

**IDA 30 Year Celebration Seminar**

Linköping, 24.09.2013



# **Industrie 4.0: Active Semantic Product Memories for Smart Factories**

**Wolfgang Wahlster**

**Professor of Computer Science, CEO and Scientific Director**



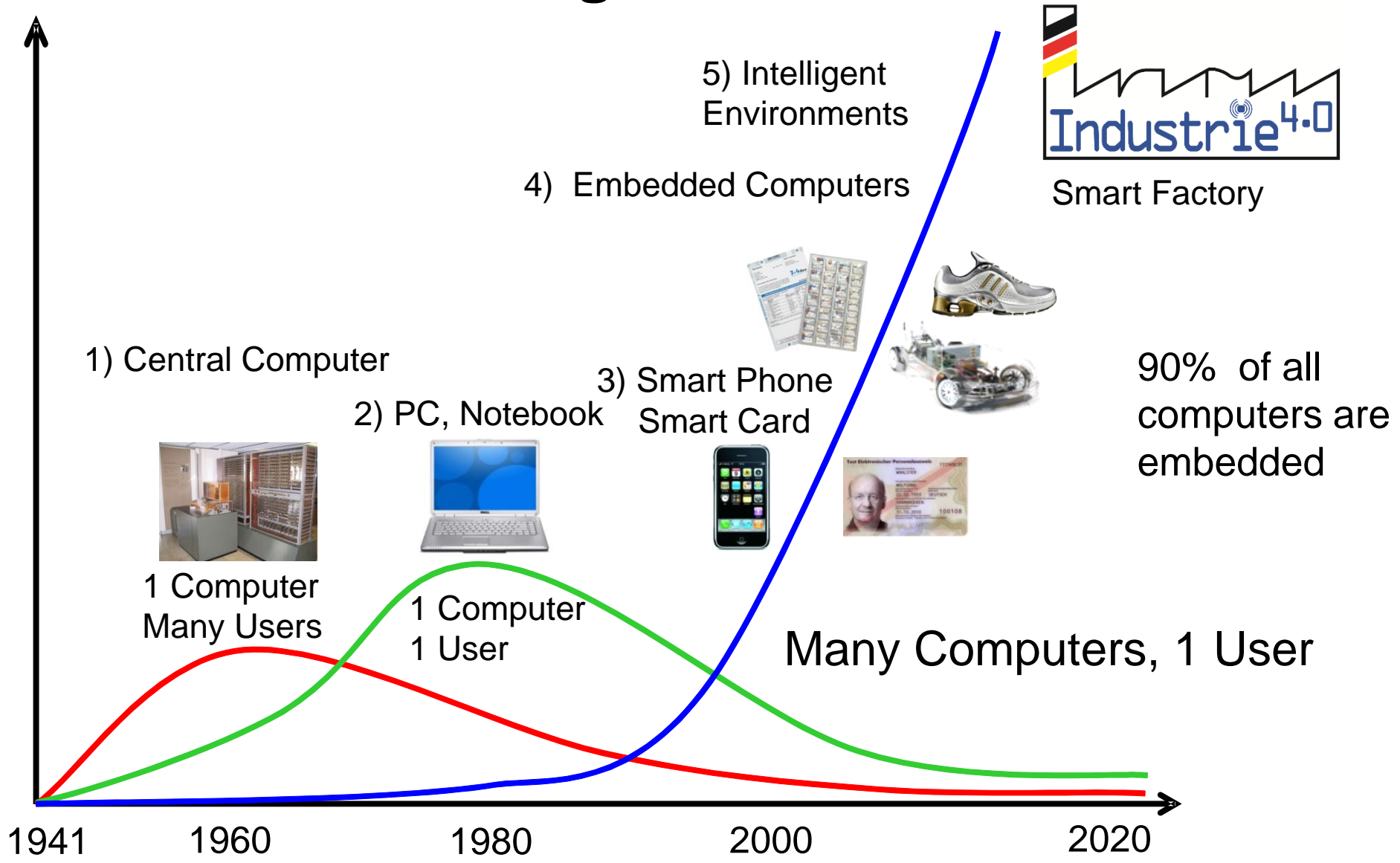
German Research Center for Artificial Intelligence  
Saarbrücken, Kaiserslautern, Bremen, Berlin, Osnabrück

Phone: +49 (681) 85775-5252/4162

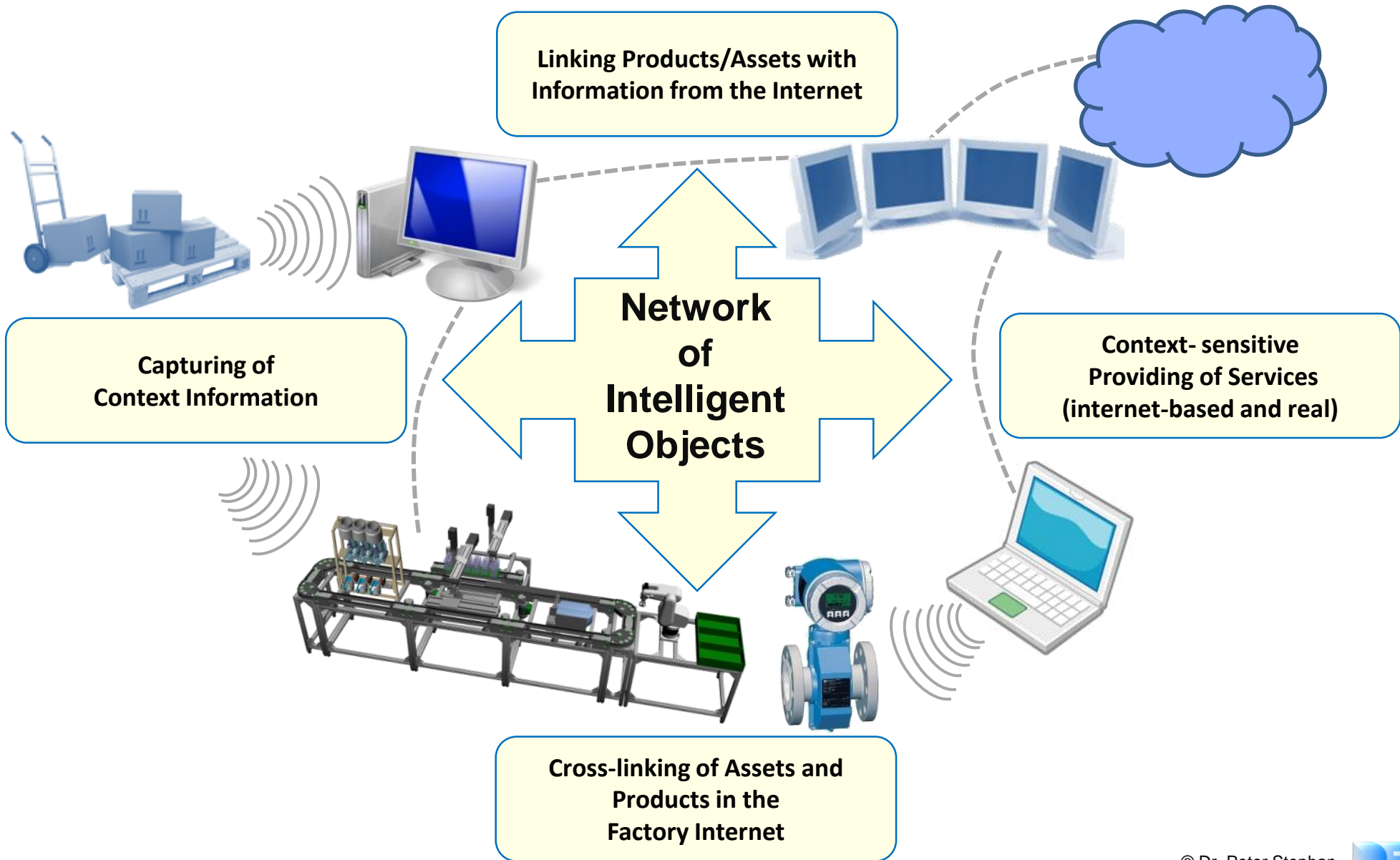
Email: [wahlster@dfki.de](mailto:wahlster@dfki.de)

WWW: <http://www.dfki.de/~wahlster>

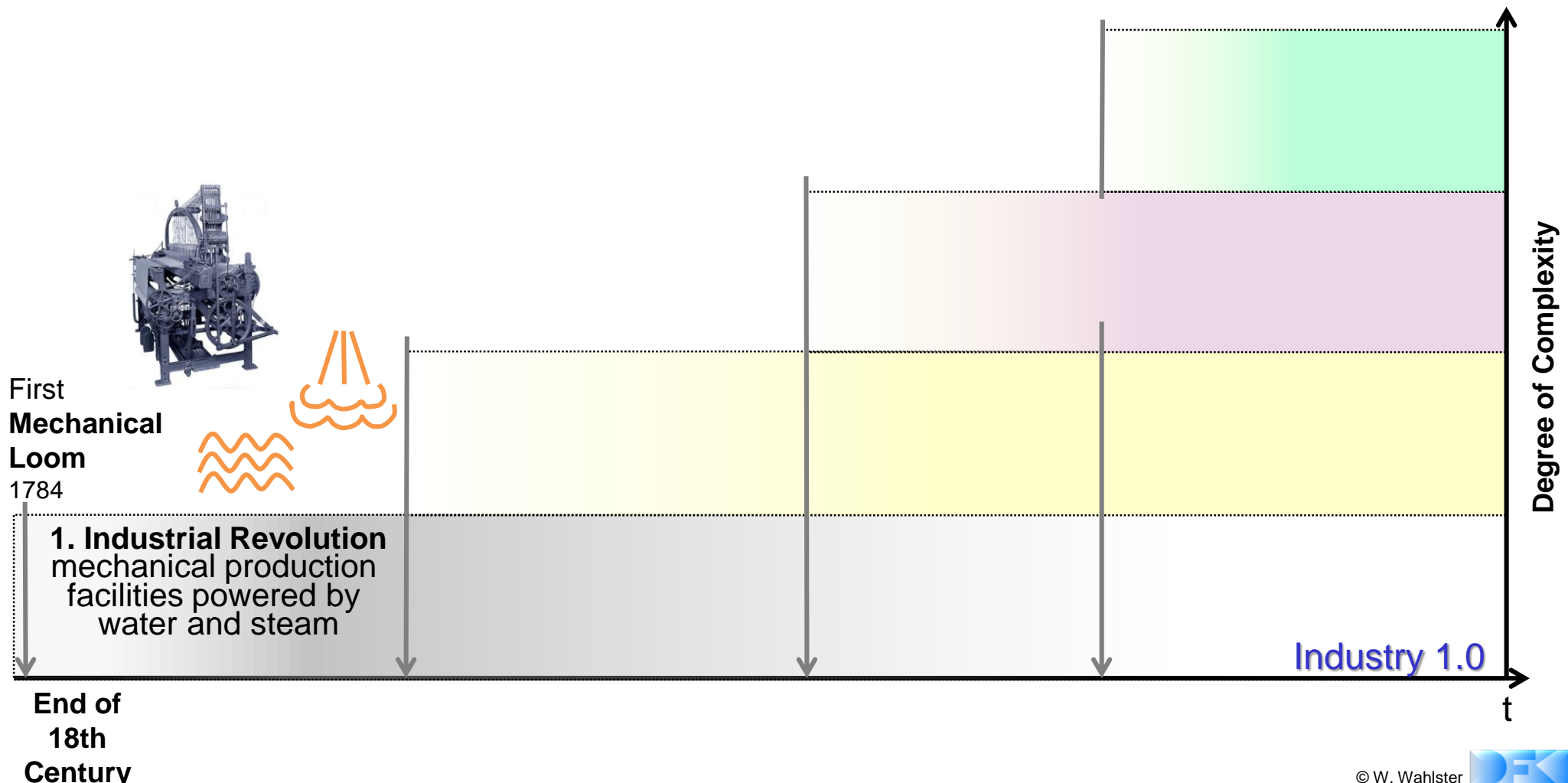
# Towards Intelligent Environments based on the Internet of Things and Services



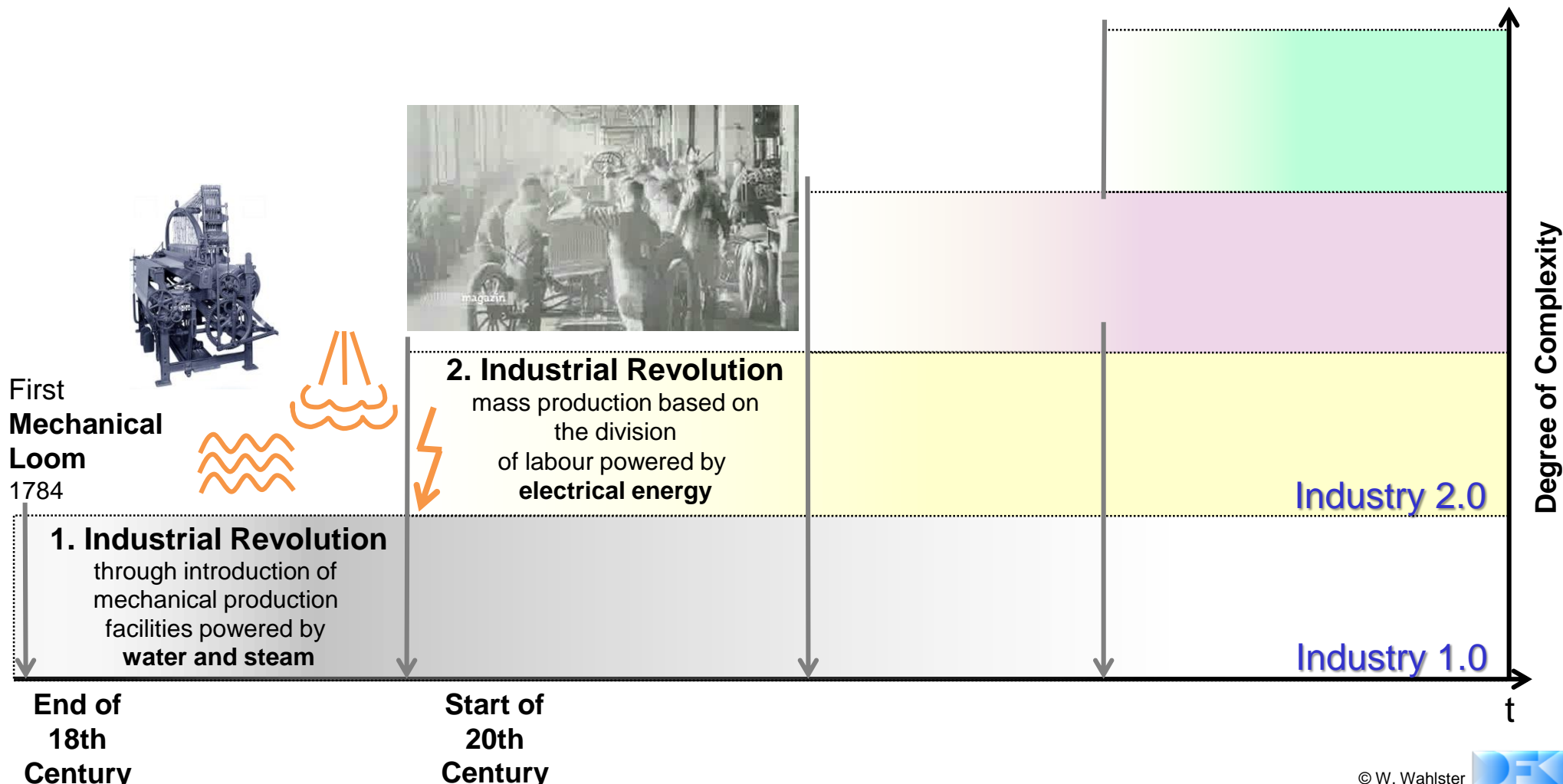
# The Smart Factory as a Network of Intelligent Objects



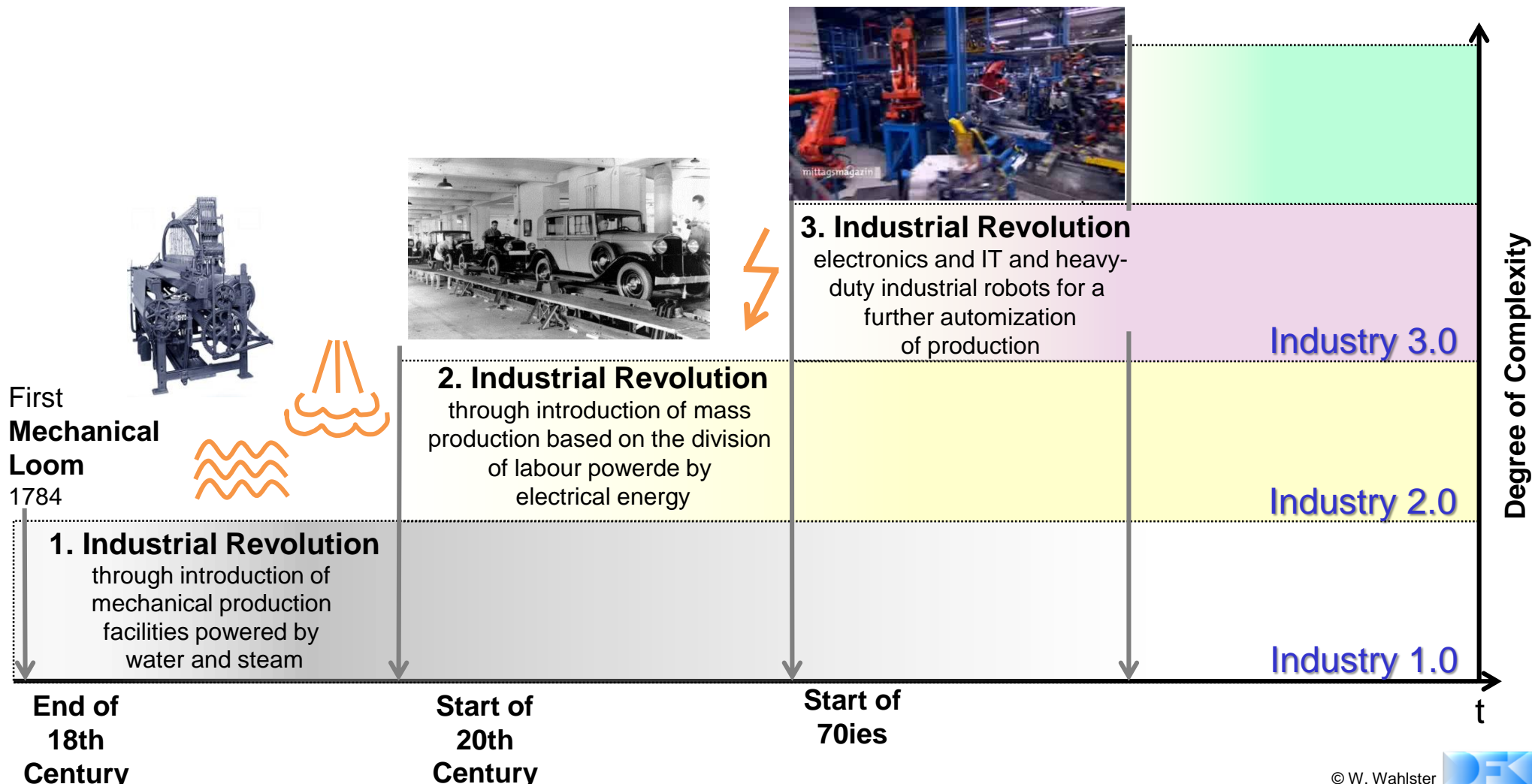
# From Industry 1.0 to Industrie 4.0: Towards the 4th Industrial Revolution



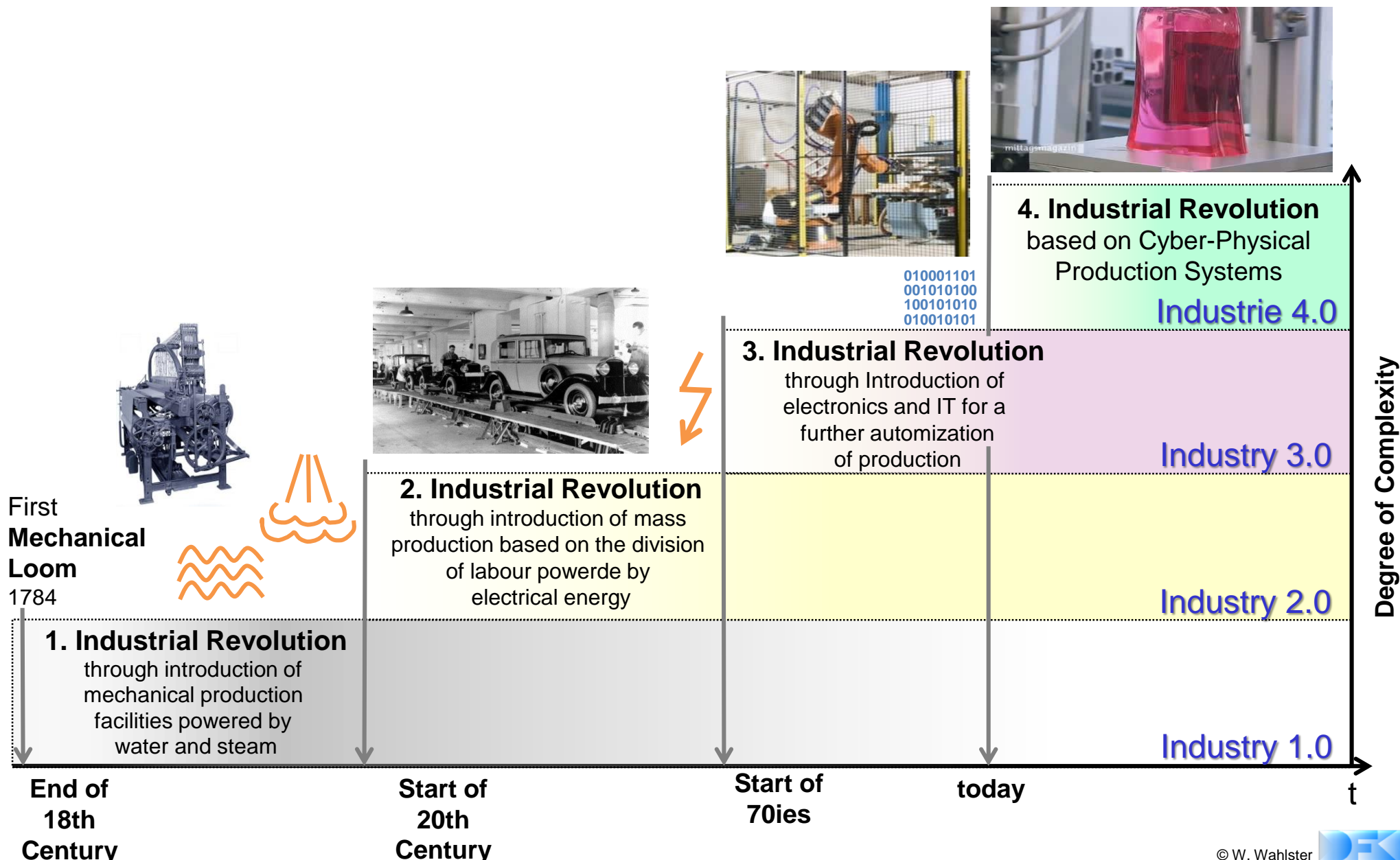
# From Industry 1.0 to Industry 4.0: Towards the 4th Industrial Revolution



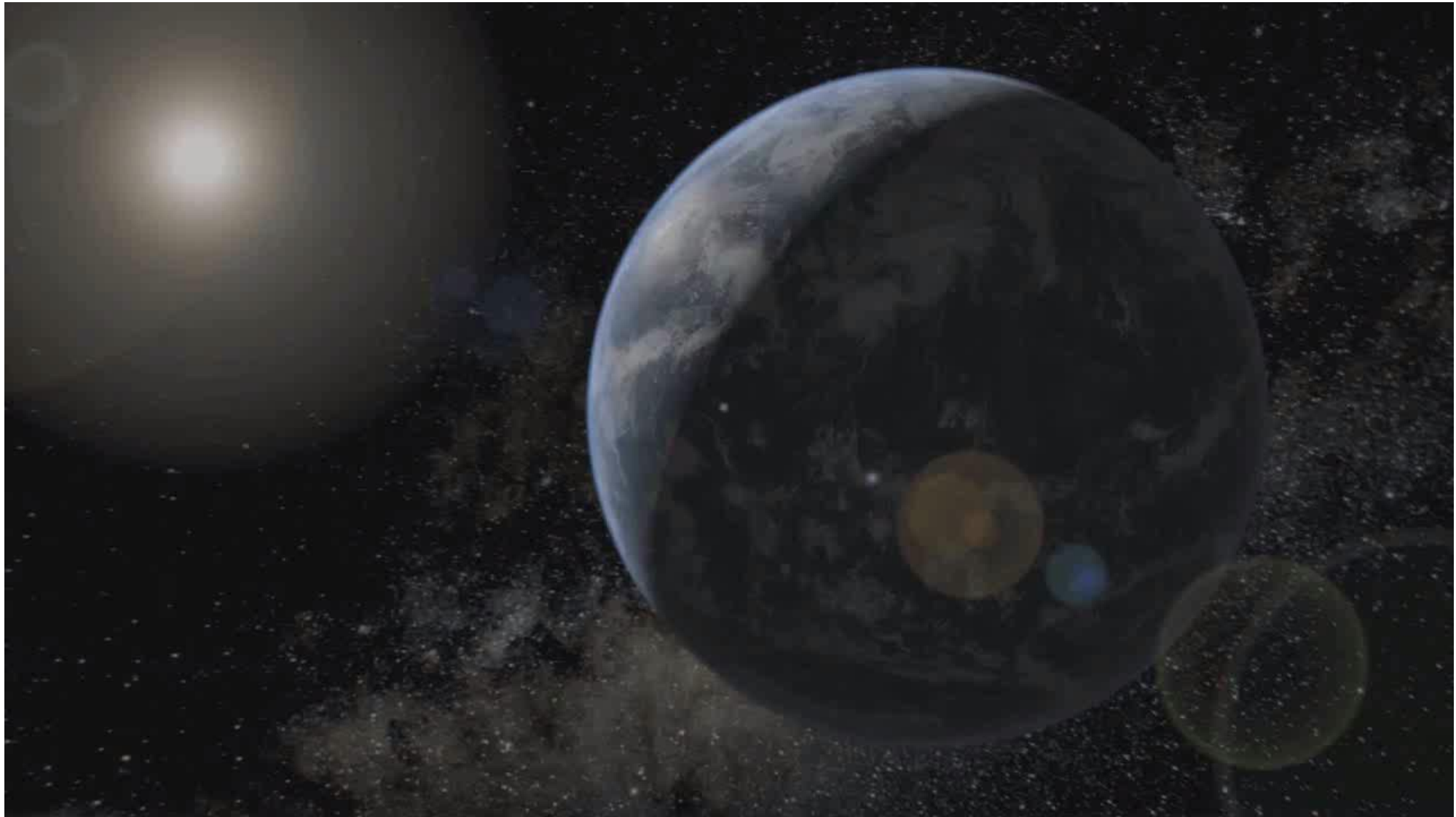
# From Industry 1.0 to Industry 4.0: Towards the 4th Industrial Revolution



# From Industry 1.0 to Industry 4.0: Towards the 4th Industrial Revolution

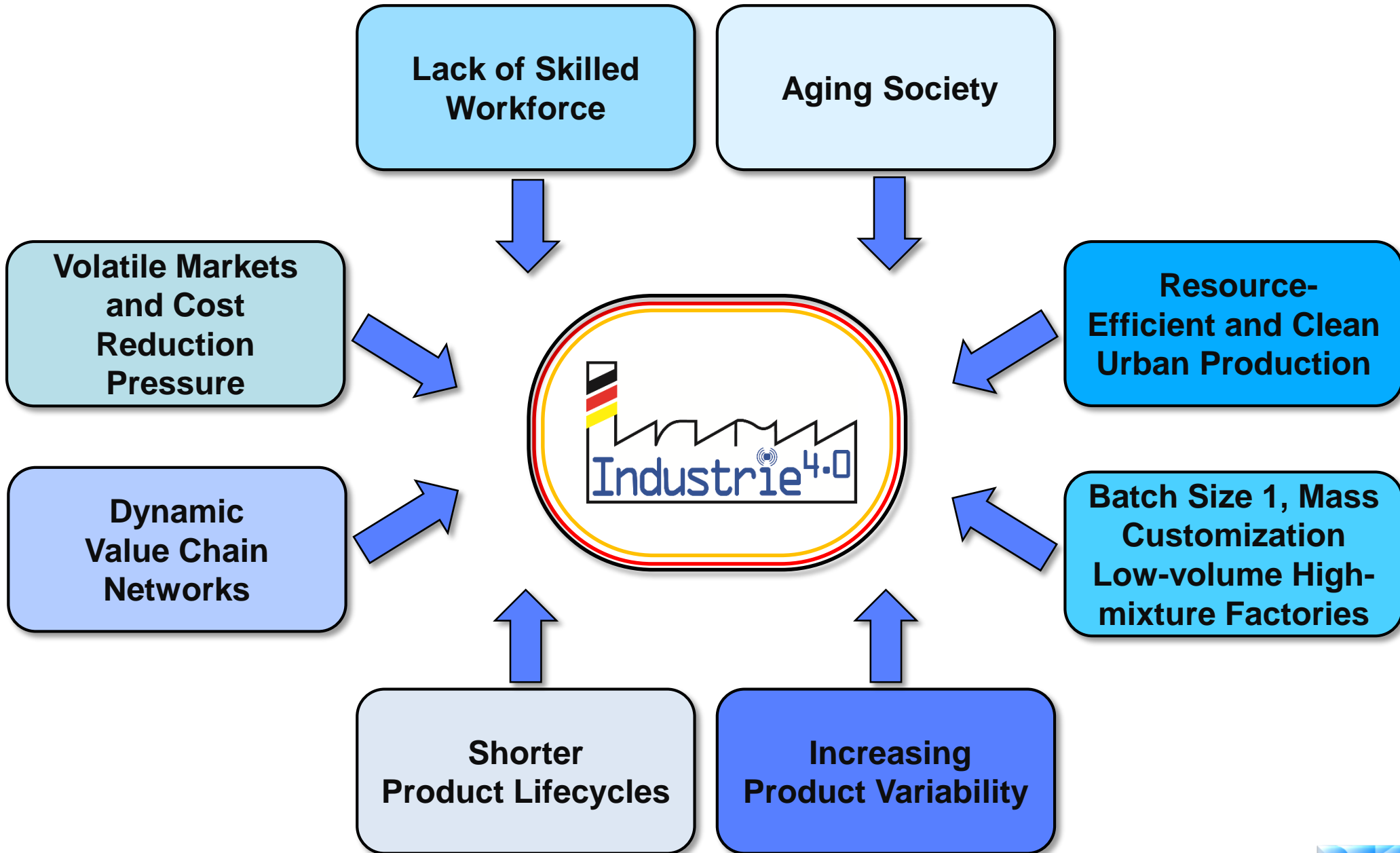


# Industrie 4.0: The Fourth Industrial Revolution





# Economic and Social Drivers



# Digital Production with Batch Size 1

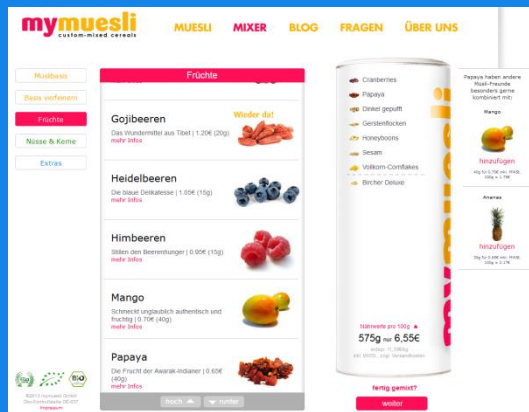
## Internet of Services

Using Internet portals to configure and order a personalized product

Future Project:



### Smart Shop: Innovative Retail Software



Make to Order

Tailored production:  
566 billion  
variants of custom-  
mixed cereals  
from:

**mymuesli**  
custom-mixed cereals

### Smart Factory: Innovative Factory Software



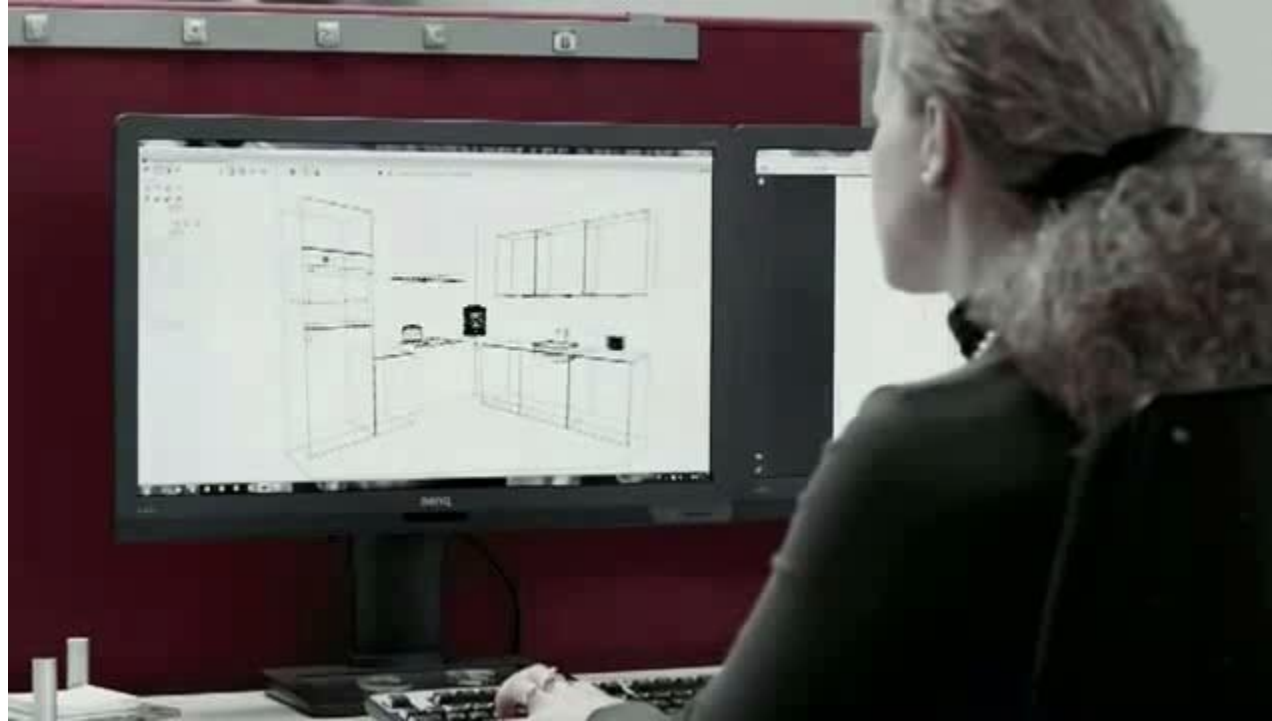
## Internet of Things Active Product Memories

Service-based manufacturing control based on CPSS

Future Project:



# Batch Size 1 Production of Complete Kitchens with Cyber-physical Production Systems



Nobilis: Largest Kitchen Manufacturer in Europe

560.000 complete kitchens per year

2.600 kitchens per day

14 million variants

Export quota 40%

- **Industrial production is the backbone of Germany's economic performance:**
  - jobs direct: 7,7 Million. indirect: 7,1 Million, every second job
  - more than als 158 € Billion trade surplus from export of industrial products
  - (export : machine tool industry, automotive industry)
- **Disruptive Paradigm Shift in Production based on the Future Internet**
  1. M2M and All-IP Factories are shifting from central MES to decentralized item-level production control
  2. The embedded digital product memory tells the machines, which production services are needed for a particular emerging product.
  3. Green and urban production based on cyber-physical production systems
  4. Apps for software-defined products and smart product services

**Germany is preparing the 4th industrial revolution based on the Internet of Things, Cyber-physical Production Systems, and the Internet of Services in Real industry.**

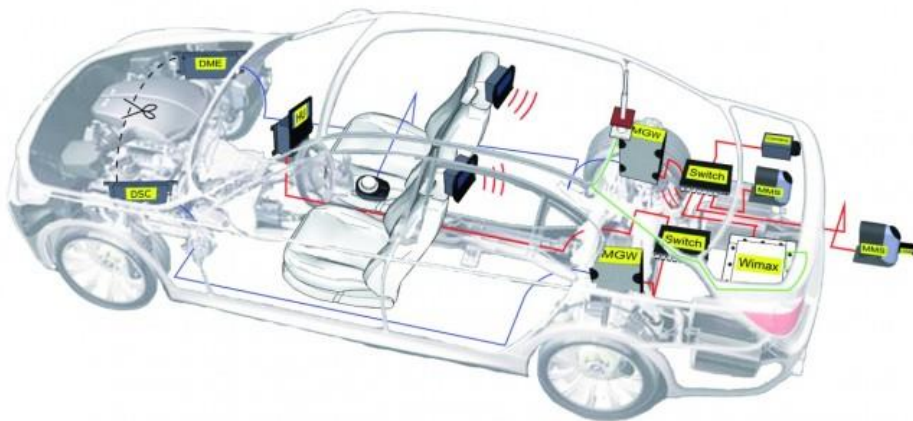
# Boosting Successful Classical Key Industries by Internet Technologies and CPS-based AI Systems

Examples in Germany: Automotive Industry and Factory Automation

## Two Revolutions: The Internet of Things and Services for the IP Car and the IP Factory

~~Special Bus Systems  
(eg. CAN, MOST, LIN, FleyRay)  
in the Car~~

~~Special Field Buses  
in factories (eg. Profibus, Interbus, CANopen,  
ControlNet, CC-Link, DeviceNet)~~



Smart Product: SEIS & SimTD:  
Internet in and between Cars



Industrie 4.0:  
Internet and Cyber-Physical Production Systems  
in Smart Factories

# Future Project Industrie 4.0 of the German Government



500 M€ for 3 Years  
National Program:  
250 M€ Funding of  
Ministry for Research and  
Ministry for Economics

**Evolution** from  
Embedded Systems  
to Cyber-Physical  
Systems

**Internet of Things**

**Intelligent Environments/Smart Spaces**  
Smart City

**Cyber-Physical Systems**  
Smart Factory, Smart Grid

**Networked Embedded  
Systems**

Intelligent Street Crossing

**Embedded  
Systems**  
Airbag

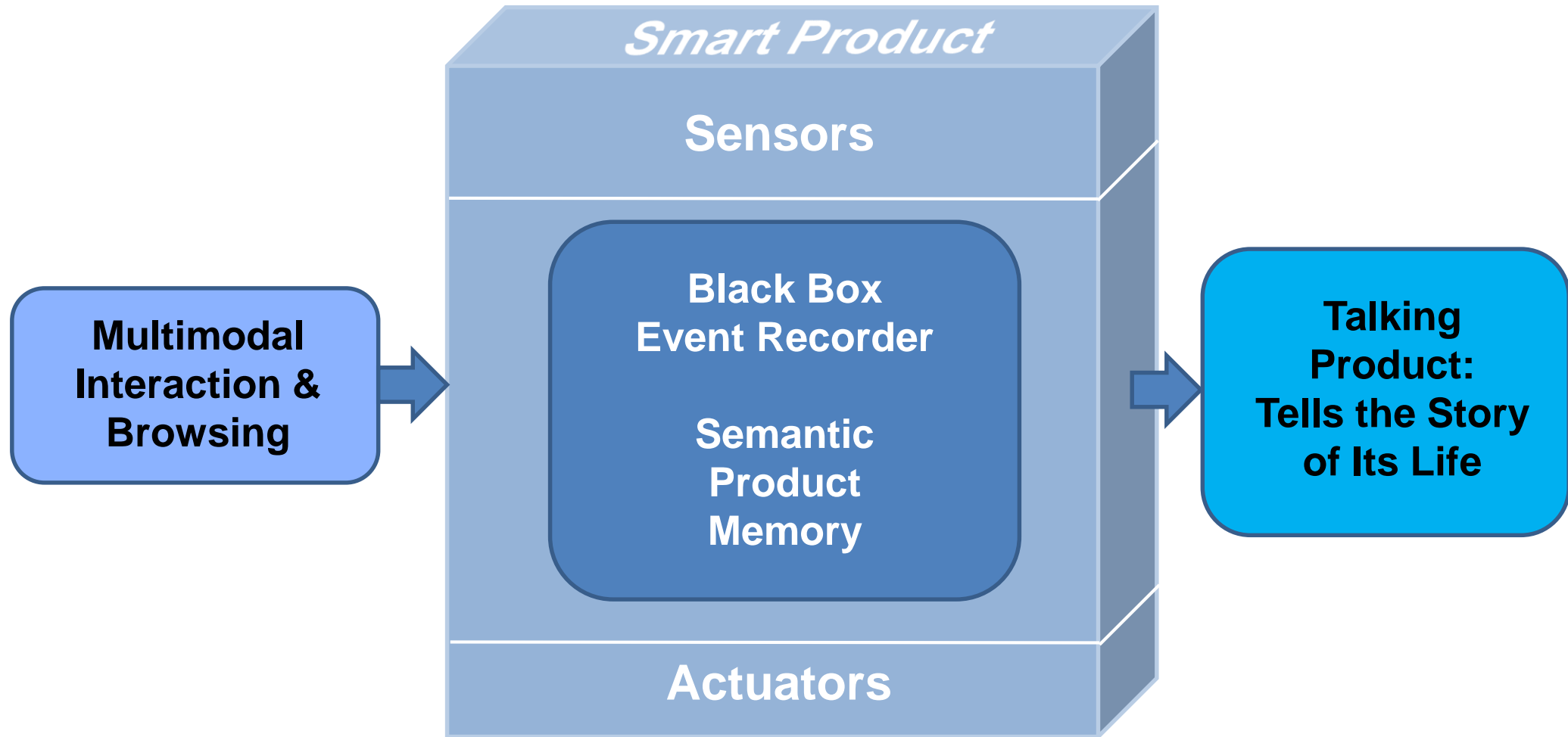
**National Roadmap  
Embedded Systems**

**Agenda  
Cyber-Physical  
Systems**

# Outline of the Talk

- 1. From Embedded Systems to Cyber-Physical Systems in the Smart Factory**
- 2. The Role of Active Semantic Product Memories in Cyber-Physical Production Systems**
- 3. Semantic Web Services in a SOA Model of Cyber-Physical Production Systems**
- 4. Industrial Assistance Systems Based on Digital Product Memories**
- 7. Conclusion**

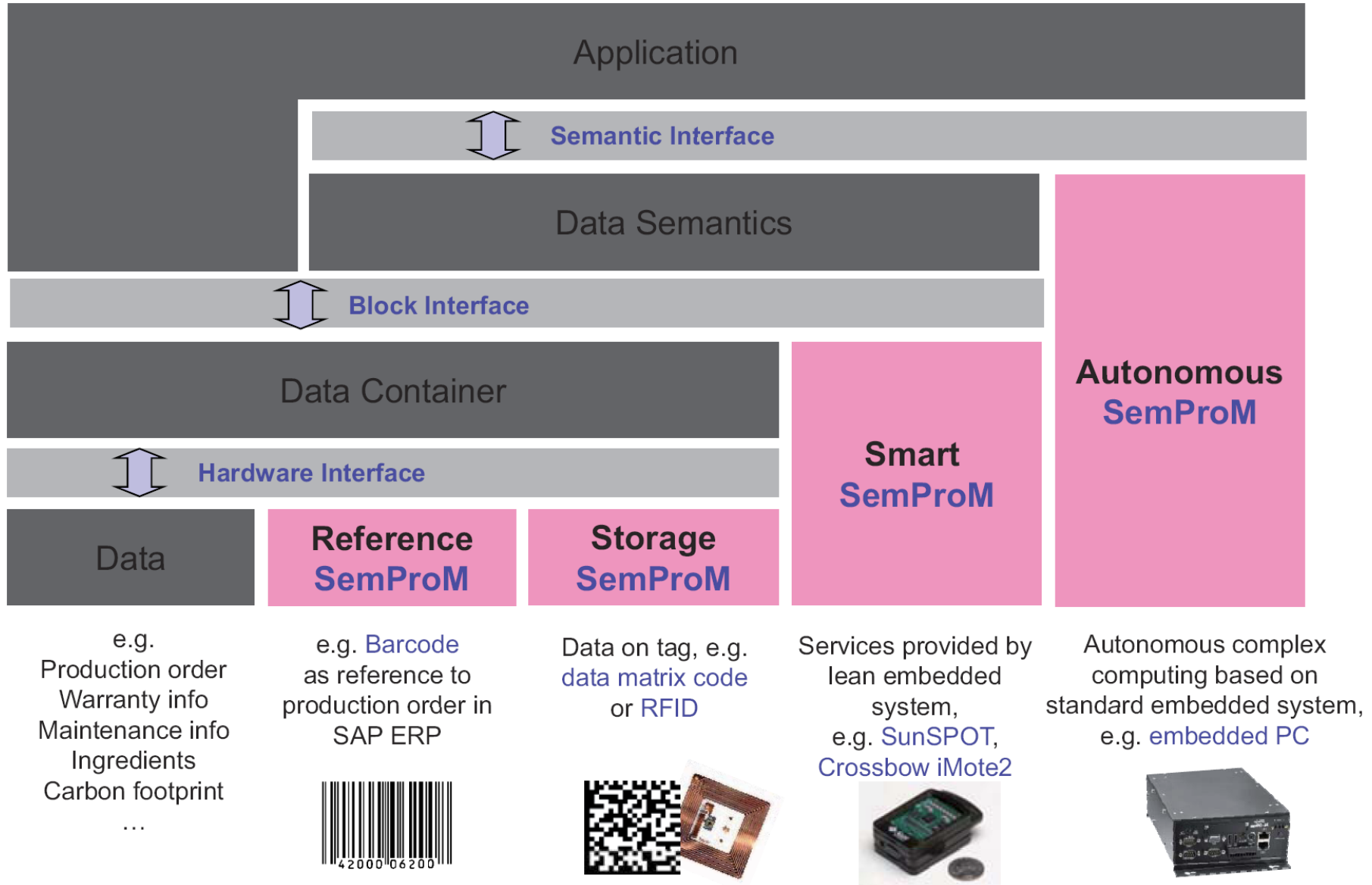
# The Semantic Product Memory Stores a Diary of an Individual Smart Object.



**The Smart Product monitors itself and its environment.**



# Four Hardware Realizations of SemProMs



# Products with Integrated Dynamic Digital Storage, Sensing, and Wireless Communication Capabilities

## ⇒ The product as an information container

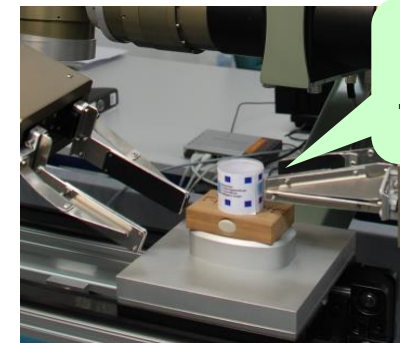
- The product carries information across the complete supply chain and its lifecycle.



I was produced on 30 April 2010 and shipped on 3 May 2010

## ⇒ The product as an agent

- The product affects its environment



Grasp at the middle

## ⇒ The product as an observer

- The product monitors itself and its environment

2 mins open  
Please close!



# Interoperability for M2M-Communication in Industry 4.0

## **μ webserver**

32bit ARM processor  
8MB SDRAM  
100Mbit Ethernet & Wi-Fi  
LINUX on DIGI Connect

**OPC-UA**  
(Open Process Control  
Unified Architecture)  
**Server for M2M**



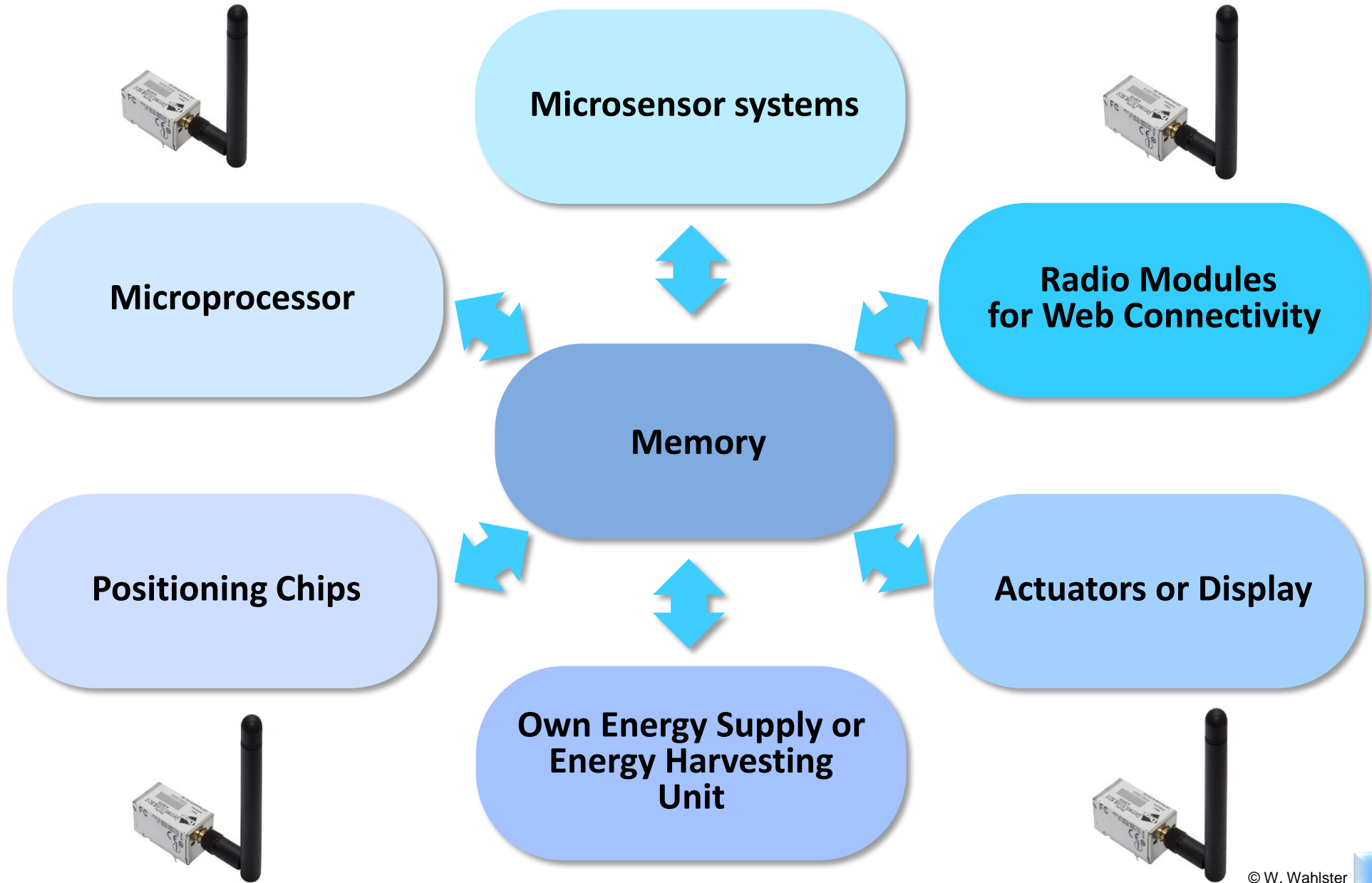
The heart of an industrial CPS: XML-based Web server or very fast binary communication based on the TCP protocols

# DFKI's SmartFactory: The World's First Living Lab for Cyber-Physical Production Systems



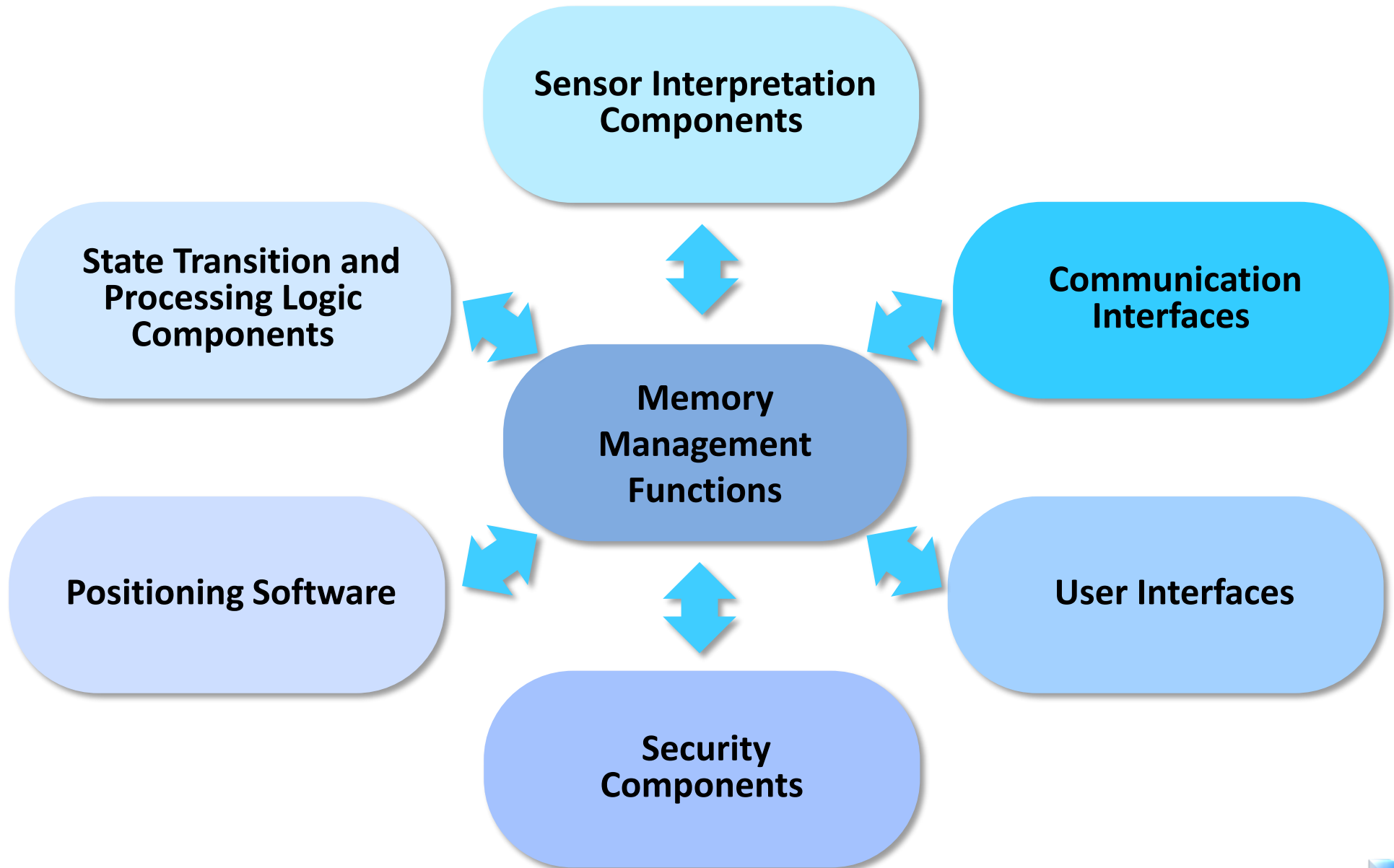
# CPS Hardware for a Digital Object Memory

embedded or attached to a physical object



# CPS Software for a Digital Object Memory

embedded or attached to a physical object



# From Bits and Bytes to Semantics

driven by  
**Electrical Engineering**

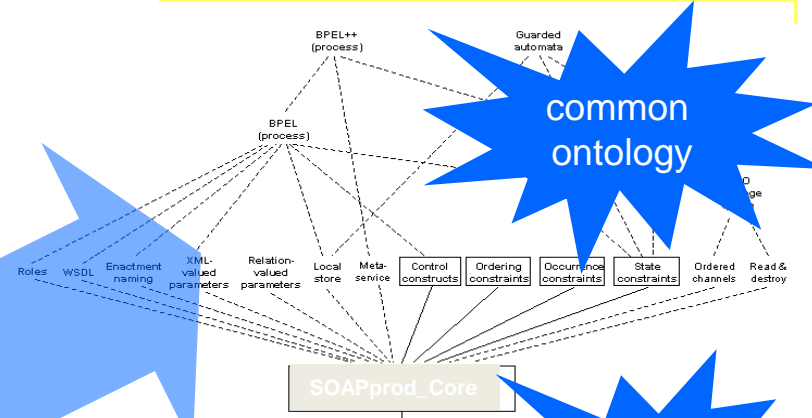
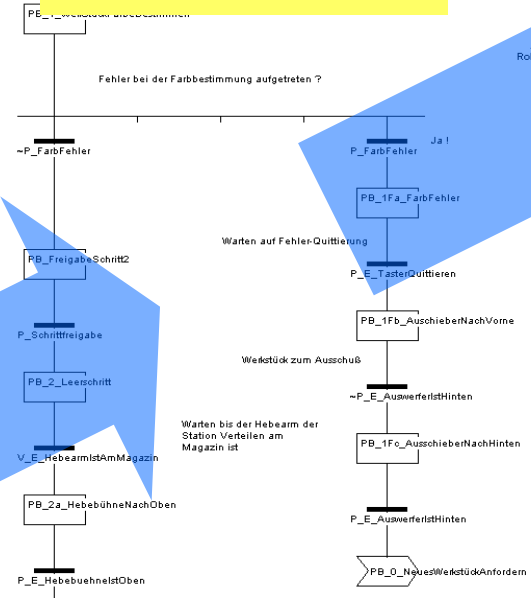
driven by  
**Software Engineering**

To semantic services

From bits and bytes

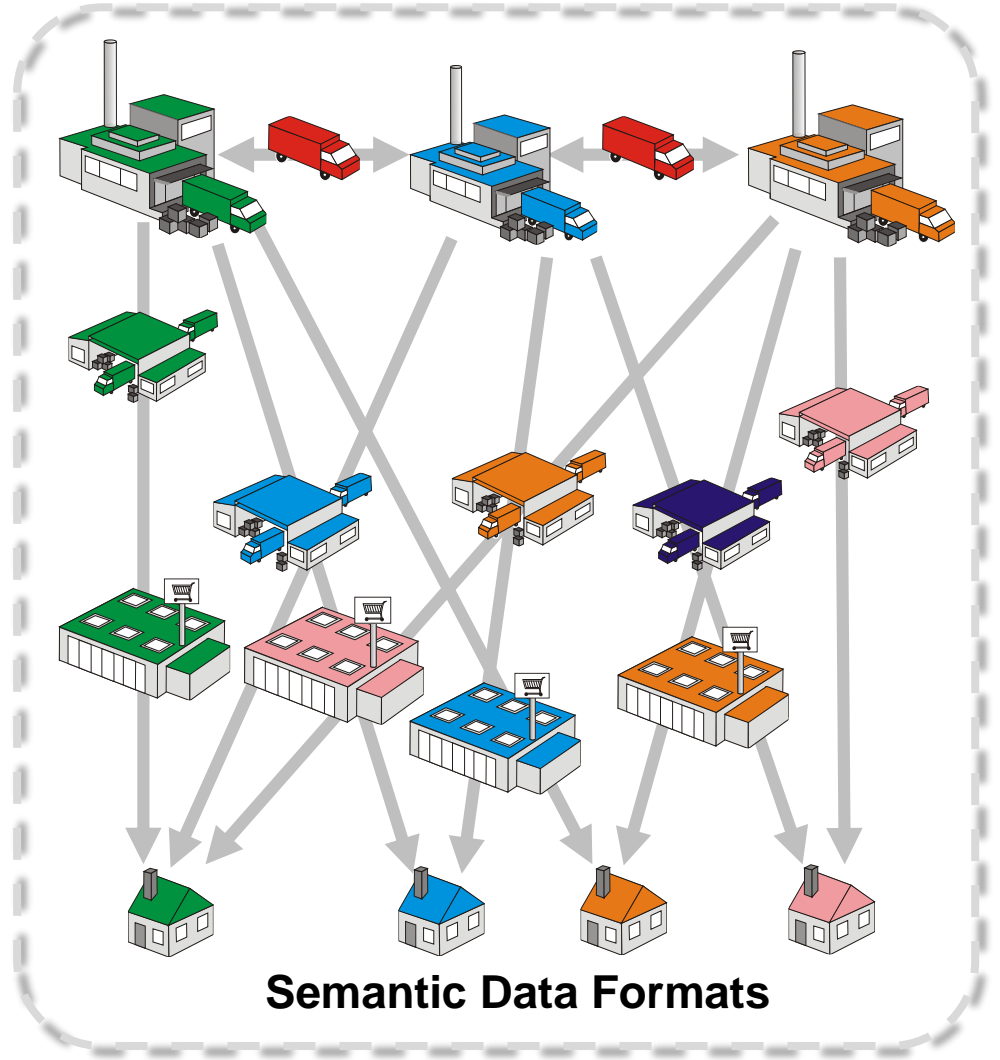
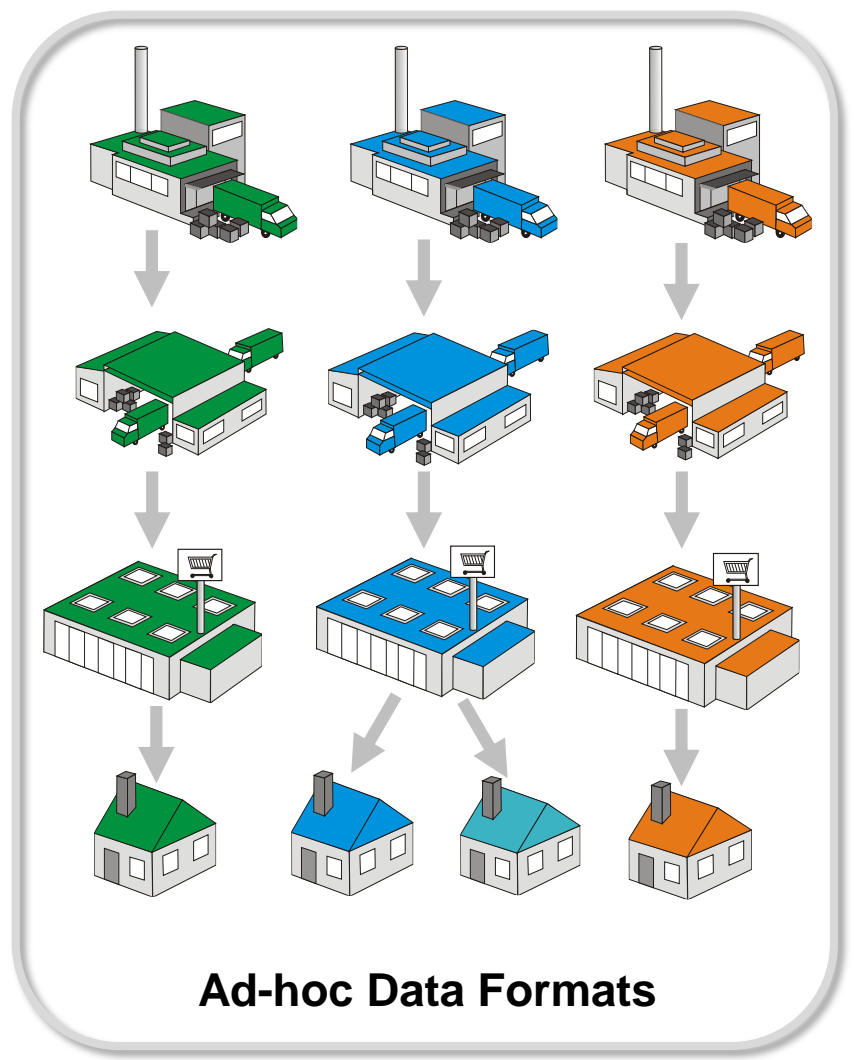
Antrieb einschalten		
U	E_FERN	;Antrieb auf Fern
UN	E_STOER	;keine Störung
UN	E_NOTAUS	;Not-Aus nicht bet.
U		
UN	HAND	;nicht Hand-PLS
U	AUTO_EIN	;Auto-EIN Befehl
O		
U	HAND	;Hand-PLS
U		
O	HAND_EIN	;Hand-EIN-Befehl PLS
O	A_EIN	;Selbsthaltung
]		
=	A_EIN	;Antrieb EIN
BE		

Via functions



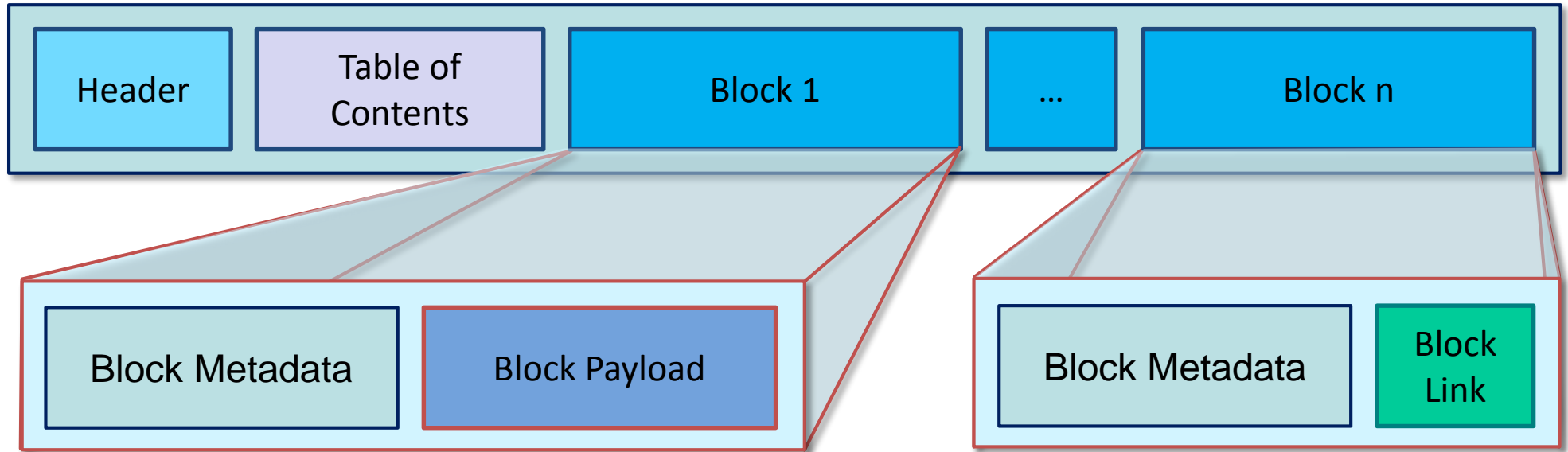
driven by  
**Semantic Technologies**

# Closed-Loop versus Open-Loop Product Memories

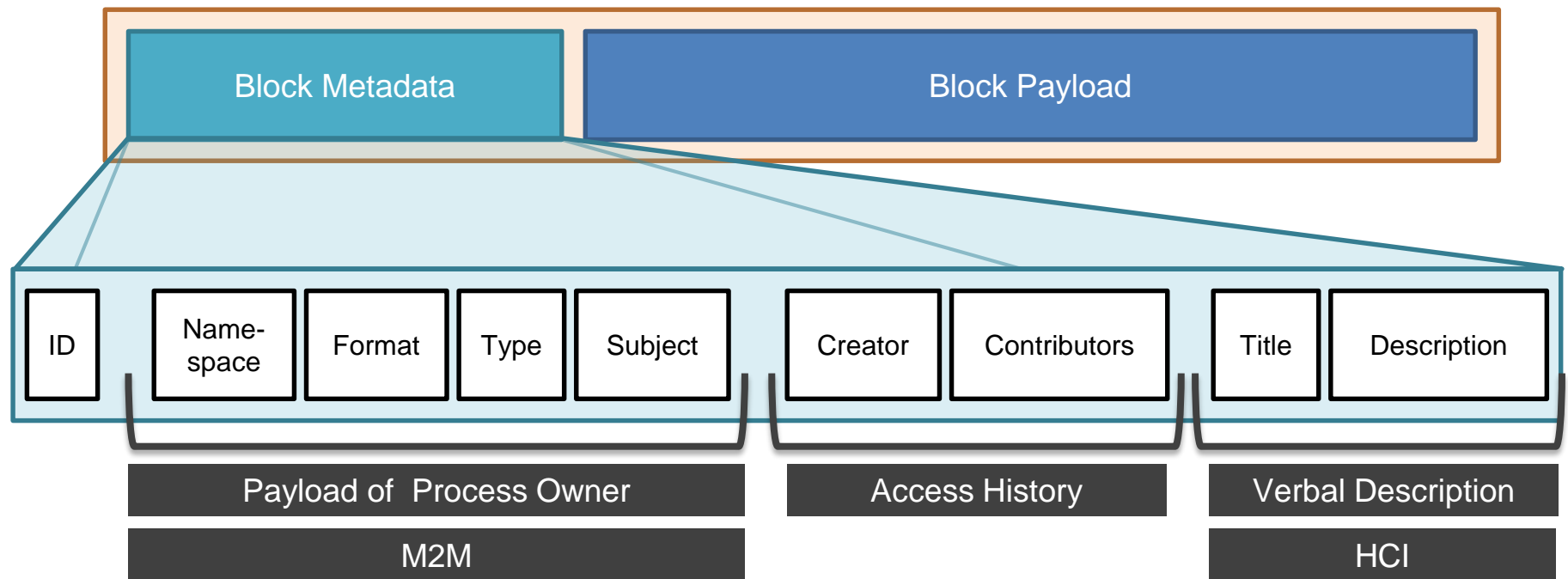




# The Structure of the Object Memory Model (OMM, W3C Standardization)



# Meta Descriptions for the Semantics of Payloads for Process Owners



```
<omm:omm>  
<omm:header>  
  <omm:version>1</omm:version>  
  <omm:primaryID  
    omm:type="url">http://www.w3.org/2005/Incubator/omm/samples/p1</omm:primaryID>  
  <omm:additionalBlocks omm:type="omm_http">  
    http://www.w3.org/2005/Incubator/omm/samples/p1/ext</omm:additionalBlocks>  
</omm:header>
```

Header

Identifier

```
<omm:toc>...</omm:toc>
```

Block

Description for Machines

External Blocks

```
<omm:block omm:id="11">  
  <omm:format omm:schema=  
    "http://www.w3.org/2005/Incubator/omm/schema/attributeList.xsd">  
    application/xml</omm:format>  
  <omm:title xml:lang="en">log event</omm:title>  
  <omm:subject><omm:tag omm:type="text" omm:value="event" /></omm:subject>  
  <omm:payload>  
    <omm:attributeList>  
      <omm:attribute omm:key="action">Transport</omm:attribute>  
      <omm:attribute omm:key="begin">2013-01-11T19:03:00+01:00</omm:attribute>  
      <omm:attribute omm:key="end">2013-01-11T19:04:00+01:00</omm:attribute>  
    </omm:attributeList>  
  </omm:payload>
```

Description for Humans

Key Words

Semantic Content

```
...  
</omm:block>  
</omm:omm>
```

# From Bits and Bytes to Semantics

driven by  
**Electrical Engineering**

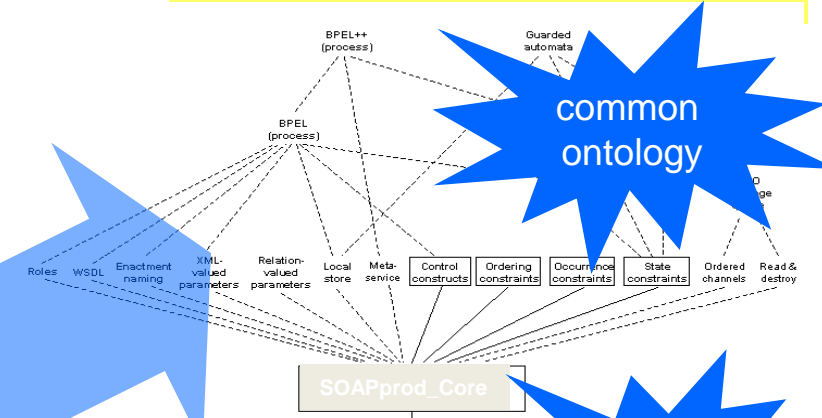
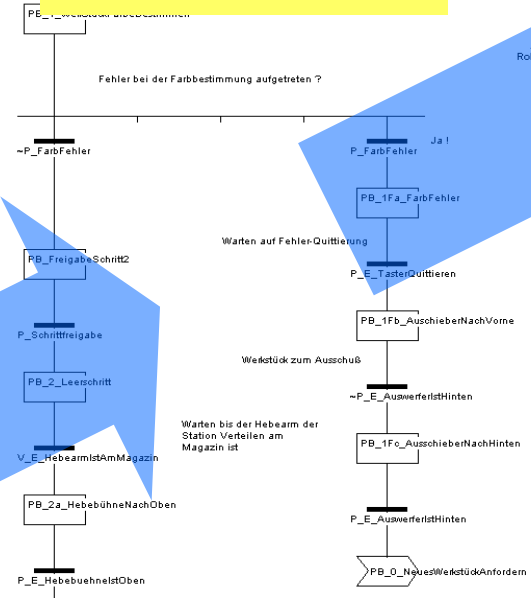
driven by  
**Software Engineering**

To semantic services

Via functions

From bits and bytes

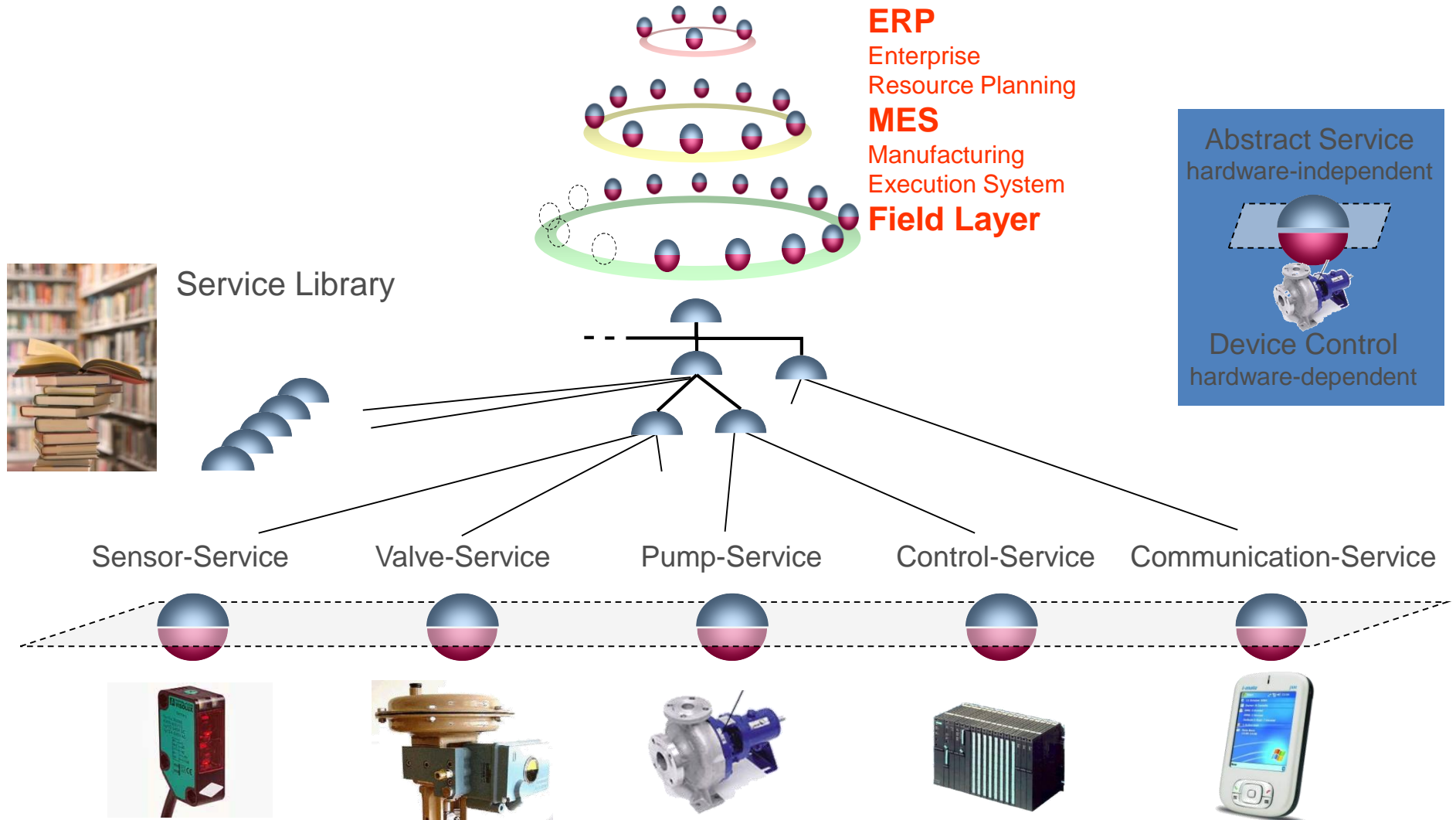
Antrieb einschalten		
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U		
UN	HAND	;nicht Hand-PLS
U	AUTO_EIN	;Auto-EIN Befehl
O		
U	HAND	;Hand-PLS
U		
O	HAND_EIN	;Hand-EIN-Befehl PLS
O	A_EIN	;Selbsthaltung
]		
=	A_EIN	;Antrieb EIN
BE		



**Semantic Technologies**  
 driven by

# Service-Oriented Planning of Plant Systems

Hardware-independent planning of plant systems



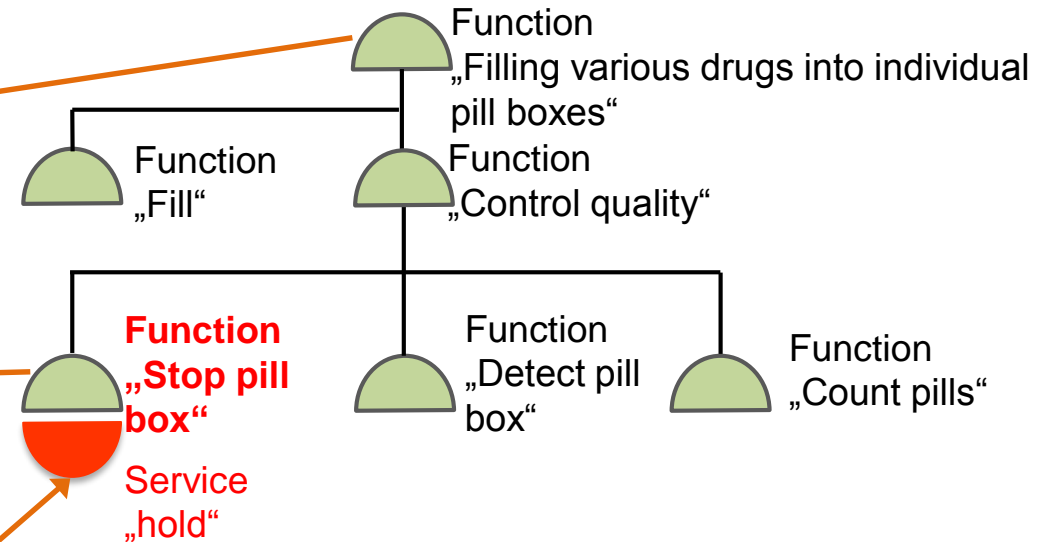
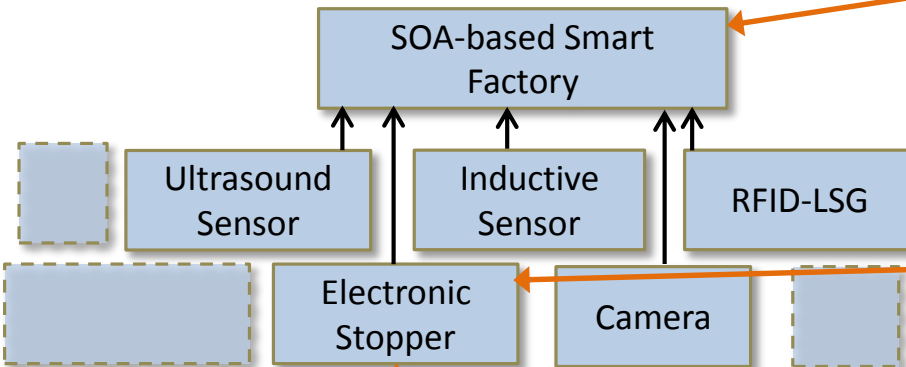
**Industrie 4.0: All-IP Factories, no chaos of field buses, Internet-based Factory Networking based on IoS and IoT**

# Semantic Web Services for Industrie 4.0:

## The Semantic SOA Model of the Smart Factory

### Physical Model

### Functional Model



Web-Service „stopper“  
 Operation: „hold“  
 IP 192.168.178.29

### Service Directory



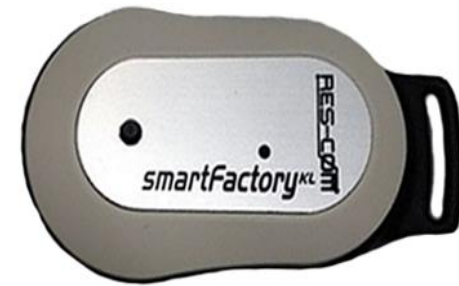
# The Smart Keyfinder with its Semantic Product Memory Chip



Semantic Product Memory Chip in the backcover plastic frame with product specification

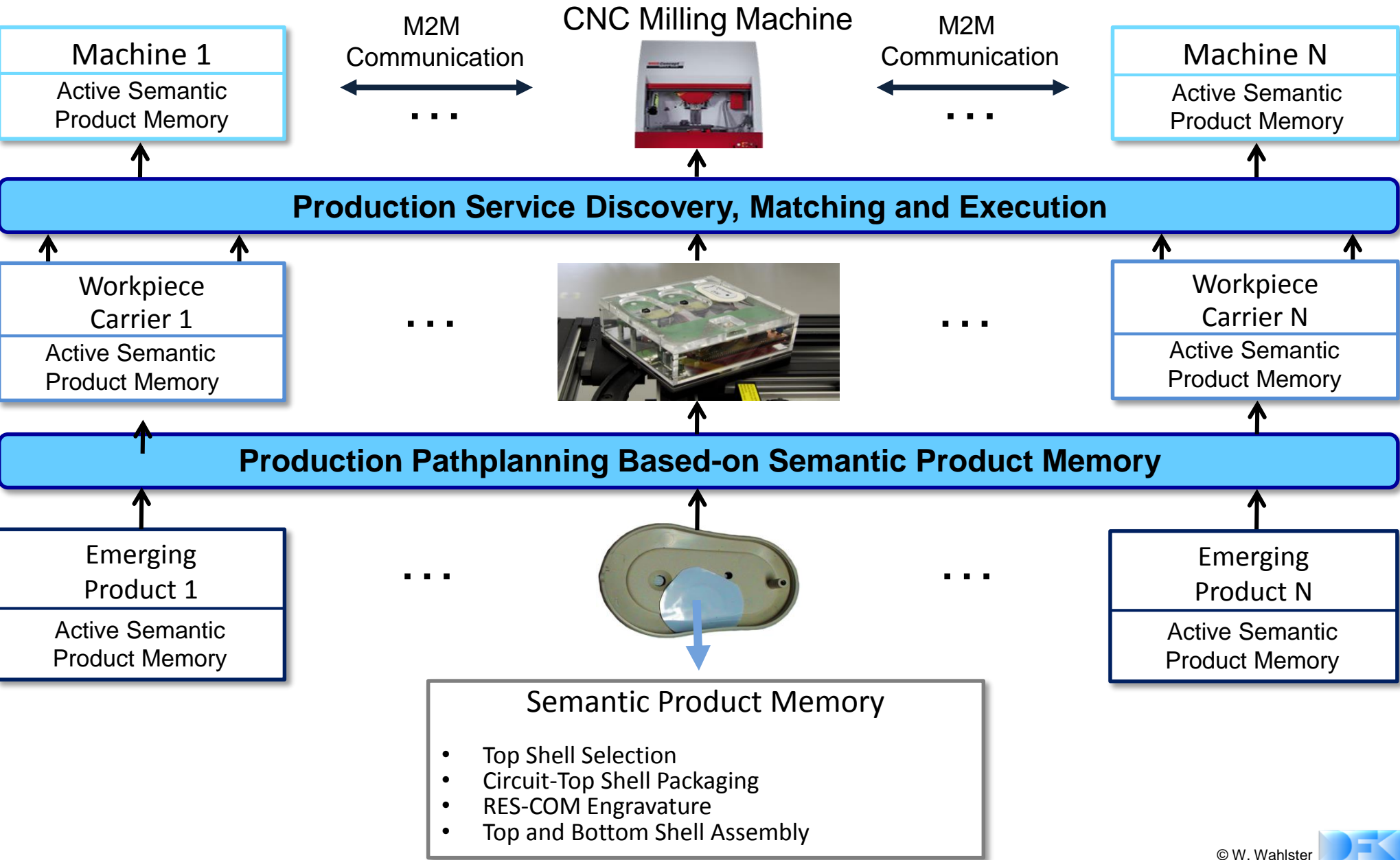


Bluetooth circuit board with keyfinder logic packaged inside a plastic shell



Personalized keychain with custom metal tag on the front produced by an engraving machine

# Key Components of a Service-Oriented Cyber-Physical Production Systems





# The Intelligent Workpiece Carrier: A Complex Cyber-Physical System



# Dynamic Planning Based on Service Composition in a SOA Architecture for Smart Factories

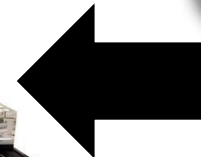


Plug &  
Produce



Green  
Production  
Minimize CO2

Abstract  
Process  
Specification



Conveyor1.transport  
(lowSpeed)

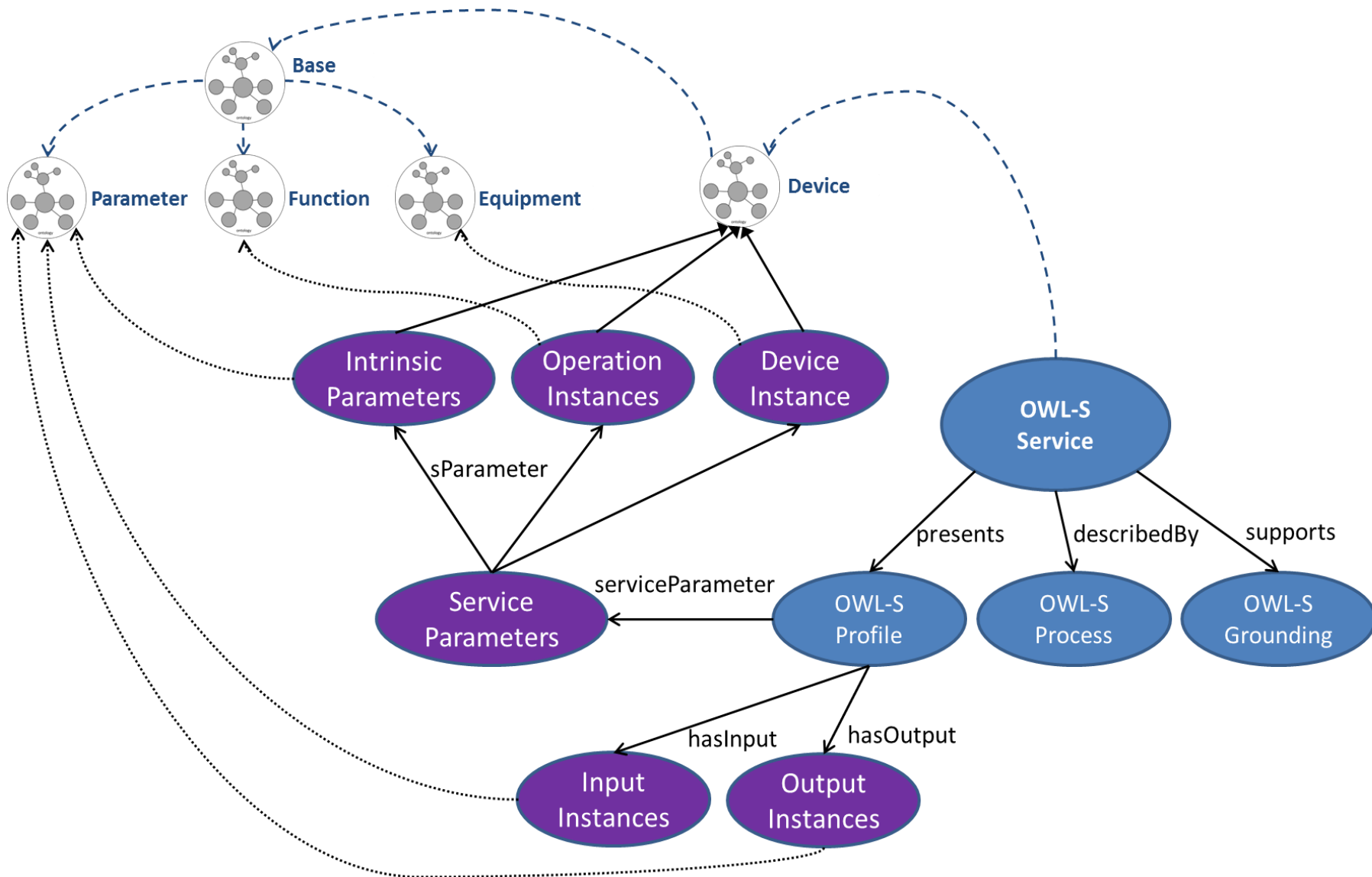
Pick&Place.insertBottom  
(AssemblyPlace4)

Pick&Place.insertBoard  
(AssemblyPlace4)

Pick&Place.insertCap  
(AssemblyPlace4)

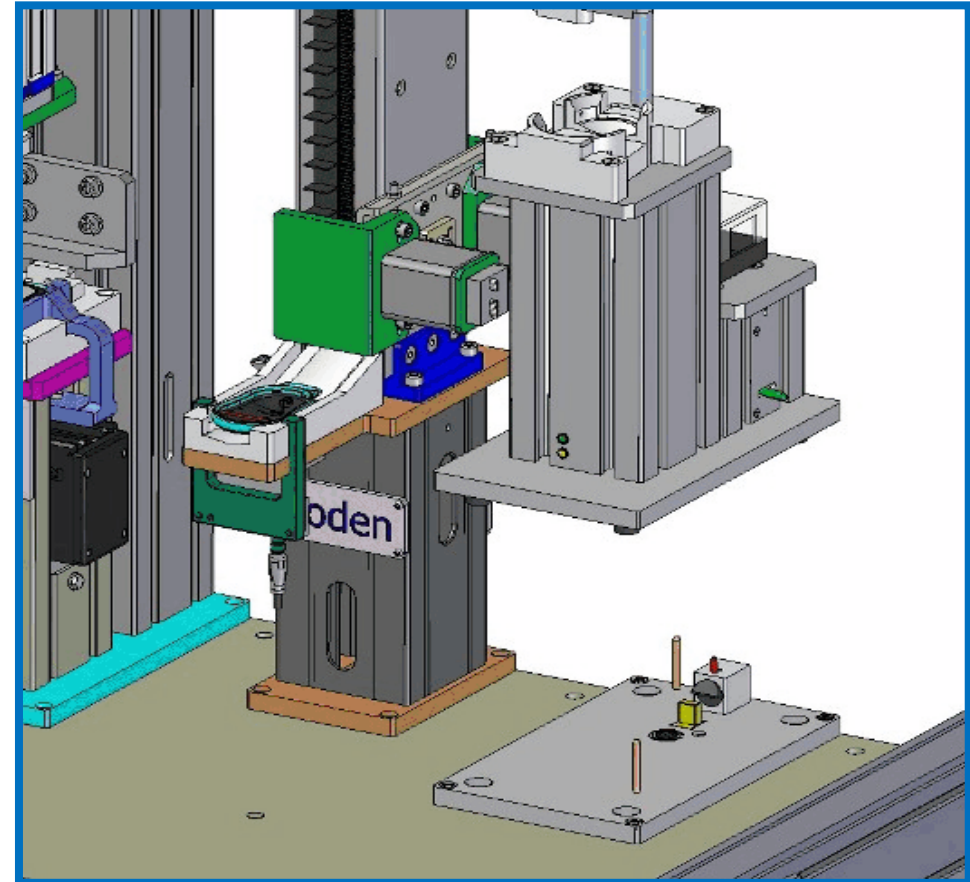
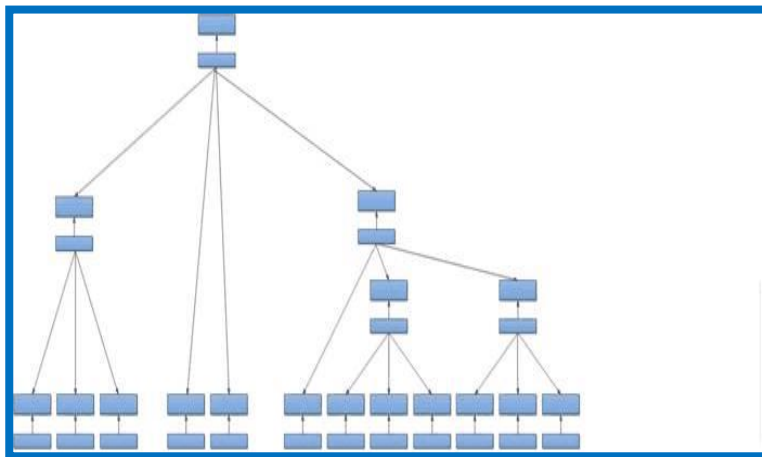
AssemblyPlace4.compress

# Semantic Description of all Factory Components as Services in OWL-S



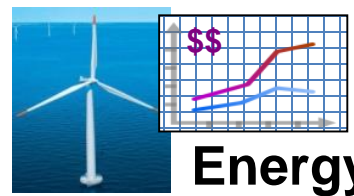
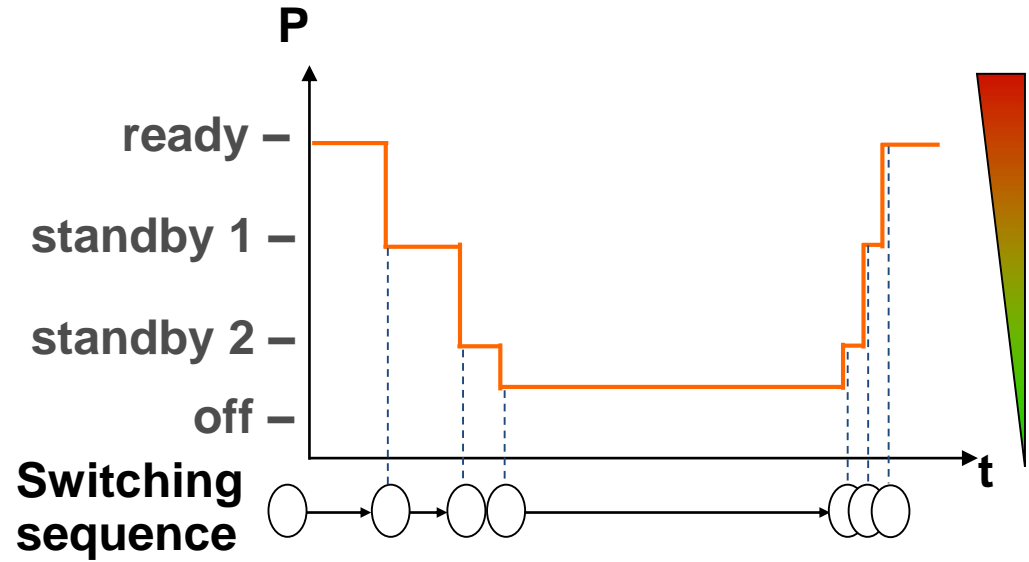
# Plug&Produce based on Adaptive Service Ontologies

- Plugin of CPS production components on a physical, digital and semantic level
- Automated Expansion of the Service Ontology

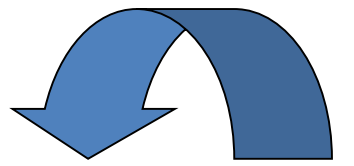
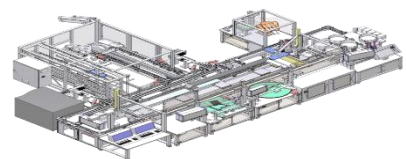


New Assembly Component  
is installed on-the-fly

# Resource-optimal Production Planning based on Dynamic Energy Prize Schemes



## Factory Model



## Goal Function

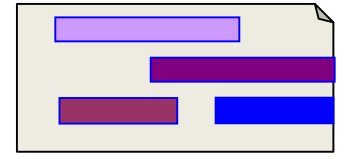
$$f_t = \sum_{d=0}^{\#devices} \sum_{i=now}^{i_{max}} f_e \cdot e(a(i, d)) + f_w \cdot w(a(i, d)) + f_c \cdot c(a(i, d))$$

## Constraints:

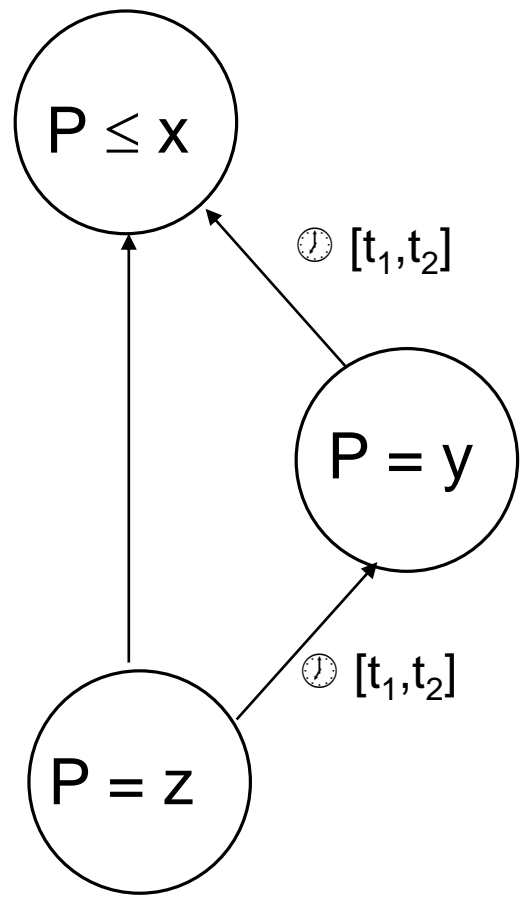
$$\forall w(i) : \exists ! p(i)$$

$$b_{min} \leq b \leq b_{max}$$

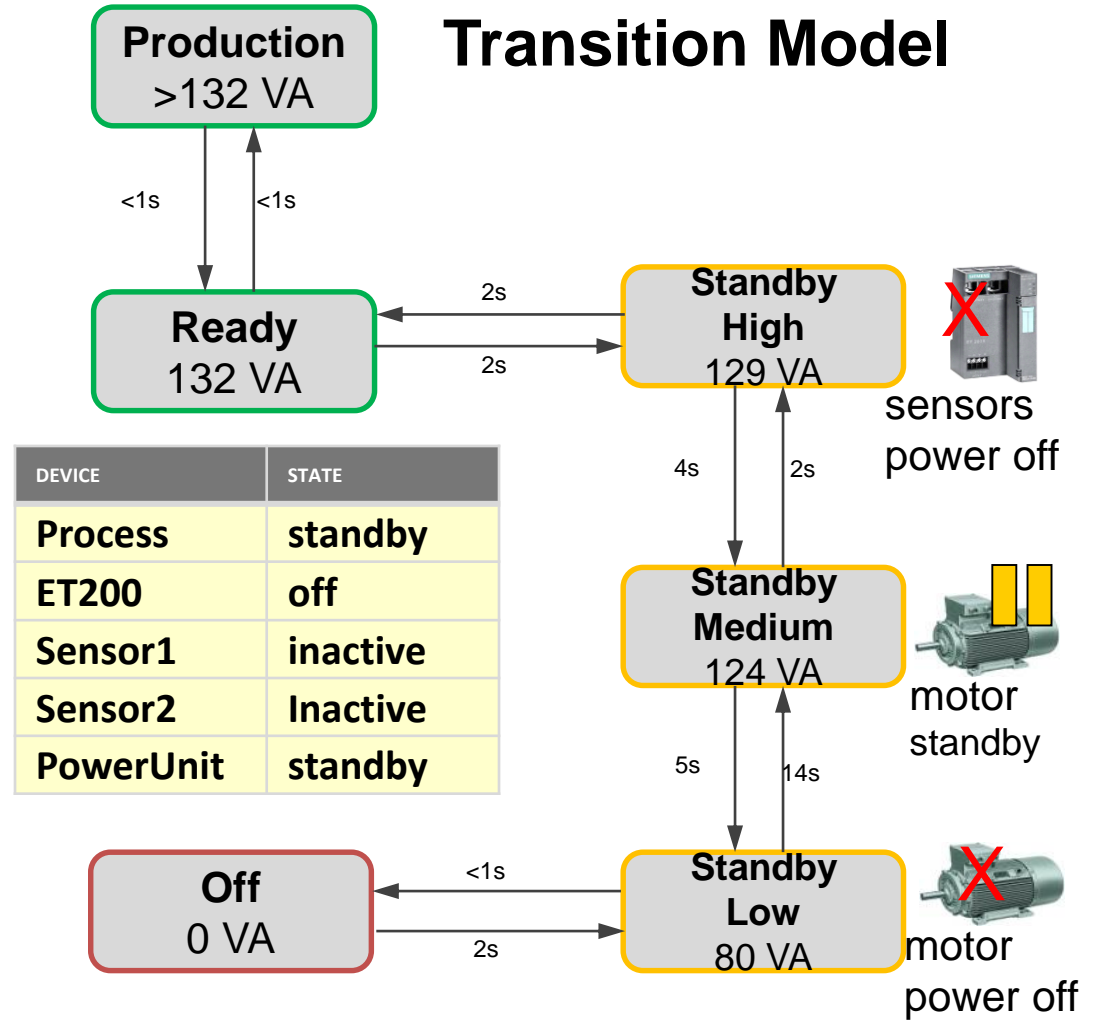
## Schedule:



## Priced Timed Automaton Model



## Resource-Aware State Transition Model

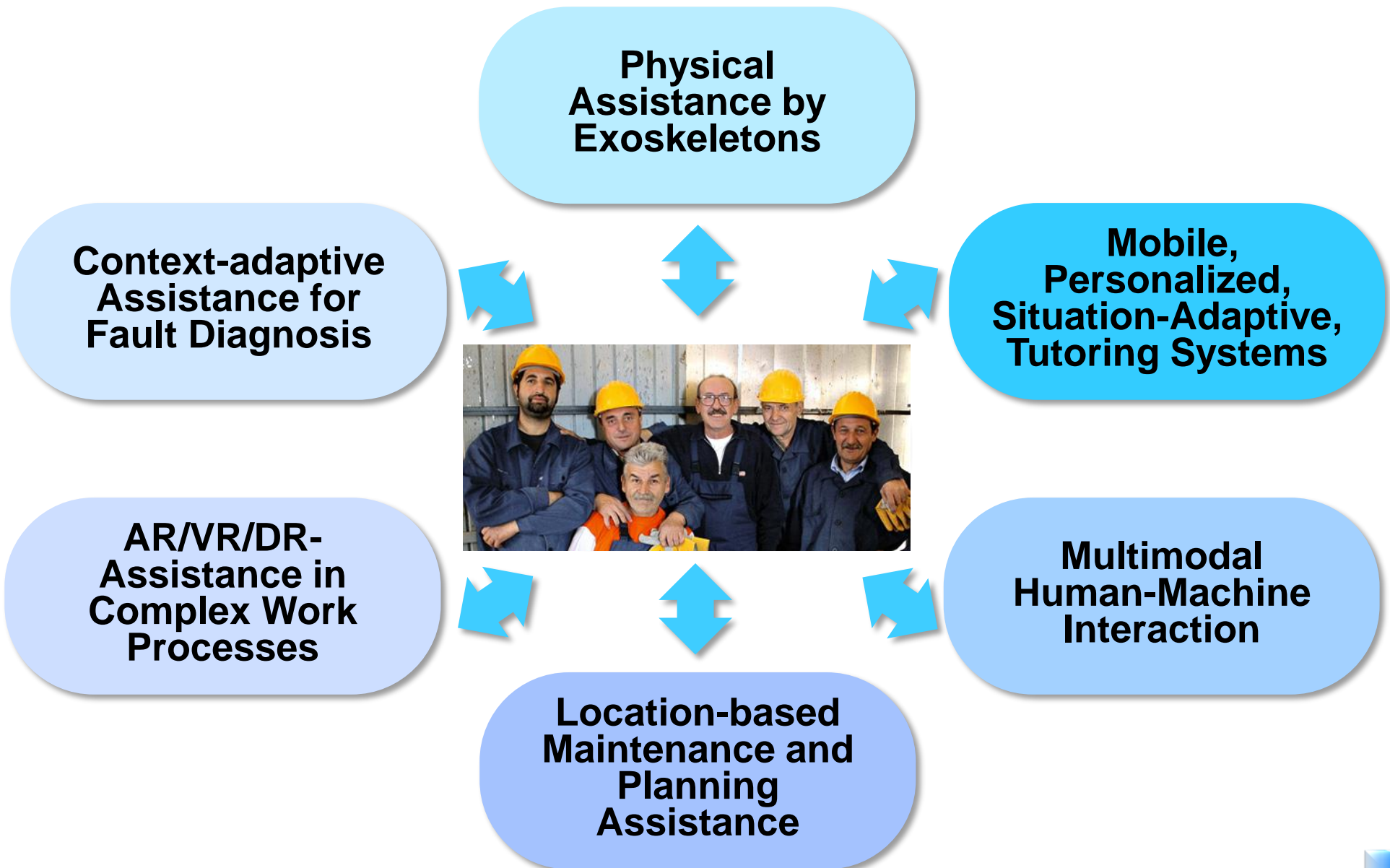


Meta Description possible with Sandewall's and Doherty's Non-monotonic Temporal Logics based on Features and Fluents

# Location-based Industrial Assistance Systems in Smart Factories for Resource Efficiency Improvements



# Human-Centered CPS-based Assistance Systems for the Smart Factory





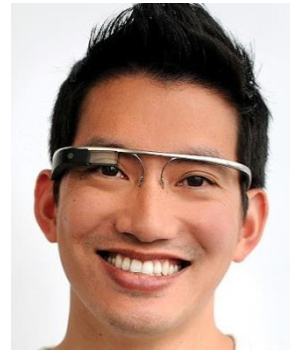
# App Stores for the Smart Factory



# Advanced Industrial Assistant Systems Based on Augmented Reality Technologies



Industrial Environment

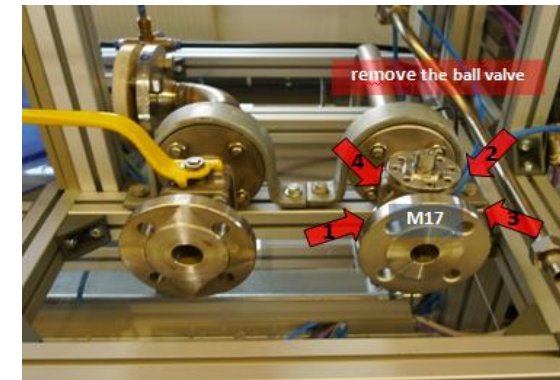
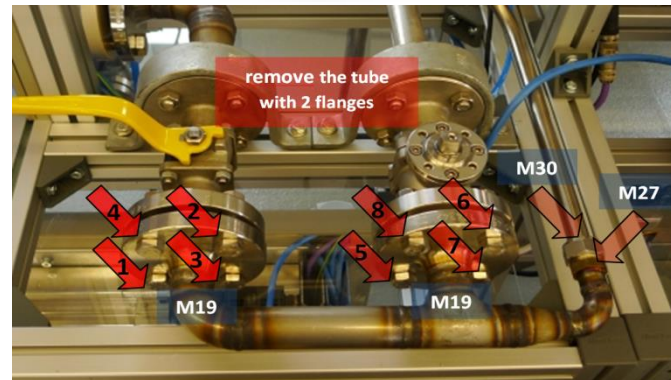
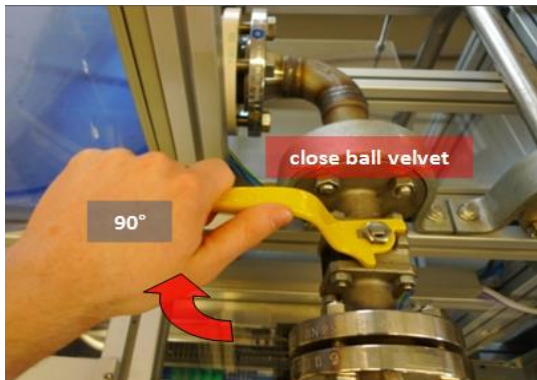


Industrial Worker with Google Glasses



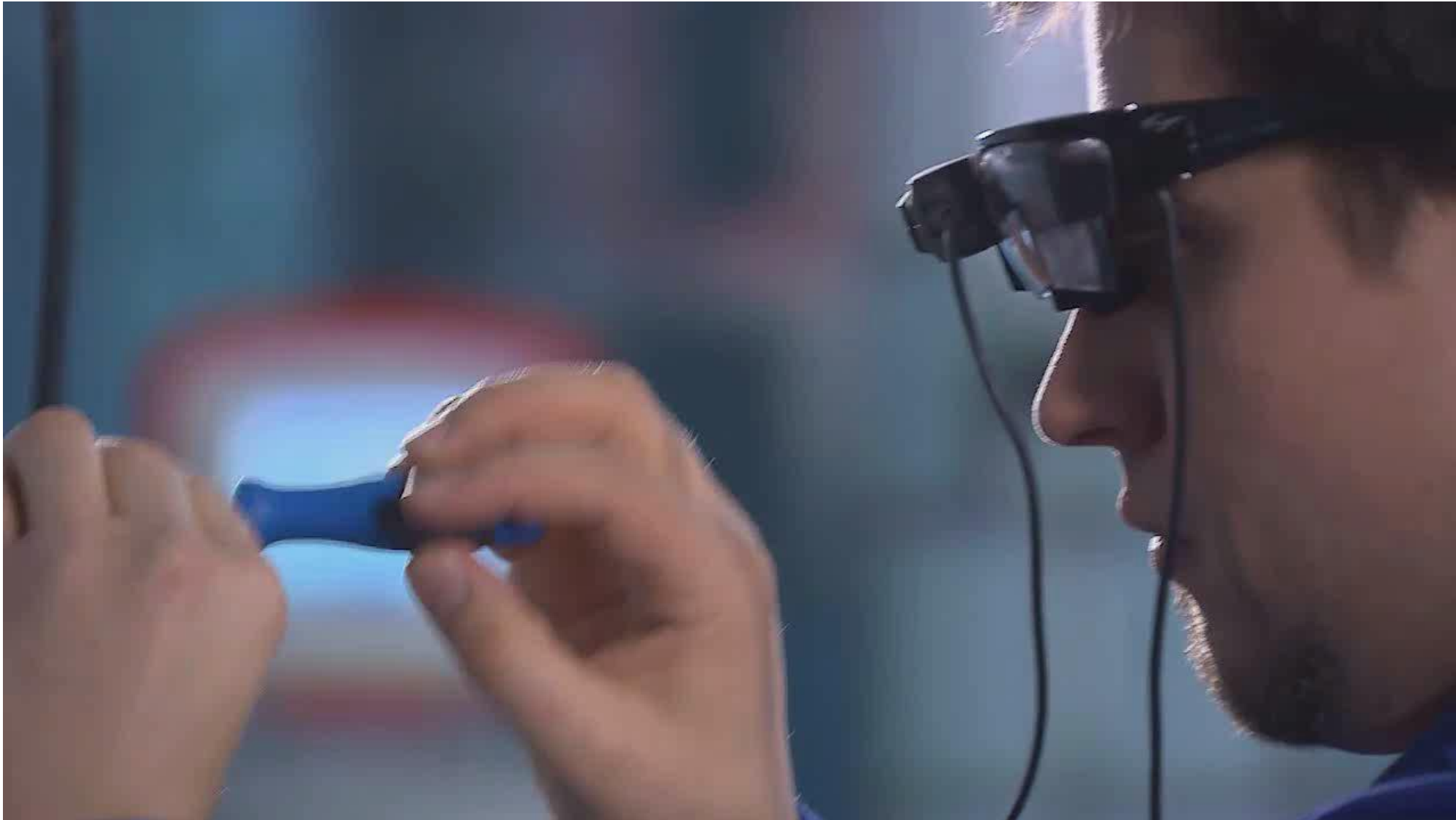
Tools

Mobile, Interactive and Situation-Aware Tutoring



# Look-Through Technology Used in the Smart Factory

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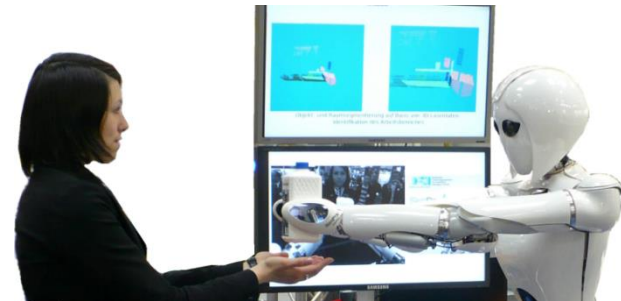


# Industrie 4.0: Robots are no Longer Locked in Safety Work Cells but Cooperate with Human Workers

Today



Tomorrow



**A new generation of light-weight, flexible robots collaborate with humans in the smart factory**

# DFKI's Fembot AILA: Using the Semantic Product Memory for Adaptive Grasping

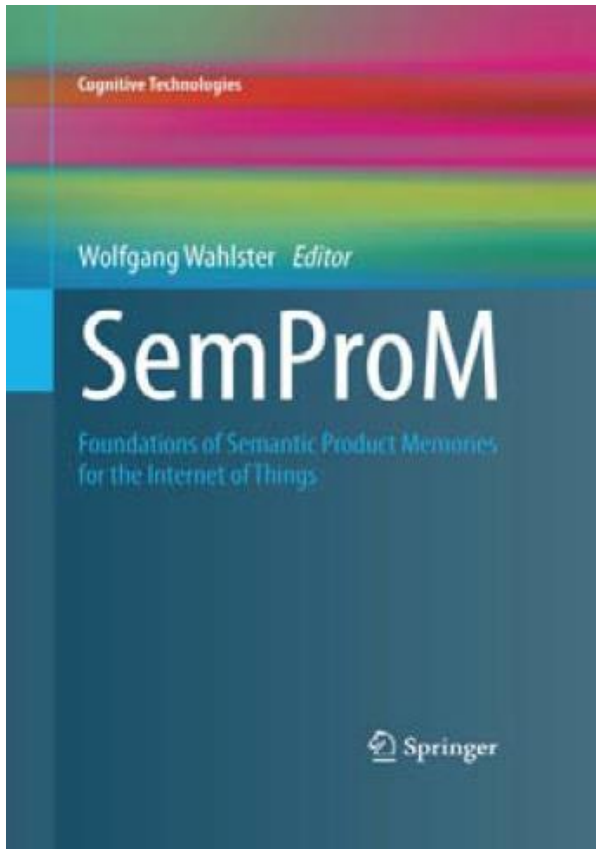
**Stereo Cameras in the Head and a 3D Camera on the Torso for Approaching an Object**



**Reading Size, Weight and Lifting Points from the Product Memory with an antenna in the left hand – the Robot gets instructions from the product being produced in the CPPS**

# Most Recent Book on Product Memories in the Springer Series „Cognitive Technologies“

IDA 30



## **SemProM** **Foundations of Semantic Product Memories** **for the Internet of Things**

**Series: Cognitive Technologies**

**Wahlster, Wolfgang (Ed.)**

412 Pages

ISBN 978-3-642-37376-3

Electronic Order:

<http://www.springer.com/computer/ai/book/978-3-642-37376-3>



# President Obama has introduced the “re-industrialization” strategy for the US

In the **US**, the great **spike in unemployment** over the past five years was disproportionately due to loss of manufacturing jobs.



Innovation in **Germany** builds on legacies: in industrial specializations, workforce skills, and proximity to suppliers with diverse capabilities.



MIT Taskforce on  
Innovation and  
Production Reports  
**MAKING IN AMERICA**  
MIT Press, 2013

The potential of German patterns extends **well beyond defending niches against lowcost competition** with incremental advances.

They create new businesses, **not usually through start-ups - the U.S. model** - but **through the transformation of old capabilities and their reapplication, repurposing, and commercialization**

# Conclusions

1. **Cyber-Physical Production Systems** and **Semantic Product Memories** are the Foundations for **Industrie 4.0** and introduce the **Internet of Things** into the **Smart Factory**.
2. The **Semantic Product Memory** controls the **Production Process** in a **Distributed Fashion** based on **Semantic Service Architecture** for **Manufacturing Machines**.
3. This semantic service architecture is based on a **production ontology and ubiquitous microweb servers** and realizes **intelligent matchmaking** processes between emerging products and production tools.
4. **Active semantic product memories** use **semantic web technologies, agent technologies, resource-aware planning and scheduling** and **intelligent sensor interpretation** based on **AI research**.



# Tack så jättemycket för alla år av vetenskapligt samarbete och vänskap

IDA 30



**Erik Sandewall, Patrick Doherty, Christer Bäckström,  
Lars Ahrenberg, Nils Dahlbäck, Arne Jönsson**



6th of June 1998



10th of September 2003



Thank you very much for your attention.

