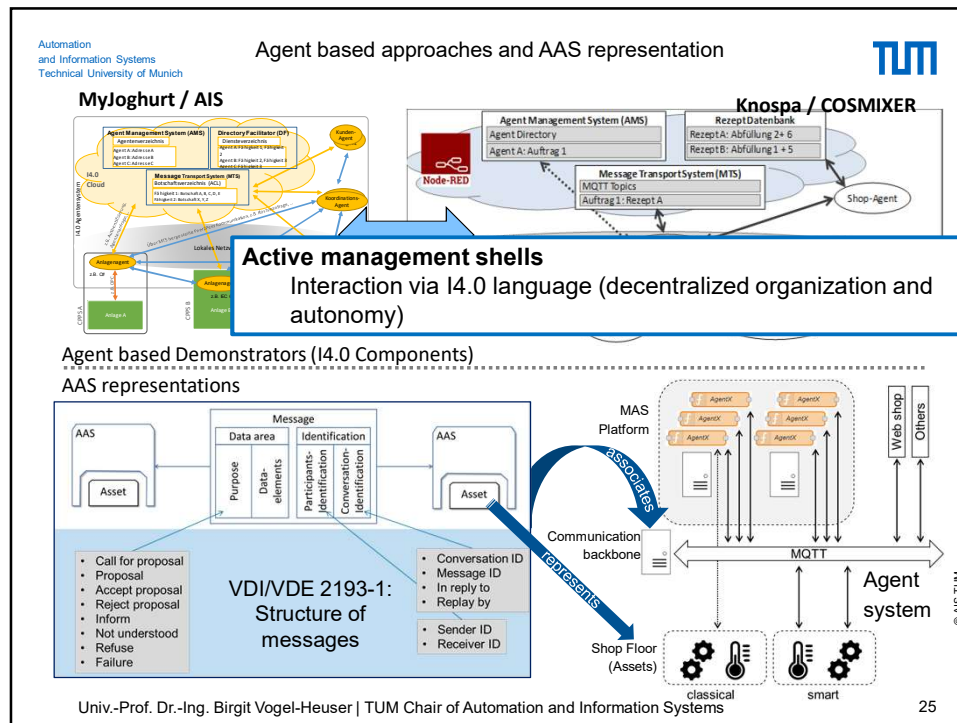
Mapping of technical system's characteristics with requirements from product and production process by means of ontologies

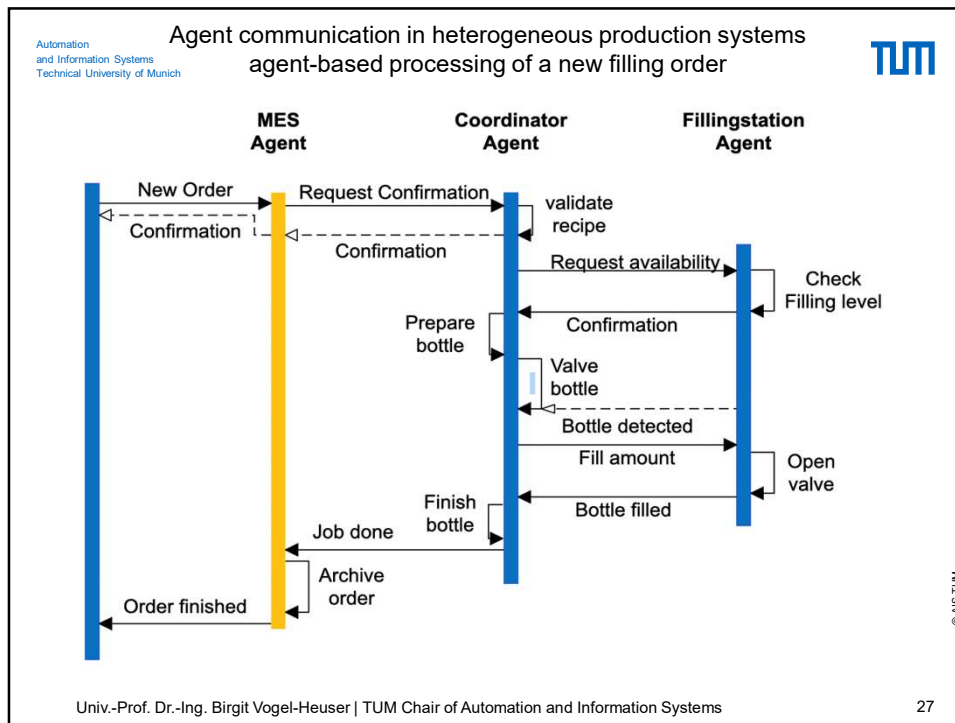
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20









Multi Agent Systems in the context of Industry 4.0 - Reusable pattern for field level control

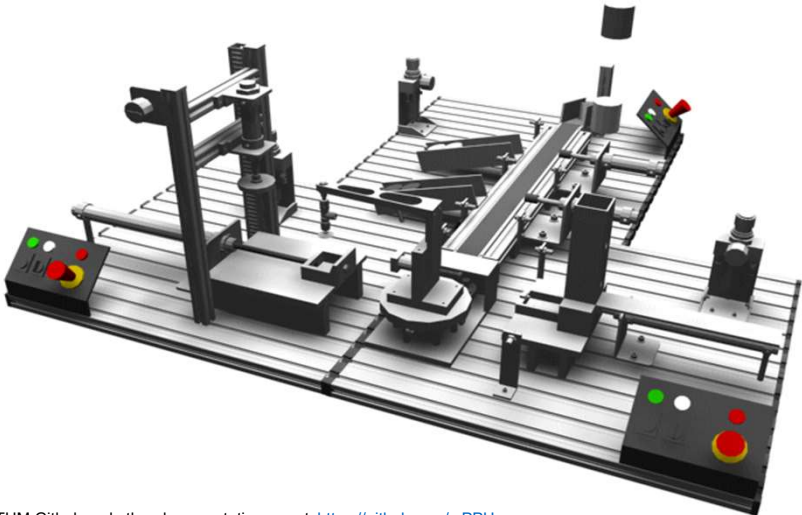
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Introduction of the small lab scale production system pick-and-place-unit (PPU)

TUM



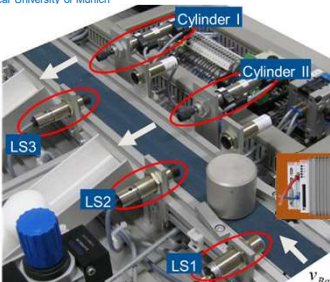
AIS-TUM Github and other documentation report: <https://github.com/x-PPU>

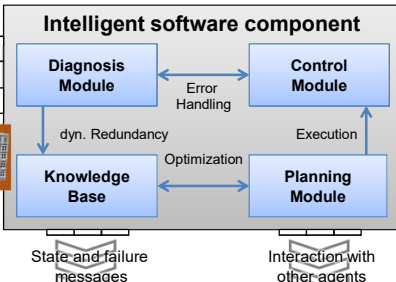
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29

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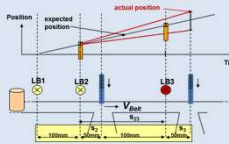
Level 0 - fault tolerant sensor (Model based with agent)





Diagnosis Module

- Evaluation of sensors values
- Execution of failure diagnosis



Control Module

Control of the plant module or other sub-agents

Extend()

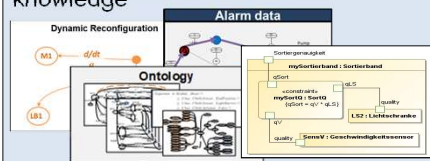
Retract()

FB Separator

ToggleSeparator()

Knowledge Base

Models of the agents' local knowledge



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30

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Details on PPU use case

- LS3 is faulty → no value
- Pusher I: when to push?

Fault Handling

- Keep processing even without LS3
- Calculating the point of time, Pusher I has to push
- Calculation via time and speed

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31

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Parametric diagram => redundancy matrix to model and implement agents knowledge

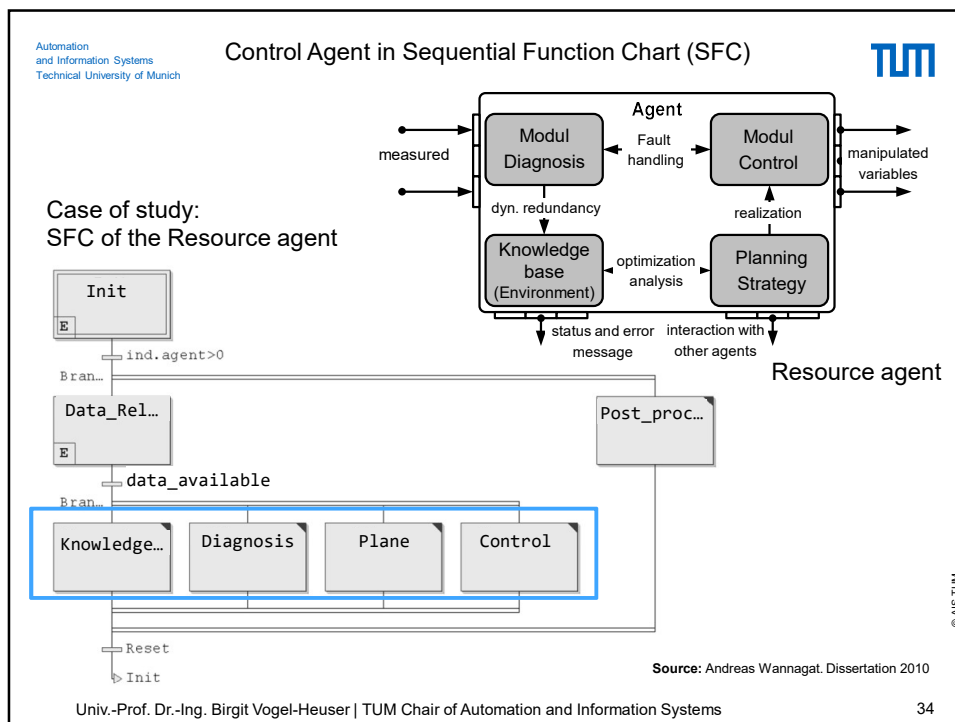
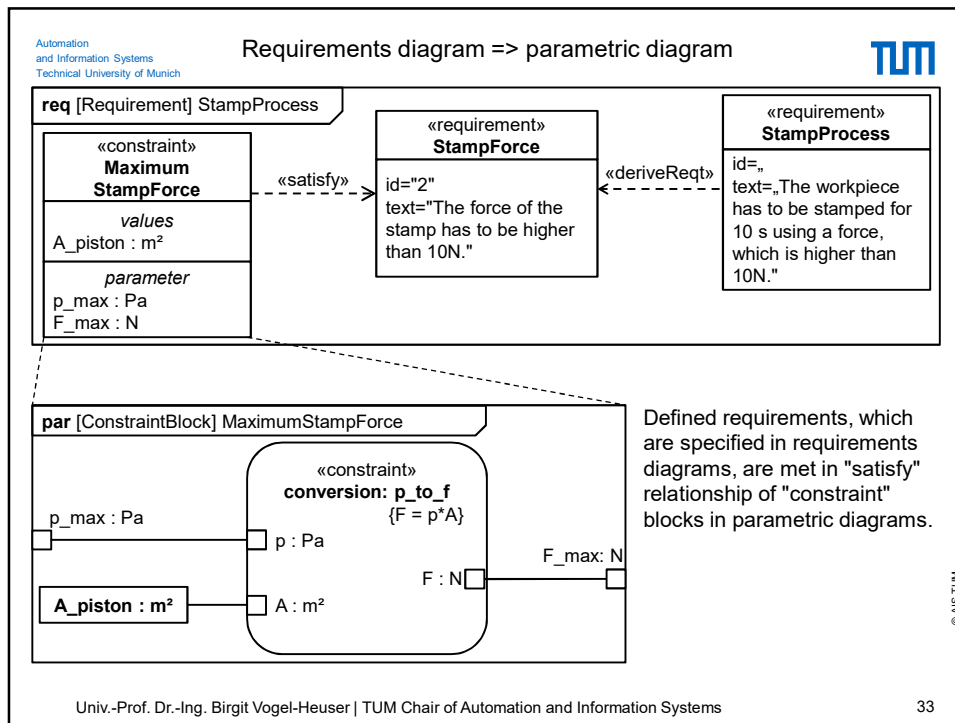
	LS1	LS2	LS3	v_{belt}
LS1	LS1	vLS2	vLS3	
LS2		LS2	vLS3	
LS3			LS3	
v_{belt}		vLS2	vLS3	v_{belt}

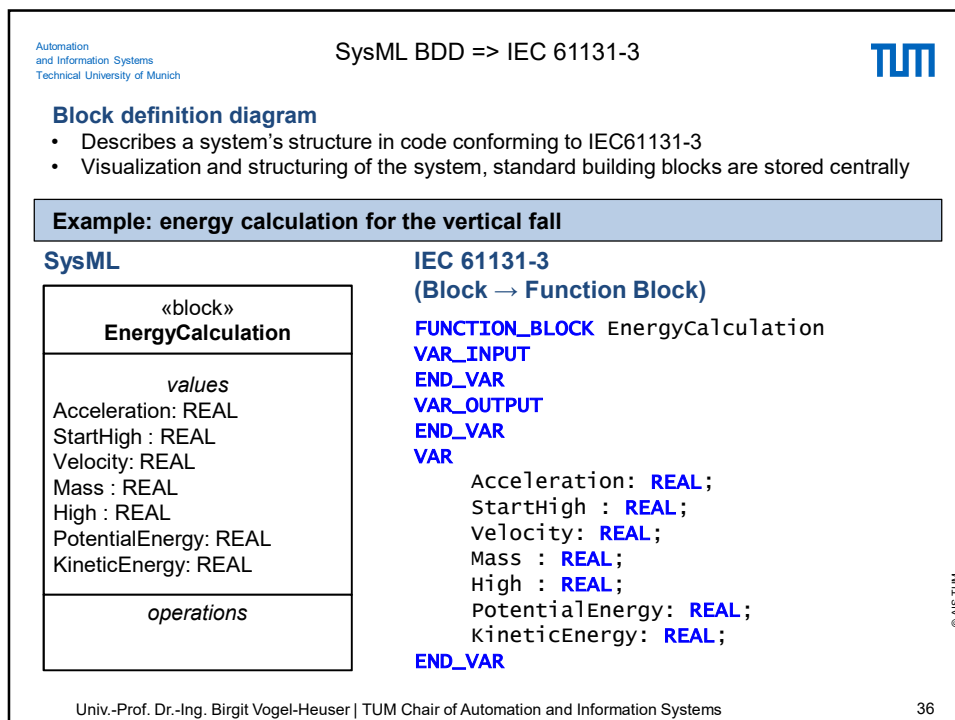
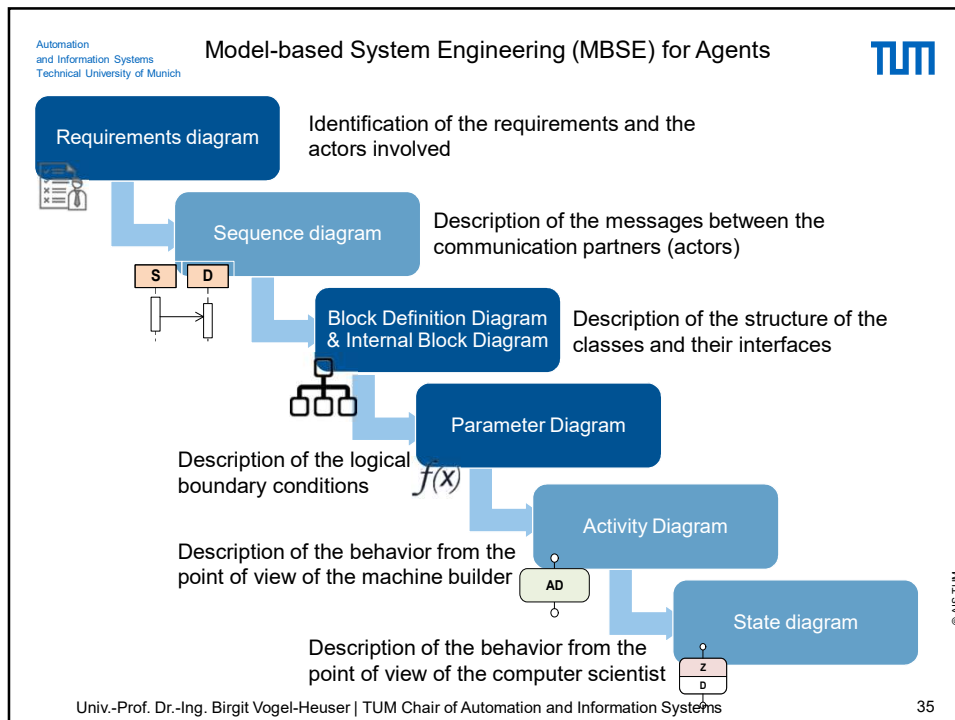
Real sensor
Virtual sensor

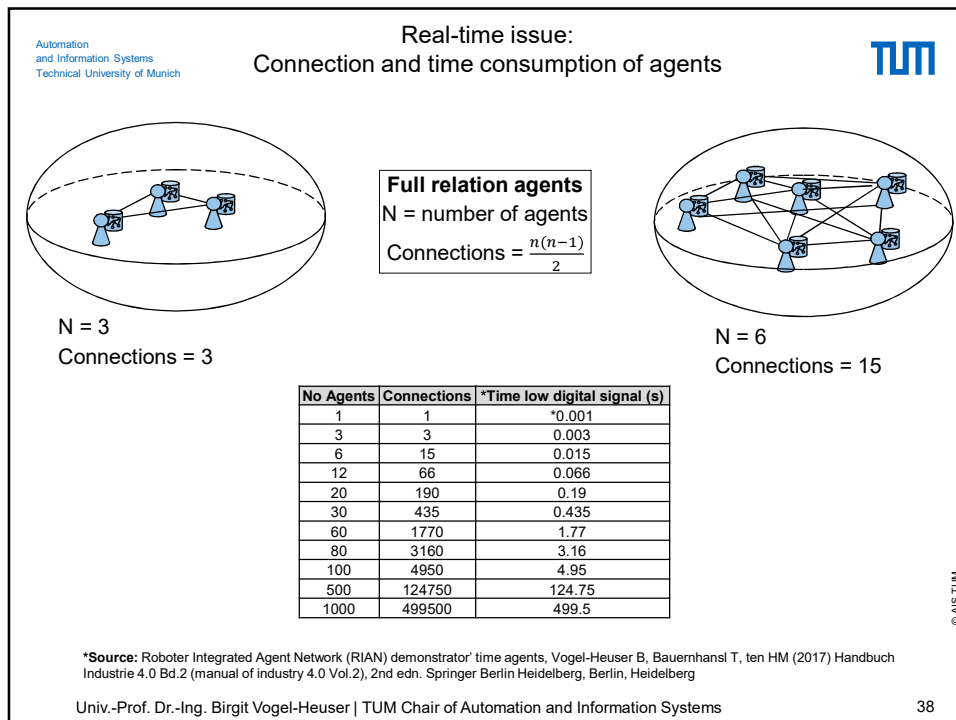
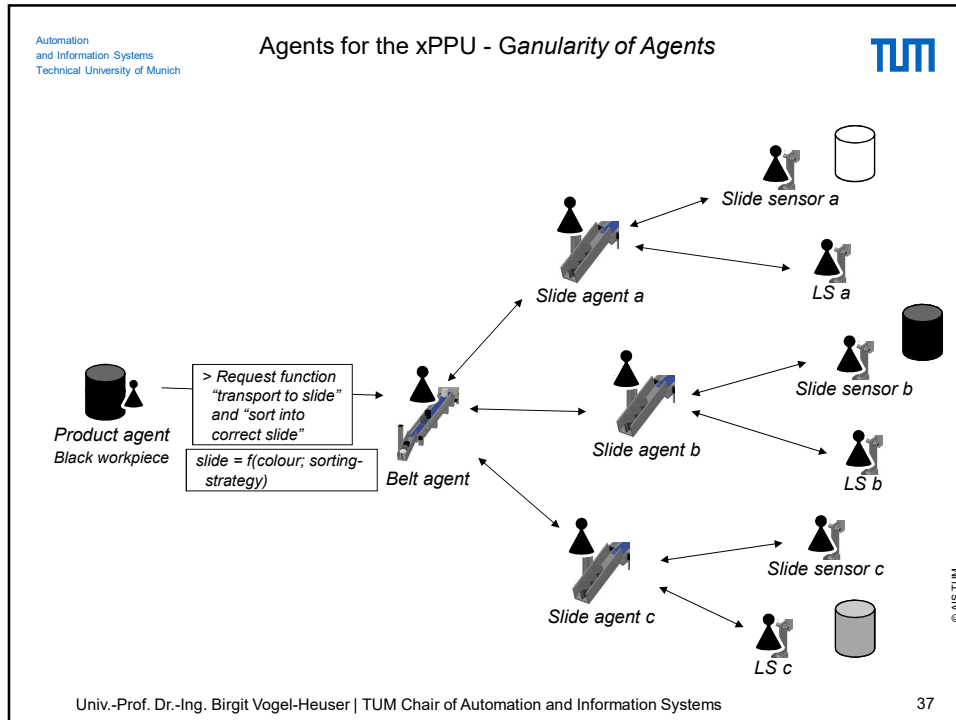
Supporting information

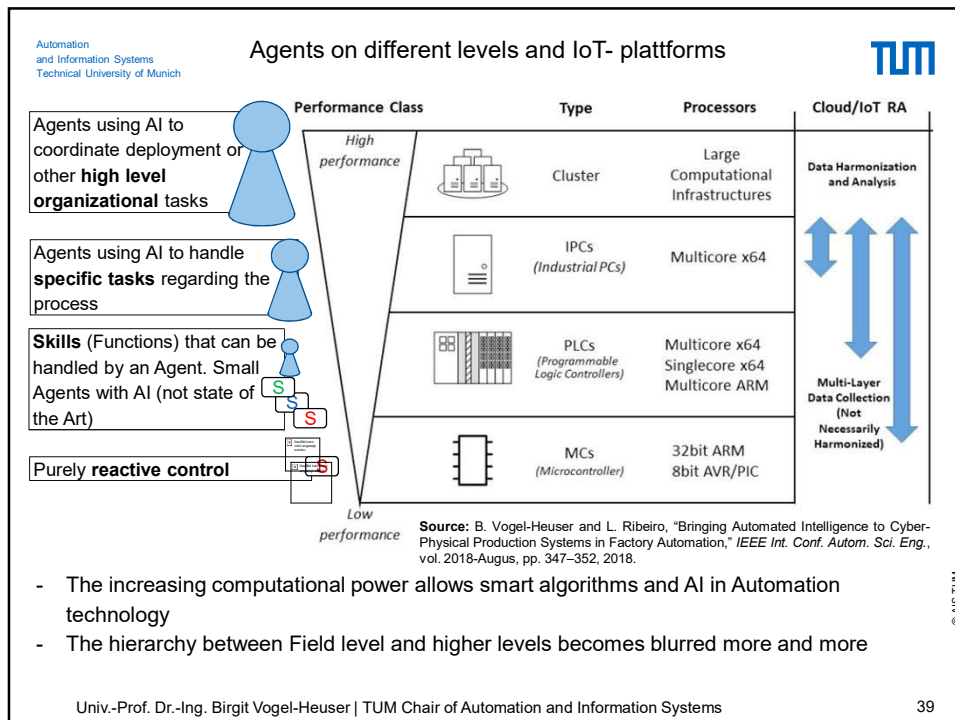
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32









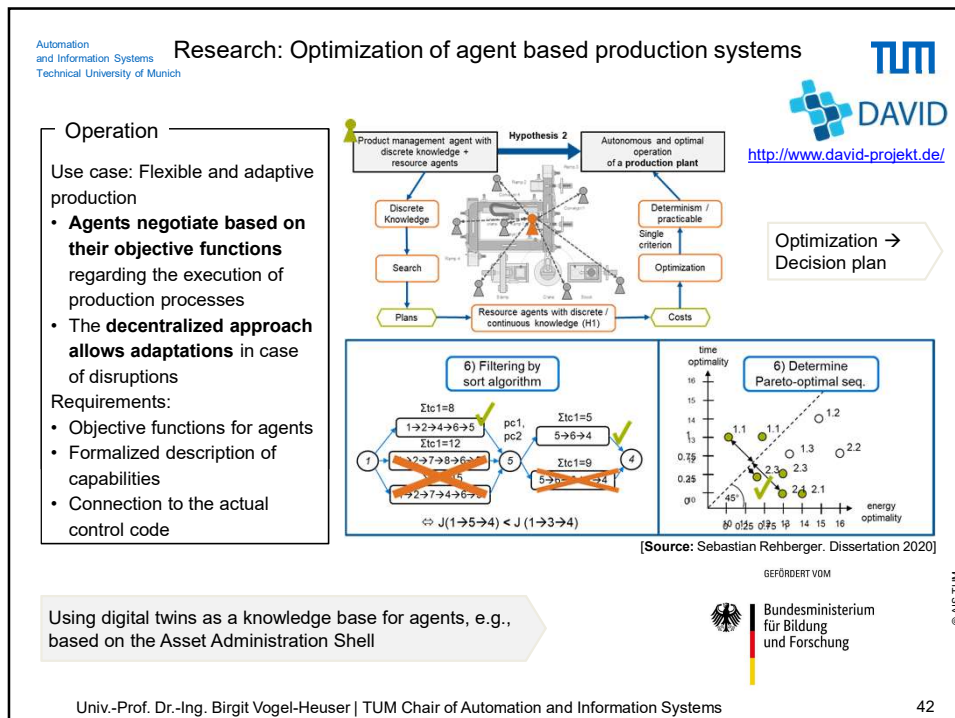
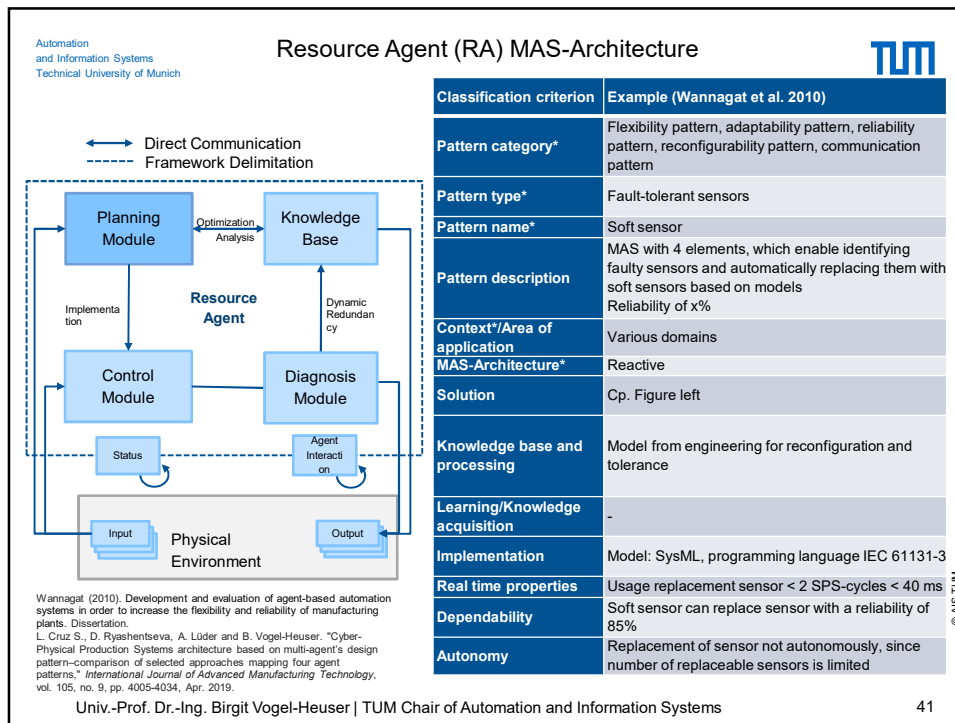
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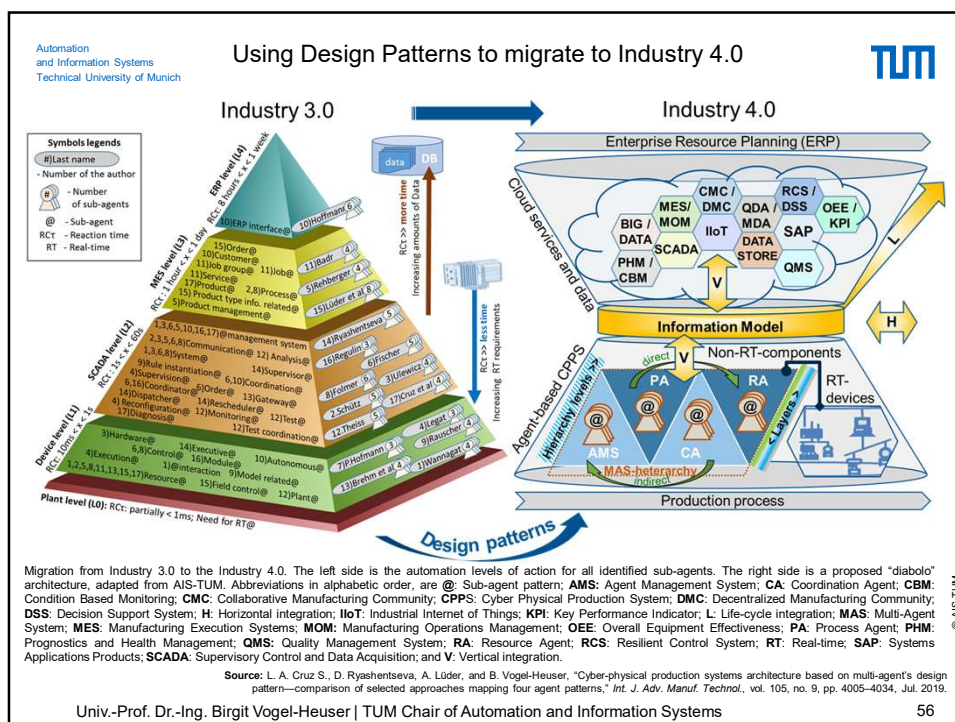
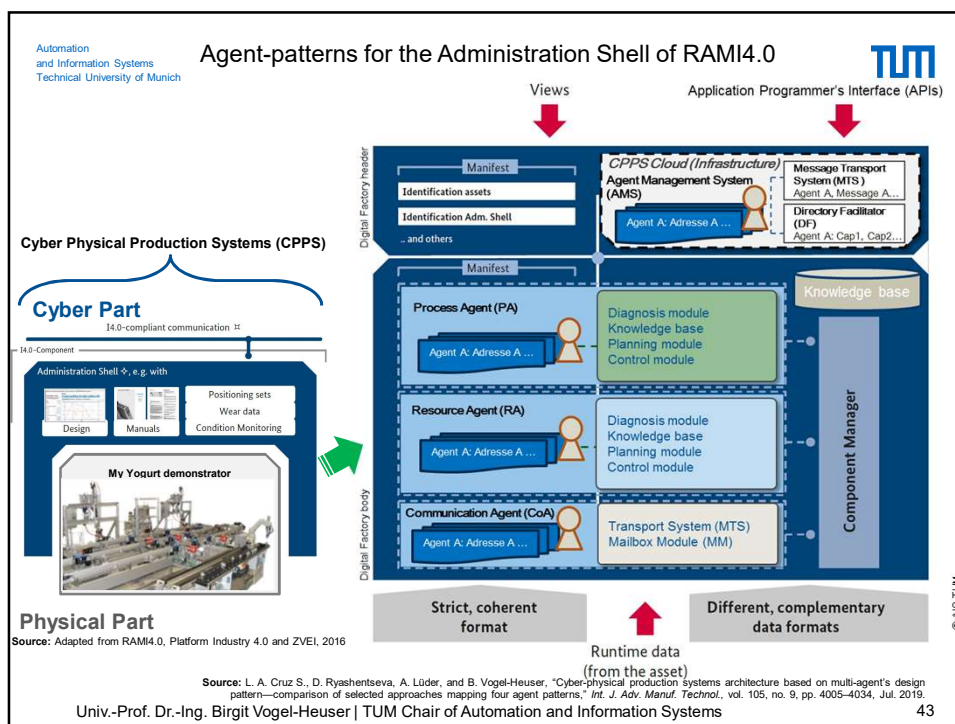
- Reusable pattern for field level control

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40





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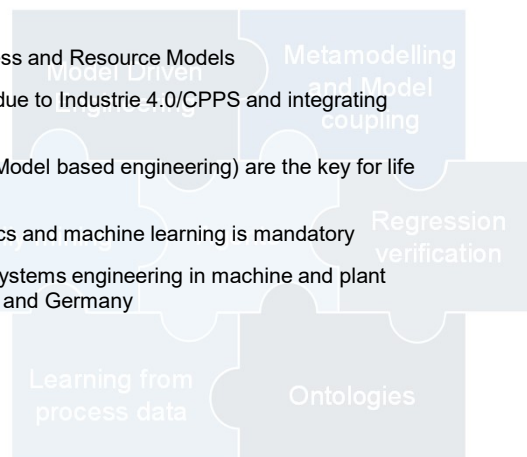
45

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Self-x automation- Conclusion and Future Work



- ✓ Inconsistency identification during engineering and runtime
- ✓ Availability using agents
- ✓ Flexibility based on Product, Process and Resource Models
- Renaissance of agent technology due to Industrie 4.0/CPPS and integrating smart data algorithm
- Software and System Modularity (Model based engineering) are the key for life long evolution
- Integration of modular data analytics and machine learning is mandatory
- Success in the worldwide race in systems engineering in machine and plant manufacturing required for Europe and Germany



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46

Thank you for your attention!
We welcome international exchange students!

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Current MAS activities

- Status report on agents enabling I4.0 communication, Vocabulary, Messages, Sematic Interactions
<https://www.vdi.de/ueber-uns/presse/publikationen/details/agents-for-the-realisation-of-industry-40>
- Guideline VDI/VDE 2653 "Agent Systems in Automation Systems" German GMA Working group FA 5.15
 - 1 : "Fundamentals", 2 : "Development", 2018
 - Sheet 3 : "Application", 2019
 - Sheet 4 : "Multi-agent Systems in Industrial Automation Patterns", publication in 2020
- International IFAC TC 3.1 computers in control WG on agents (<https://tc.ifac-control.org/3/1/activities>)



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47