German-Czech Workshop on Industrie 4.0/Průmysl 4.0
Prague, April 11, 2016

Industrie 4.0: Cyber-Physical Production Systems for Mass Customization

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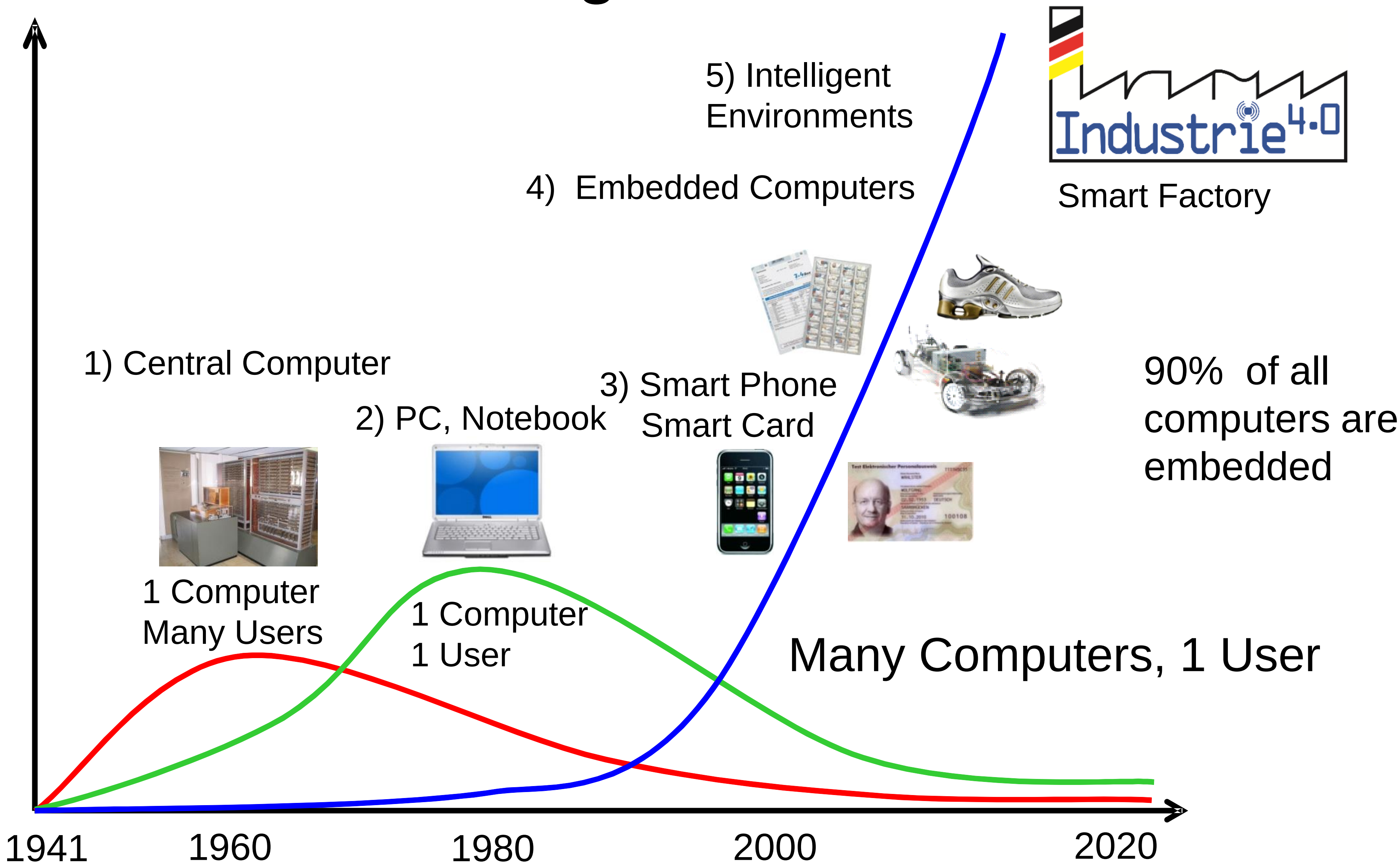
Towards Intelligent Environments based on the Internet of Things and Services



Future Project Industrie 4.0 of German Chancellor Dr. Angela Merkel

Evolution from Embedded Systems to Cyber-Physical Systems

Internet of Things

Intelligent Environments/Smart Spaces
Digital City

Cyber-Physical Systems
Smart Factory, Smart Grid

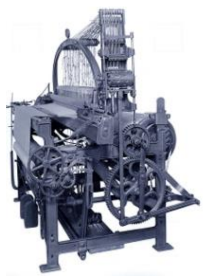
Networked Embedded Systems
Intelligent Street Crossing

Embedded Systems
Airbag

National Roadmap Embedded Systems

Agenda Cyber-Physical Systems

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



First **Mechanical Loom** 1784

4. Industrial Revolution
based on Cyber-Physical Production Systems

Industrie 4.0

010001101
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3. Industrial Revolution
through Introduction of electronics and IT for a further automization of production

Industrie 3.0

2. Industrial Revolution
through introduction of mass production based on the division of labour powerde by electrical energy

Industrie 2.0

1. Industrial Revolution
through introduction of mechanical production facilities powered by water and steam

Industrie 1.0

Degree of Complexity

End of 18th Century | **Start of 20th Century** | **Start of 70ies** | **today** | t

After an Initial Publication in 2011 the Term „Industrie 4.0“ was Propagated Exponentially

Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution

STRUKTURWANDEL: Zur Hannover Messe tritt die Initiative „Industrie 4.0" an die Öffentlichkeit. Henning Kagermann, Wolf-Dieter Lukas, Wolfgang Wahlster, drei Vertreter aus Wirtschaft, Politik und Wissenschaft, zeigen im nachfolgenden Beitrag, wie der Paradigmenwechsel in der Industrie ablaufen wird. In der nächsten Dekade werden auf der Basis Cyber-Physischer Systeme neue Geschäftsmodelle möglich. Deutschland könnte hierbei „die erste Geige" spielen.

VDI nachrichten, Berlin, 1. 4. 11, ria

Sich als Produktionsstandort auch in einer Hochlohnregion behaupten zu können, wird zunehmend zu einer Schlüsselfrage im globalen Wettbewerb.

Im Gegensatz zu anderen Industrieländern ist es Deutschland in den letzten zehn Jahren gelungen, die Anzahl der Beschäftigten in der Produktion weitgehend stabil zu halten. Nicht zuletzt wegen des stark mittelständisch geprägten, aber hoch innovativen produzierenden Gewerbes hat Deutschland auch die wirtschaftlichen Auswirkungen der Finanzkrise besser gemeistert als viele andere.

Die Entwicklung und Integration neuer Technologien und Prozesse haben dazu wesentlich beigetragen.

Produktionsstandort bleiben heißt heute, sich fit zu machen für die vom

Stellung insbesondere im Automobil- und Maschinenbau erarbeitet. Nun gilt es, den nächsten Schritt zum Internet der Dinge im industriellen Umfeld zu machen, damit Deutschland bis 2020 Leitanbieter auf diesem neuen Markt wird.

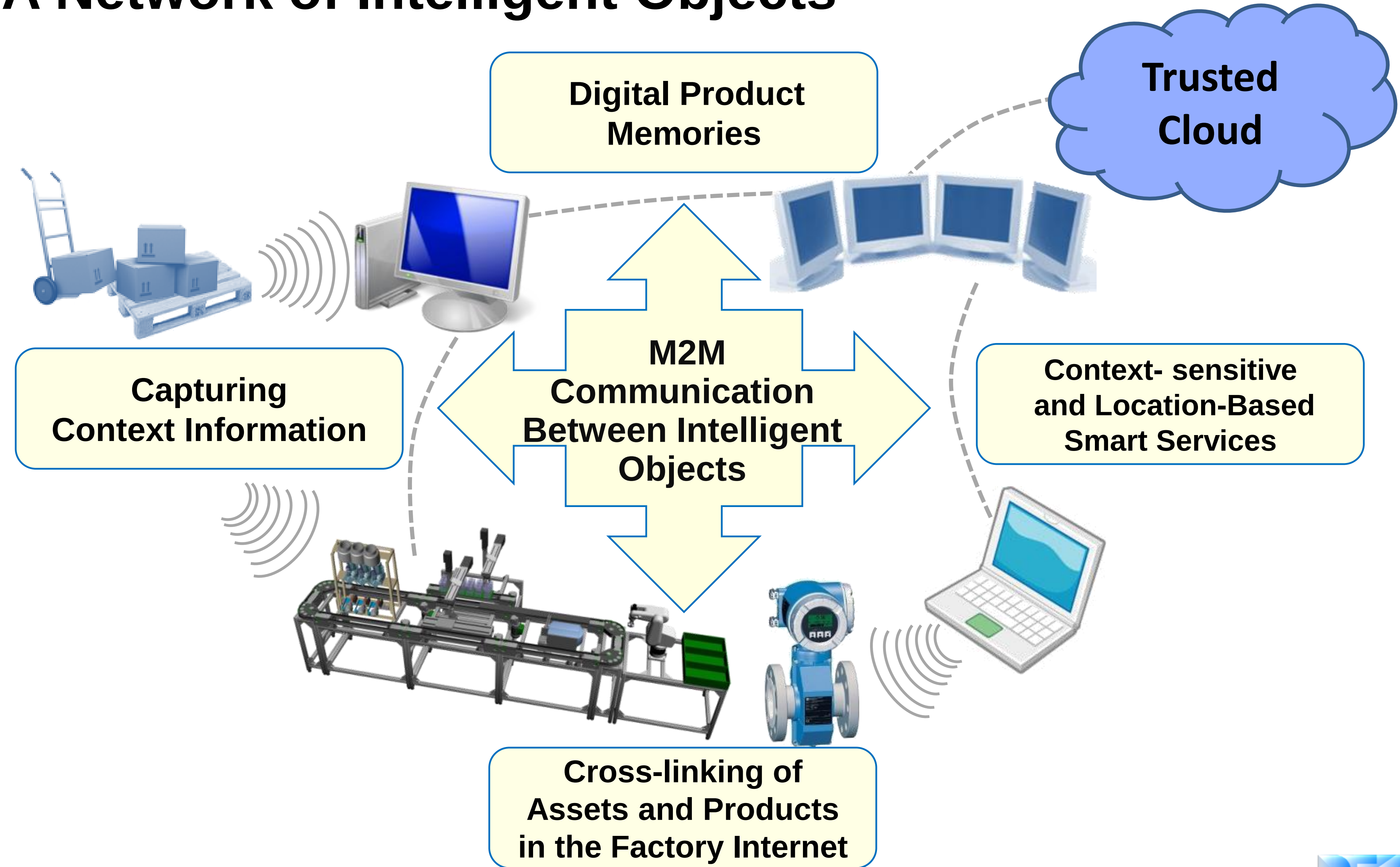
Durch die digitale Veredelung von Produktionsanlagen und industriellen Erzeugnissen bis hin zu Alltagsprodukten mit integrierten Speicher- und Kommunikationsfähigkeiten, Funksensoren, eingebetteten Aktuatoren und intelligenten Softwaresystemen entsteht hier eine Brücke zwischen virtueller („cyber space") und dinglicher Welt bis hin zur wechselseitigen feingranularen Synchronisation zwischen digitalem Modell und der physischen Realität.

Bei der Entwicklung dieser Cyber-Physischen Systeme wird in Deutschland bereits auf die Ergebnisse meh-

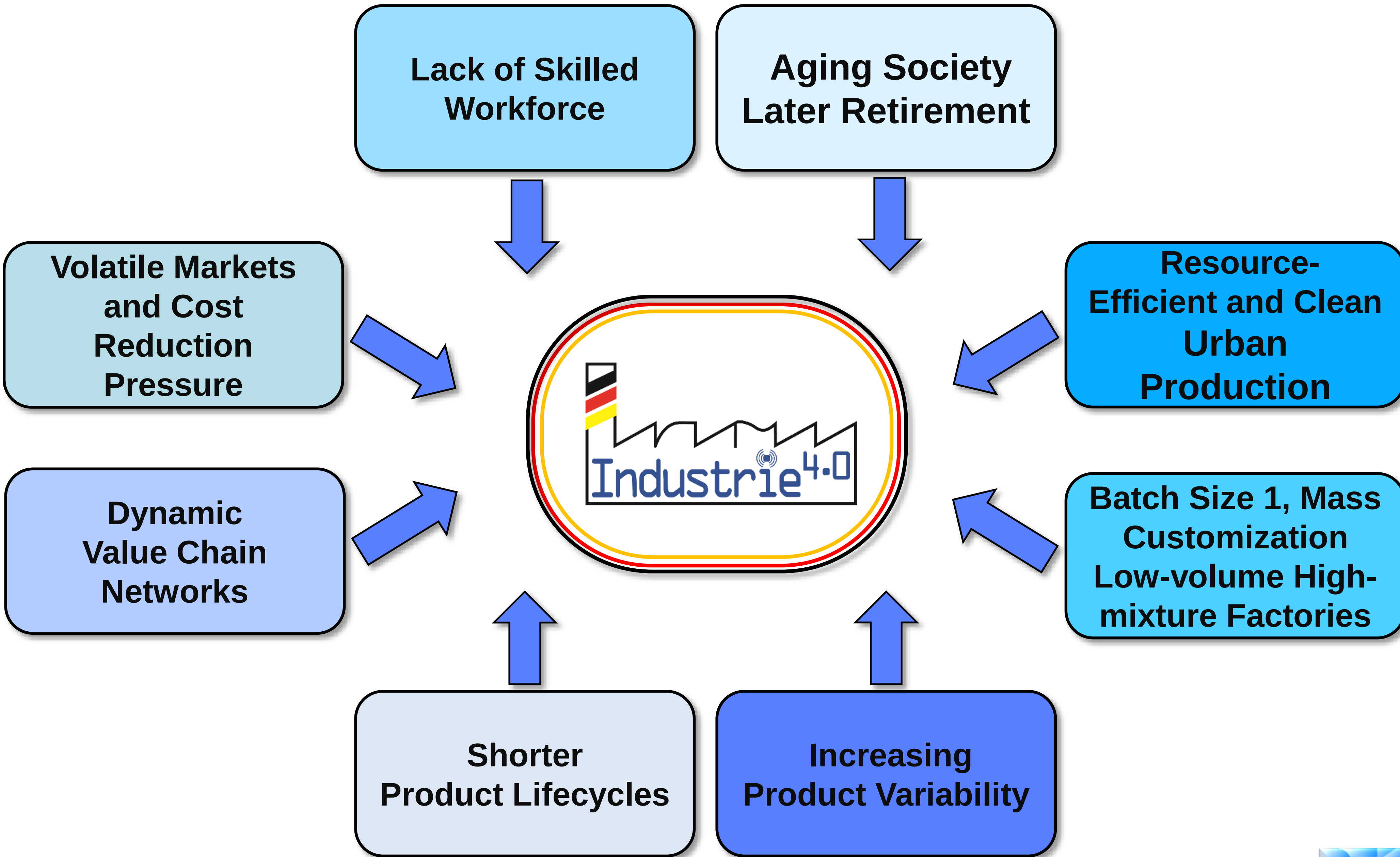
Wolfgang Wahlster, Chef des Deutschen Forschungszentrums für Künstliche Intelligenz, Henning Kagermann, Präsident der Deutschen Akademie der Technikwissenschaften, und Wolf-Dieter Lukas, Abteilungsleiter Schlüsseltechnologien im Bundesforschungsministerium, planen die Zukunft: Sie sehen Geschäftspotenziale der 4. industriellen Revolution nicht nur in der betrieb-

According to GENIOS Data Base of Publications in Germany

The Internet of Things in the Smart Factory: A Network of Intelligent Objects



Socio-Economic Drivers of Industrie 4.0



Outline of the Talk

1. The Birth of Industrie 4.0

2. Mass Customization based on Cyber-physical Production Systems

3. Semantic Technologies for Plug&Produce

4. Industrial Assistance Systems for the Next Generation of Factory Workers

5. Hybrid Team Work between Humans and Robots

6. Conclusion

The German Future Project: Industrie 4.0

- 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.

The Role of Software for Industrie 4.0

today (Industrie 3.0):

Machine plus Software

ICT as Innovation Motor No. 1
and Advanced Manufacturing

tomorrow (Industrie 4.0):

Software plus Machine

Industrie 4.0: The Fourth Industrial Revolution

Digital Production with Batch Size 1

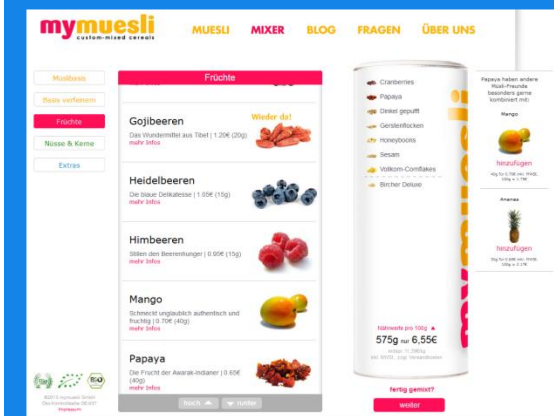
Internet of Services

Future Project:

Using Internet portals to configure and order a personalized product

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

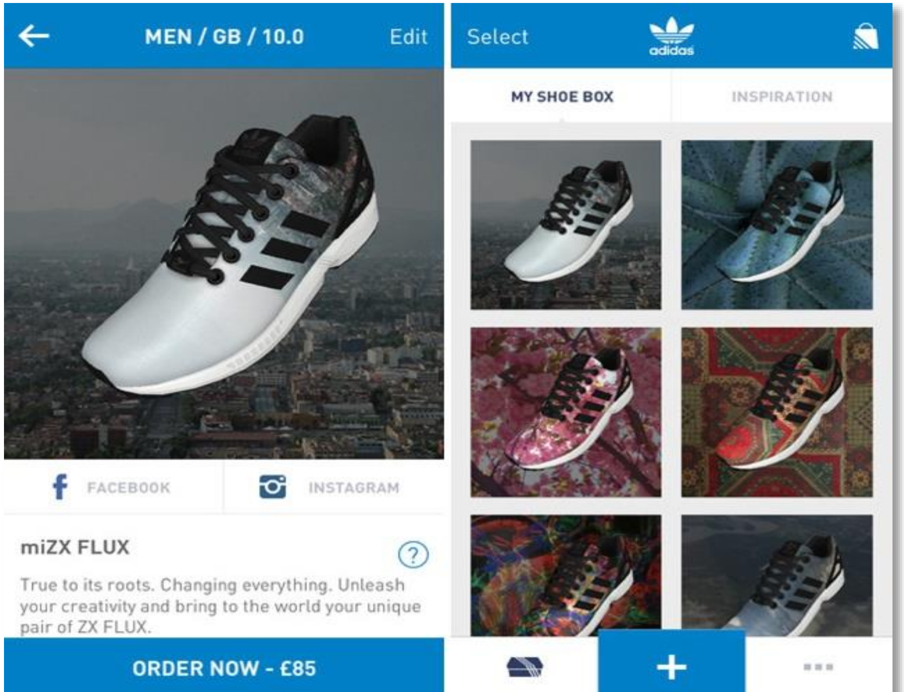
Future Project:

Mass Customization of Perfumes and their Packaging

- Customer can create her own perfume from millions of possibilities via a web portal
- Smart Factory can produce 36 000 Unique Perfume Packages per day
- 24 hours after the order via the Internet has been completed the individualized product is ready for shipment.

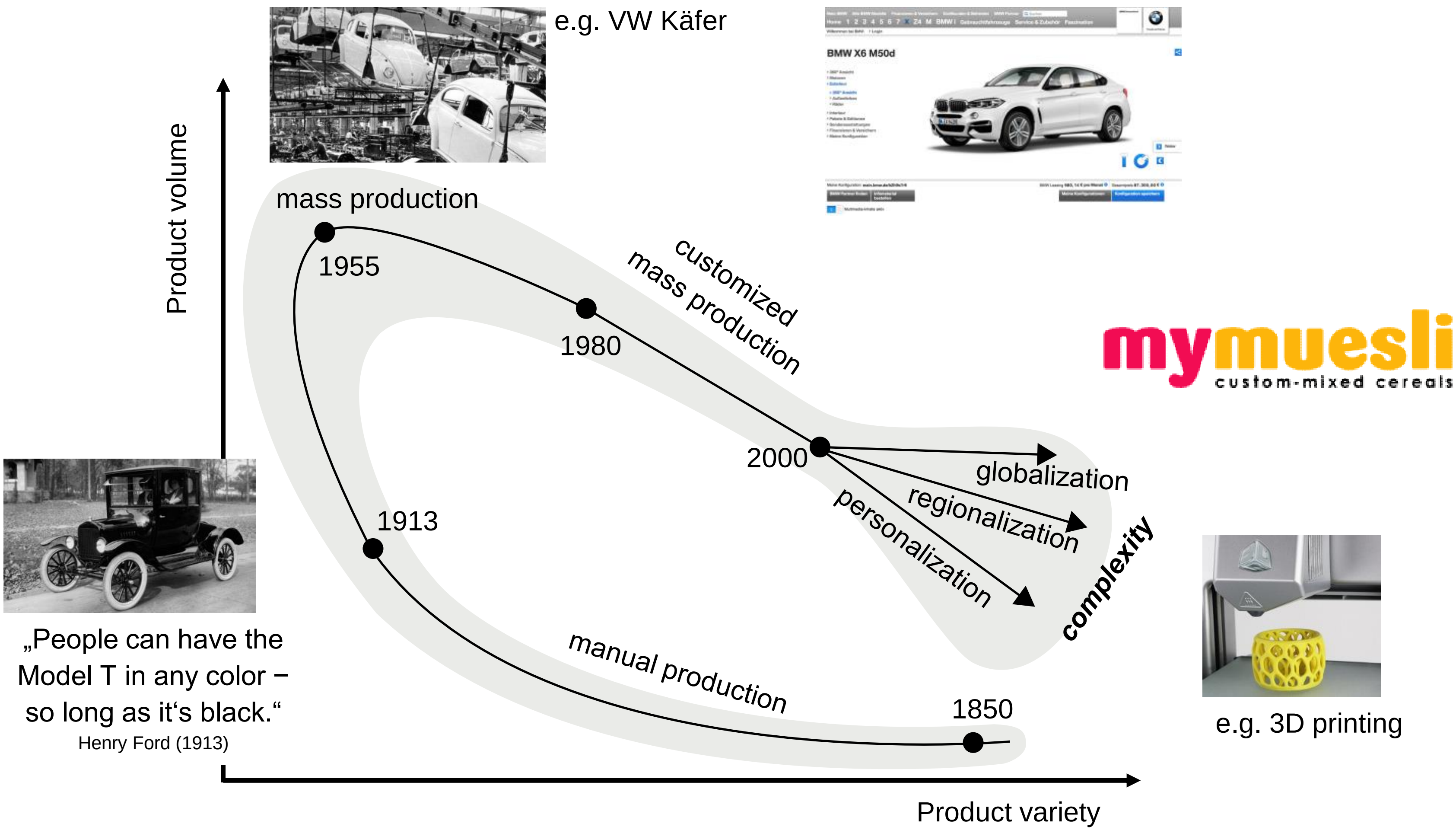
Since the customer of an individualized product, that she has designed by herself, does not accept long delivery times, the product should be produced close to the customer → advantage for local European production industry.

The Adidas Speedfactory: Bringing Sports Shoes Production back to Germany by Industrie 4.0 for Mass Customization



- The costumers can design their own short shoes using an App.
- Since the customer wants to receive his personalized product on the next day or faster, long logistic chains from low-wage countries are no longer acceptable in the era of mass customization.
- Thus, adidas decided to open various "speedfactories" for personlized shoes in Germany close to the customer, using Cyber-physical production systems (CPPS).

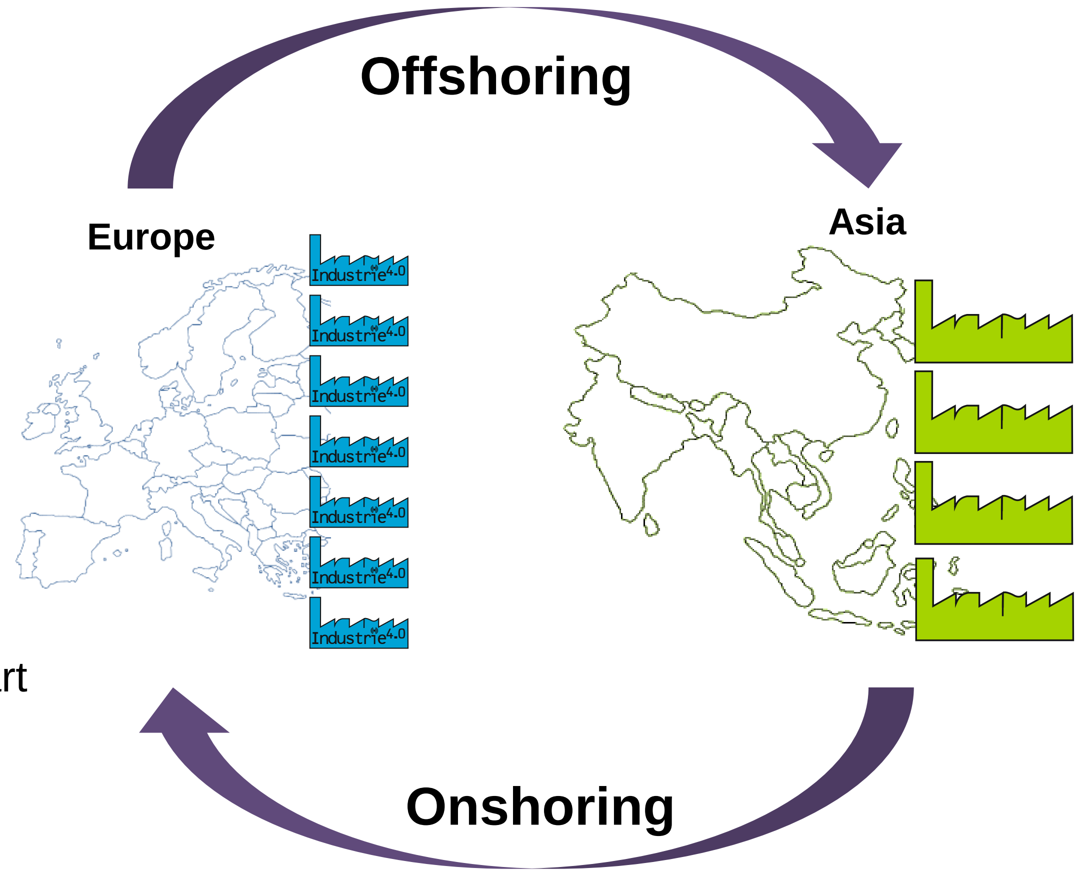
From Manual Production via Mass Production to Mass Customization



Based on: The Global Manufacturing Revolution; sources: Ford, beetleworld.net, bmw.de, dw.de

Onshoring in Industrie 4.0 versus Offshoring in Industrie 3.0

- High-wage Countries
- Industrie 4.0
- Mass Customization
- Short and Mobile Chains to Consumers in Europe
- Small Networked Smart Factories



- Low-wage Countries
- Industrie 2.0 - 3.0
- Mass Production
- Long and Complex Logistic Chains to Consumers in Europe
- Big Traditional Factories

For example: sport shoes, clothes, kitchens, appliances, consumer electronics, toys, bikes…

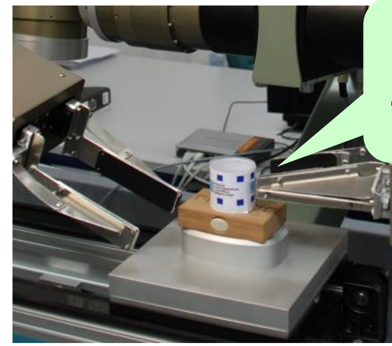
Products with Integrated Dynamic Digital Storage, Sensing, and Wireless Communication Capabilities

⇒ The product as an information container

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

⇒ The product as an agent

– The product affects its environment



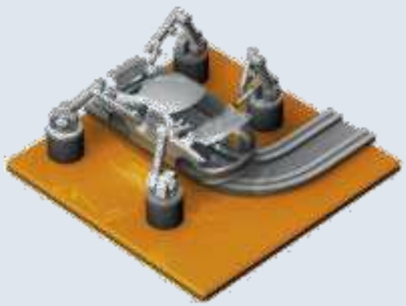
⇒ The product as an observer

– The product monitors itself and its environment

Active Semantic Product Memories for Industrie 4.0: Digital Twins and Virtual Shadows

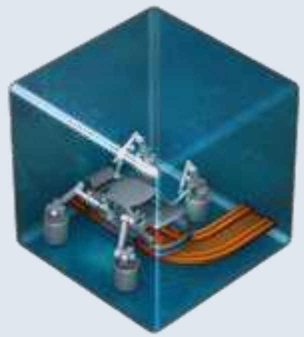
Industrie 4.0

Cyber-Physical System (CPS)



Physical Production Component

+

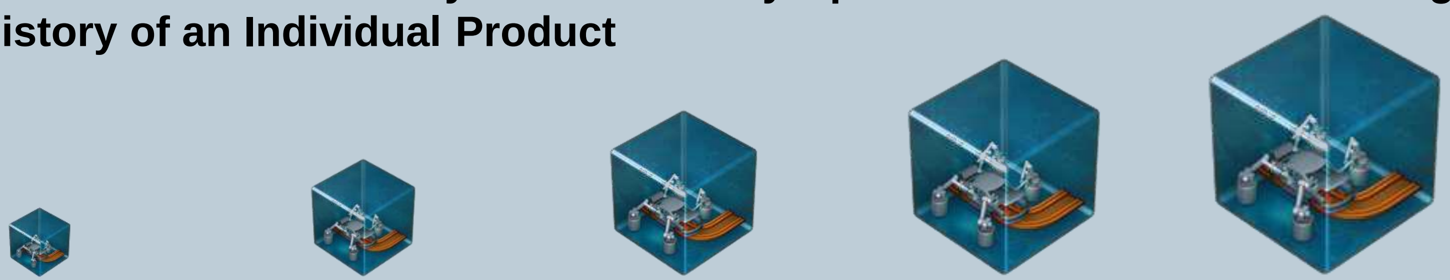


Active Semantic Product Memory as a Digital Model

Includes Information about …

- Maintenance
- Context Conditions
- Security
- Location
- Status
- Embedded Components,
- Interfaces
- CO2 Footprint
- Materials
- Handling

The Semantic Product Memory Is Continiously Updated and Serves as a Lifelog of the History of an Individual Product



Product Design → Production Planning → Production Engineering → Production → Smart Services

Source: Siemens

Smart Services Based on Active Digital Product Memories

Cyber-physical systems based on product memories

Controls its own production process

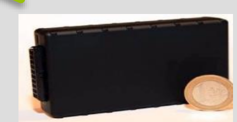
Software-defined platforms for active, digital product memories

Software environment for active product memories

Enable intelligent logistics and distribution systems

Service platforms based on product memories

Enable smart services for end customers



Deutsche Sparkassen Direct Insurance:
Dynamic insurance premiums based on driver behaviour

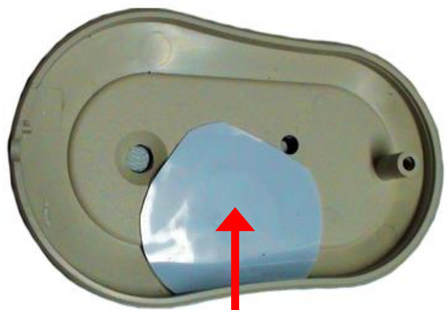
7x4 Pharma - Blister: Prevents wrong dosing

Smarter Socks from **BLACKSOCKS:**
easy sock pairing

Thousands of CPS 4.0 Form the Nervous System of a Smart Factory

In Industrie 4.0, conventional field devices and SPS (Storage Programmable Systems) will be replaced by thousands of CPS 4.0 interconnected via industrial internet protocols.

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 key-finder logic packaged inside a plastic shell

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

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From Bits and Bytes to Semantics

driven by
Software Engineering

To semantic services

driven by
Electrical Engineering

Via functions

common ontology

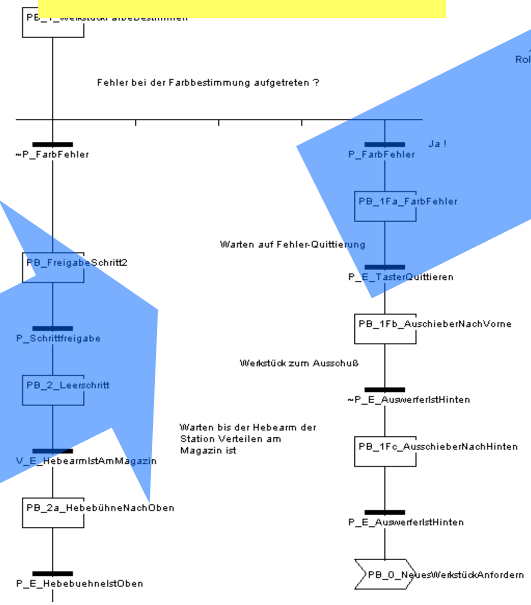
From bits and bytes

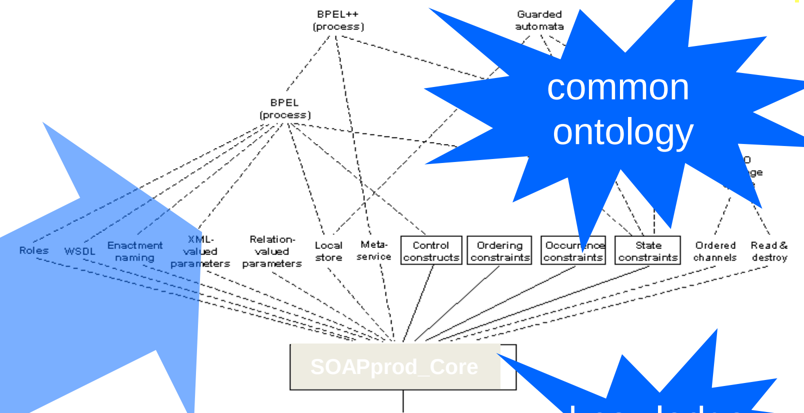
knowledge based

```
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
```





driven by
Semantic Technologies

driven by

Key Components of Service-Oriented Cyber-Physical Production Systems

Machine 1
Active Semantic Product Memory

M2M Communication
. . .

CNC Milling Machine

M2M Communication
. . .

Machine N
Active Semantic Product Memory

Production Service Discovery, Matching and Execution

Workpiece Carrier 1
Active Semantic Product Memory

. . .

. . .

Workpiece Carrier N
Active Semantic Product Memory

Production Pathplanning Based on Semantic Product Memories

Emerging Product 1
Active Semantic Product Memory

. . .

. . .

Emerging Product N
Active Semantic Product Memory

Semantic Product Memory

- Top Shell Selection
- Circuit-Top Shell Packaging
- RES-COM Engravature
- Top and Bottom Shell Assembly

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

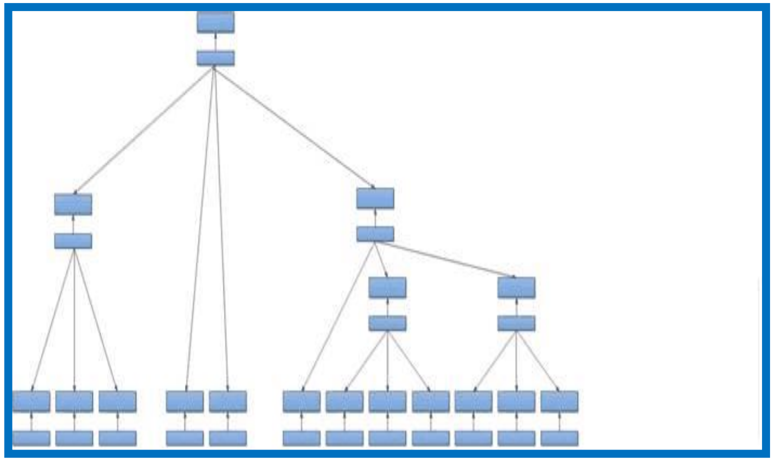
The Intelligent Workpiece Carrier: A Complex Cyber-Physical System

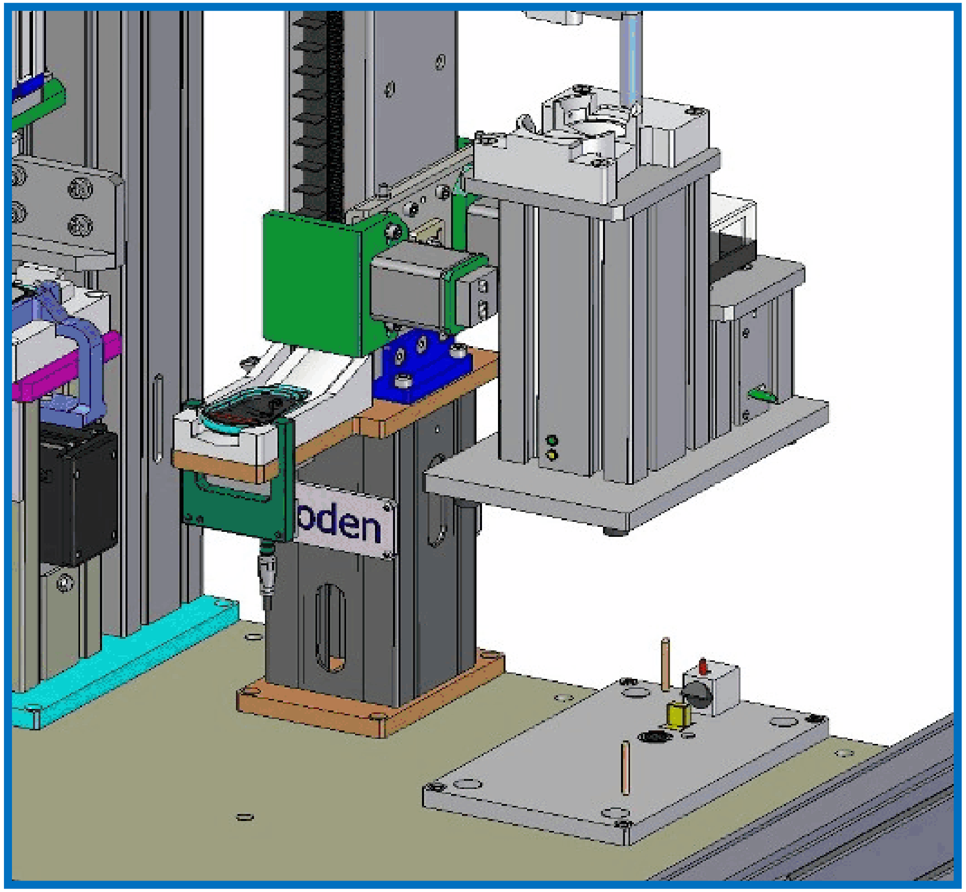
The Taxi to Production Services

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





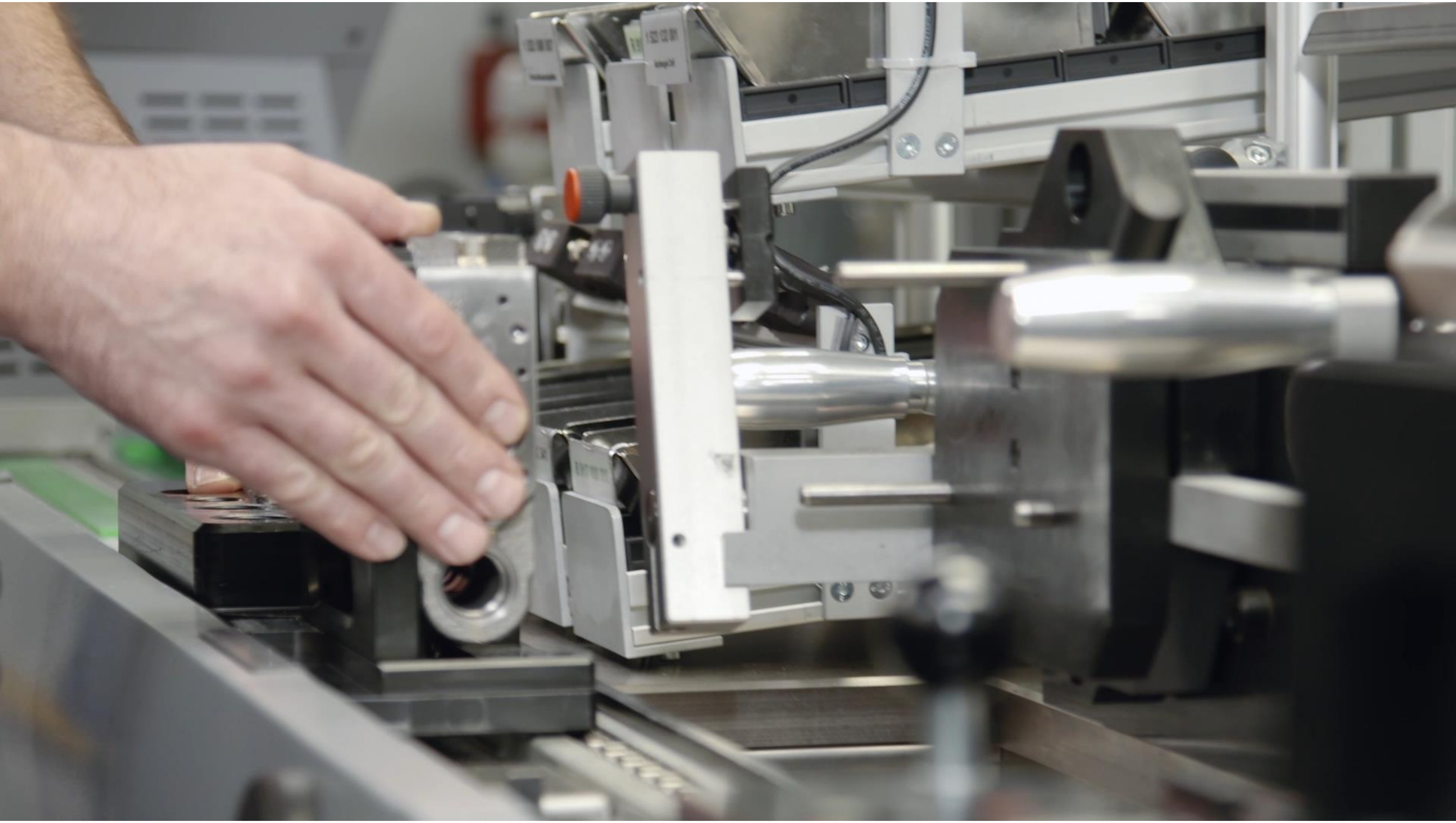
New Assembly Component is installed on-the-fly

DFKI‘s Multi-Vendor Automation Line in the Industrie 4.0 Paradigm

Seamless Interoperability, Multiadaptivity, and Plug&Produce

9 Manual Workstation | 8 Weighing Module | 7 Quality Control | 6 Laser Marking | 5 Robot Module | 4 Force Fitting | 3 Production | 2 Engraving | 1 Storage Module

The Smart Automation Line of Bosch-Rexroth



Cooperation with DFKI and Power4Production Center in the SmartF-IT Project

Source: Bosch-Rexroth

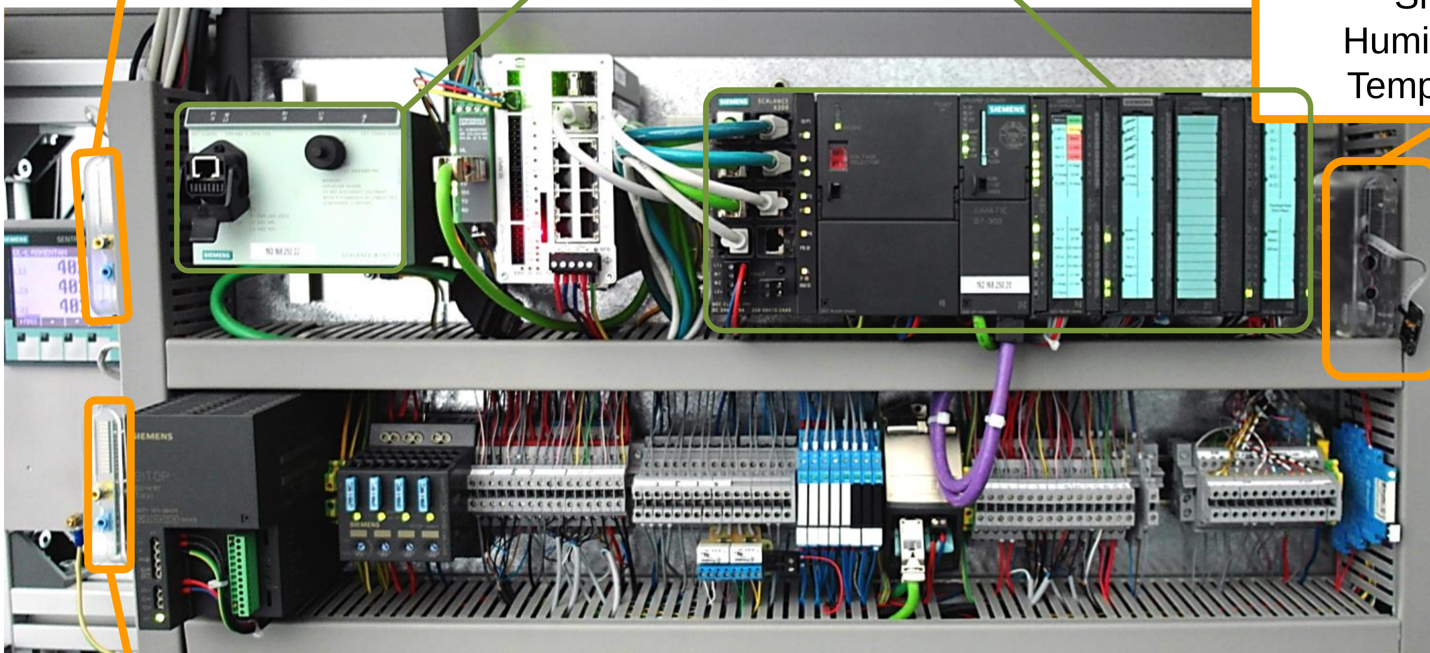
The Retrofitting of Legacy Factories with an Additional Layer of Cyber-Physical Systems

Rasberry PI 1
CPS as an Active Product Memory
for the Emerging Product

WLAN Router

Classical SPS

Gadgeteer with
Sensors for
Acceleration,
Shock,
Humidity and
Temperature



Rasberry PI 2
CPS for Processing Sensor Data from
the Additional Sensor Web

Professional Alternative
MICA by
HARTING

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

Physical Assistance by Exoskeletons

Context-adaptive Assistance for Fault Diagnosis

Mobile, Personalized, Situation-Adaptive, Tutoring Systems

AR/VR/DR-Assistance in Complex Work Processes

Multimodal Human-Machine Interaction

Location-based Maintenance and Planning Assistance

App Stores for the Smart Factory

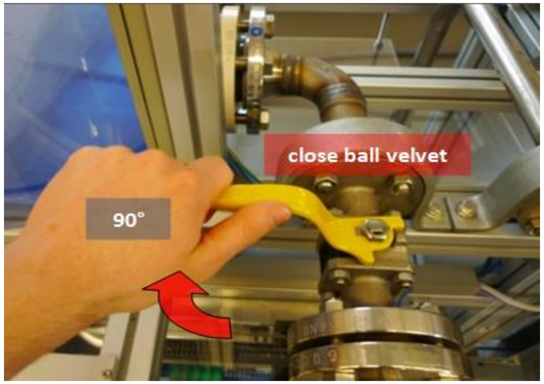
Advanced Industrial Assistant Systems Based on Augmented Reality Technologies

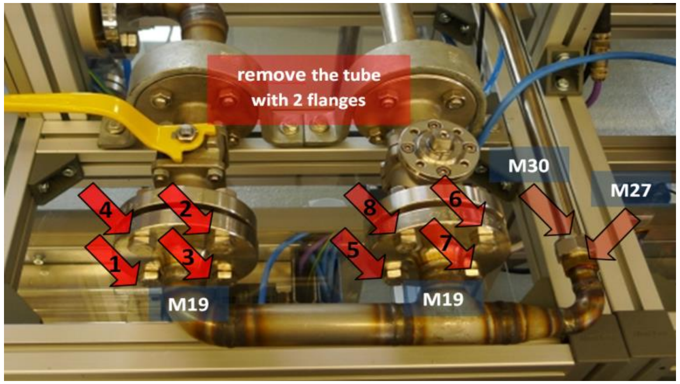
Industrial Environment

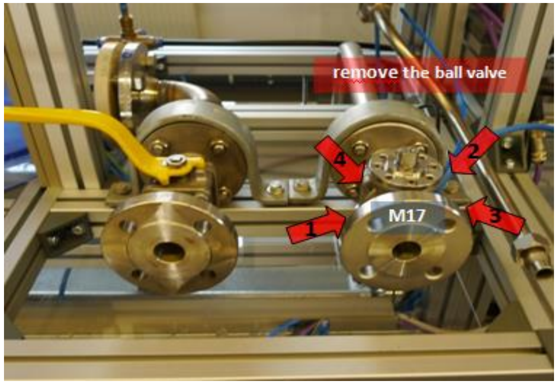
Industrial Worker
with Google Glasses

Tools

Mobile, Interactive and Situation-Aware Tutoring



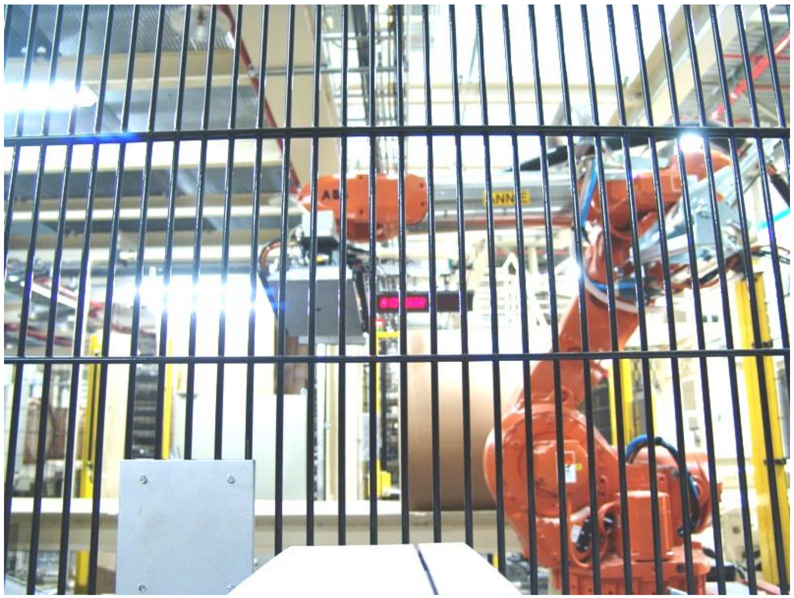




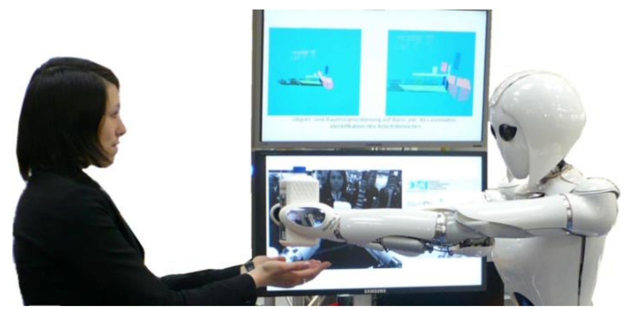
Look-Through Technology Used in the Smart Factory

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

Today



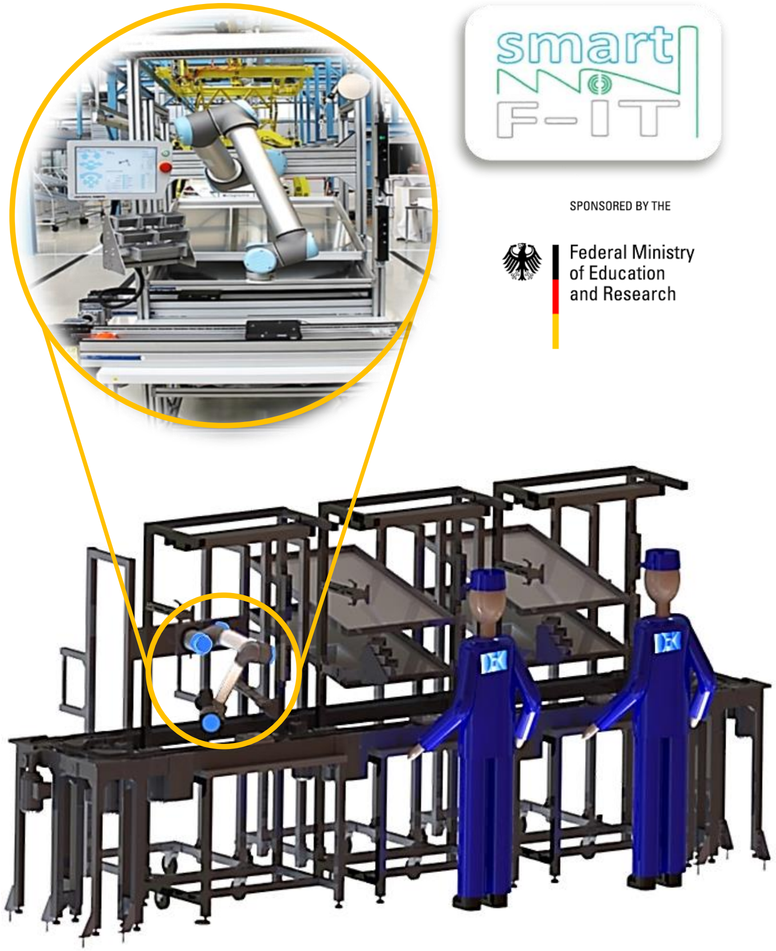
Tomorrow



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

Bosch's APAS Cobot in DFKI's SmartF-IT Assembly Line

Multiadaptive Assembly System for Highly Flexible Hybrid Job Floors



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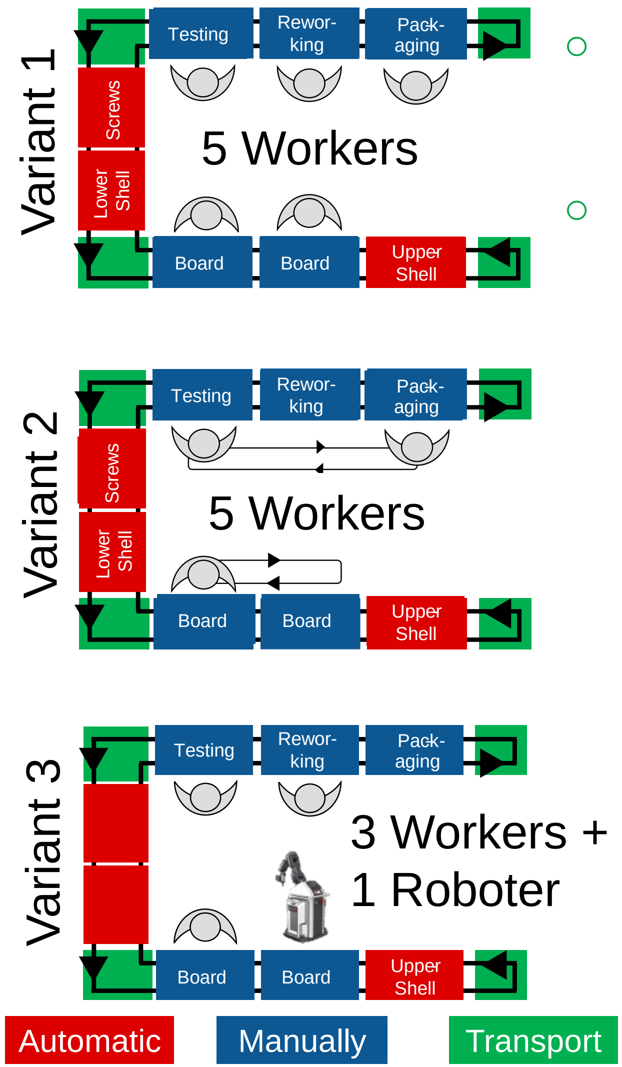
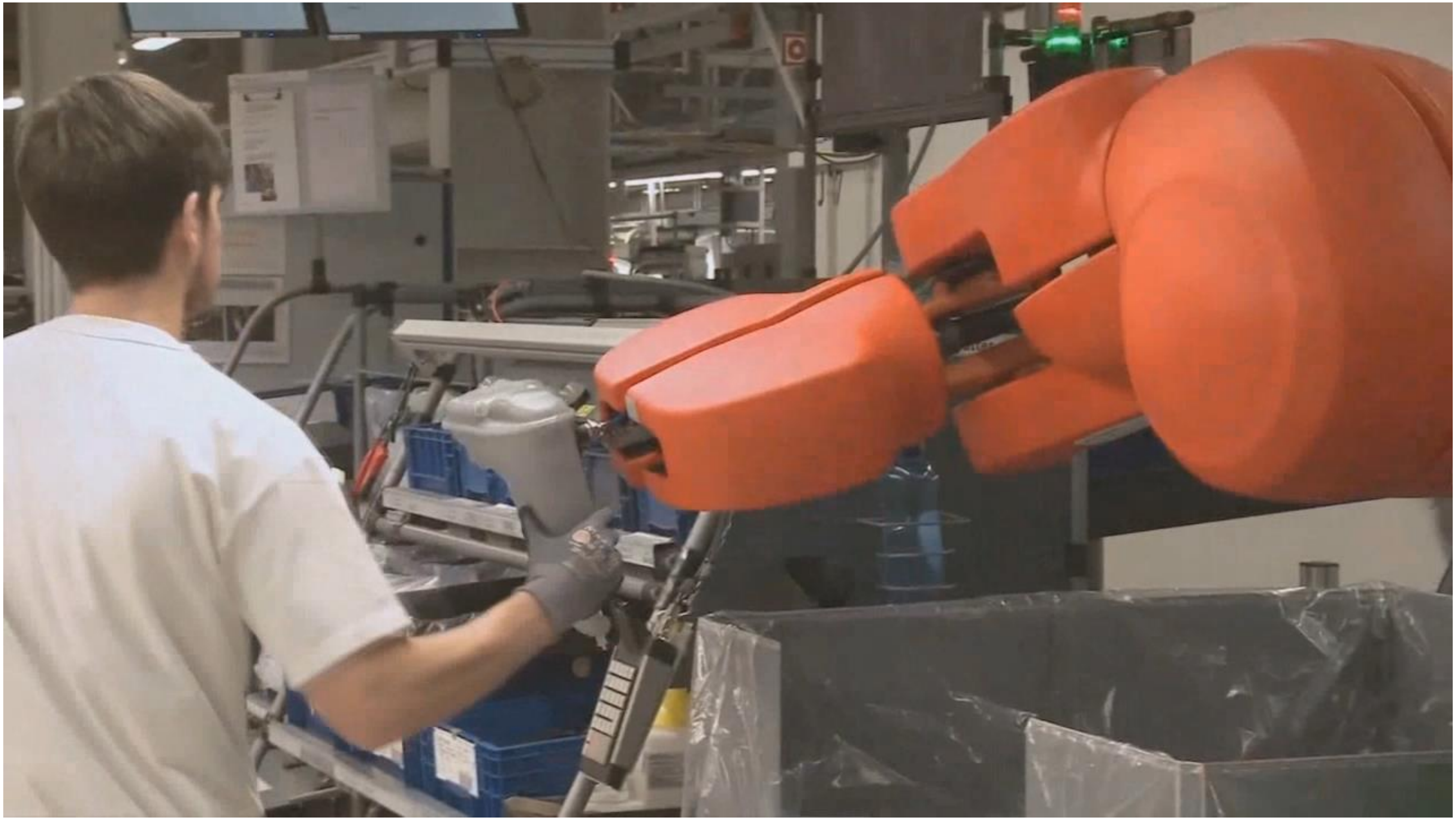


- Use of OMM/OMS as a Active Product Memory
- Use of Assistance Functions in Planning and Production

Bosch APAS (Automatic Production Assistants)

Human-Robot Collaboration at an AUDI Assembly Plant



Collaborative Robotics at BMW

Source: BMW

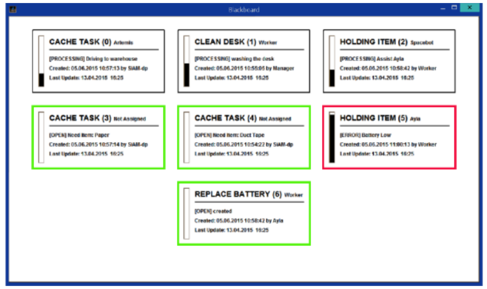
DFKI's Fembot AILA: Using the Semantic Product Memory for Adaptive Grasping

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

Hybrid Teams of People, Robots and Softbots

Demo Task:
An object (example: cell phone) with individual interiour cushioning is packed into a shipping box.



Blackboard provides all working tasks

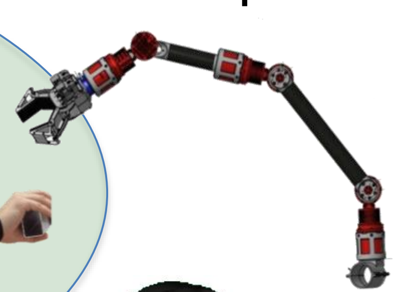
team members can allocate tasks according to their abilities

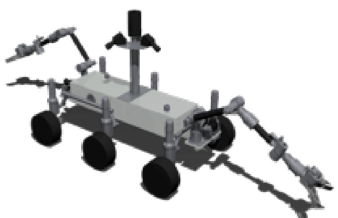
Aila: customer interface

Manager/Technician: supervising/aiding the process

Worker: executing the human tasks

Compi: worker support





Artemis: intra-logistics robot

humans are in the center of production

HYSOCIATEA
HYBRID SOCIAL TEAMS

Gloria: worker interface

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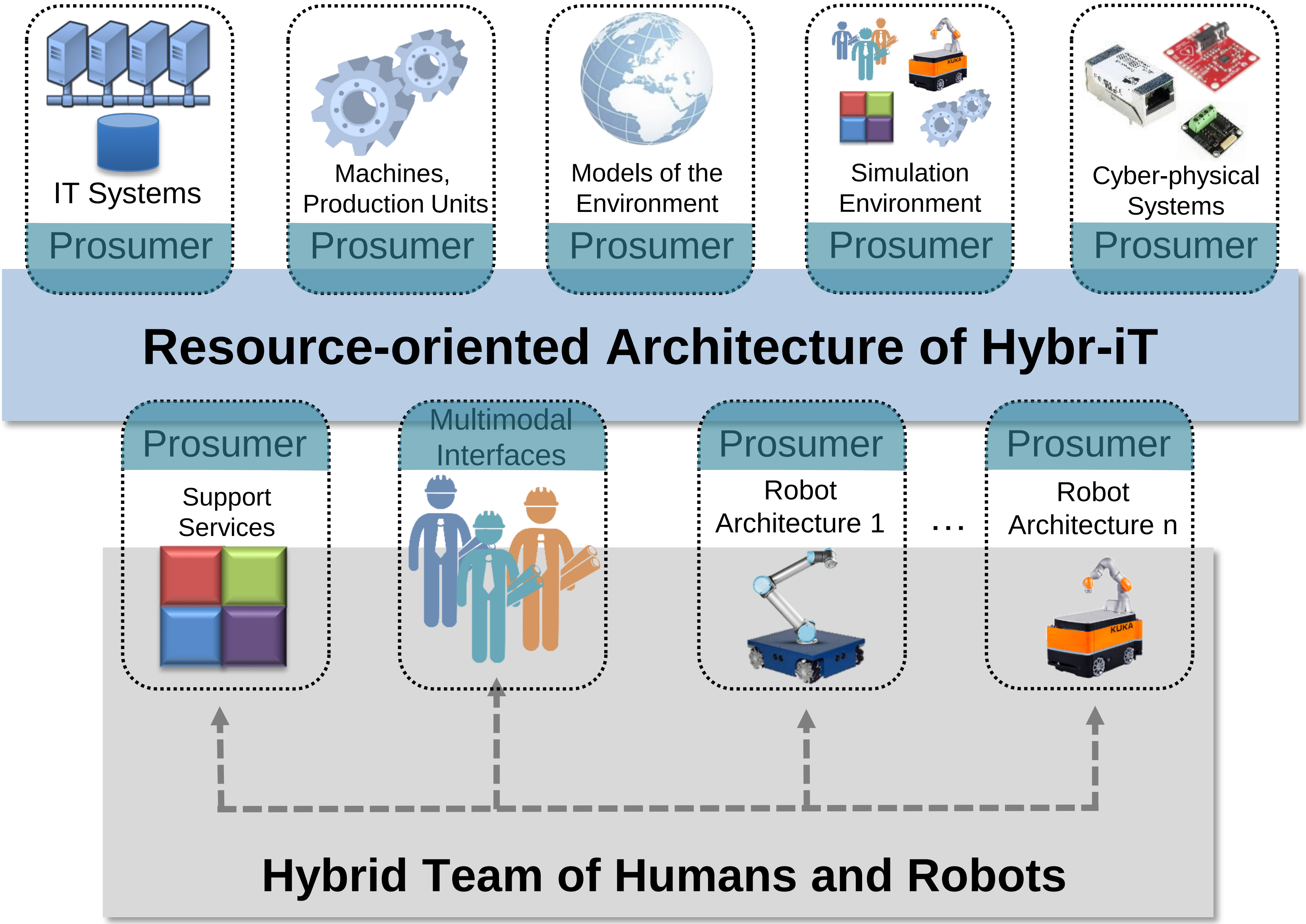
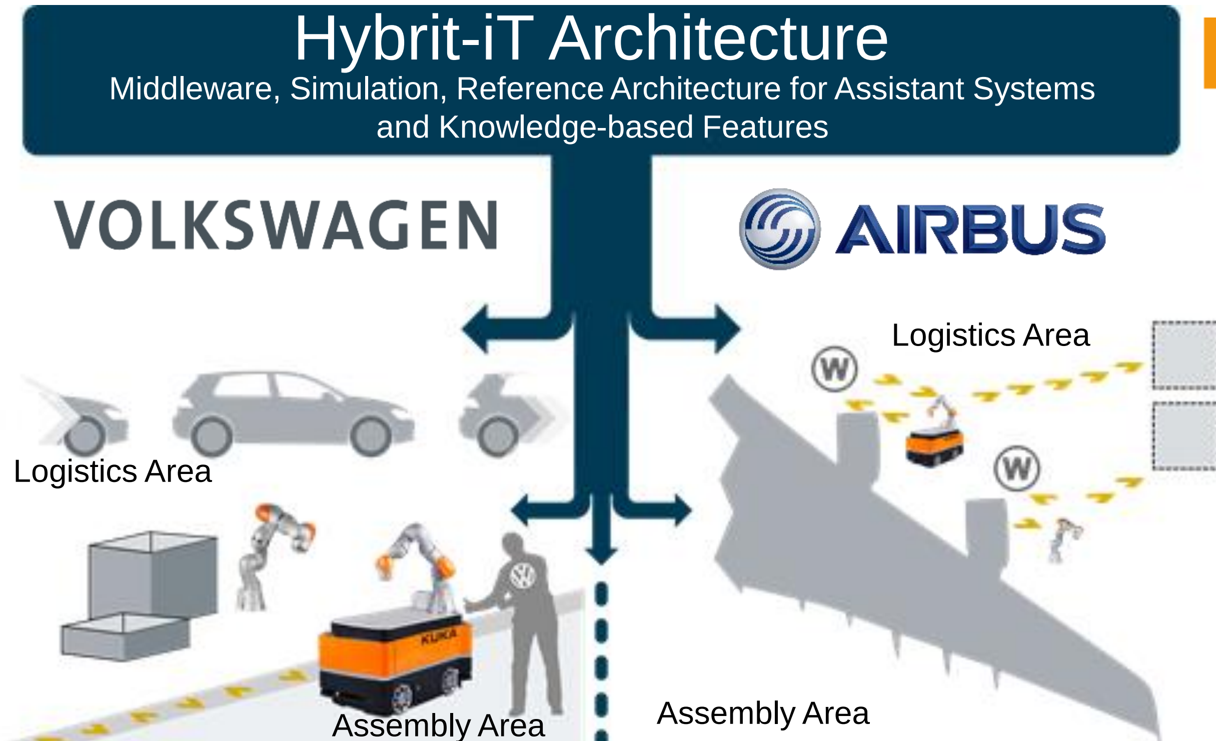
Collaborative DFKI Robot COMPI: Resilient Plan Execution with Realtime Replanning

Hybrid Multiagent Collaboration in Cyber-physical Production Systems



Hybrid Teams: Robots Collaborate with Humans in Physically Challenging Overhead Assembly Tasks



Industrie 4.0: Smart, Green, and Urban Production

Smart Production

High-precision, superior quality production of high-mix, low volume smart products

Green Production

clean, resource-efficient, and sustainable

Urban Production

Smart Factories in the city close to the employees‘ homes

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

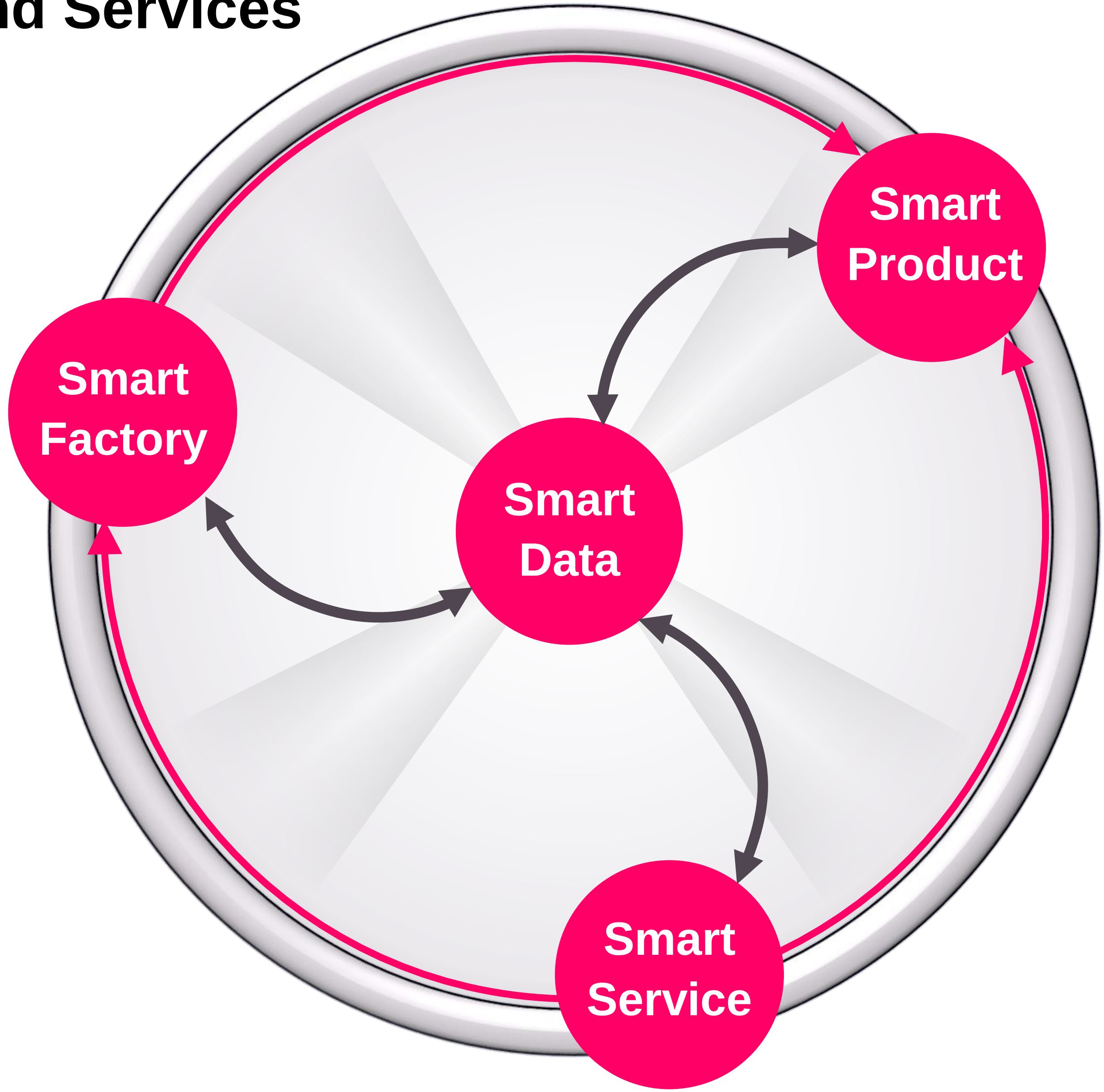
Innovation in Germany builds on legacies: in industrial specializations, workforce skills, and proximity to suppliers with diverse capabilities.

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

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

Smart Data as the Jet Engine for Smart Factories, Products and Services

Industrie 4.0



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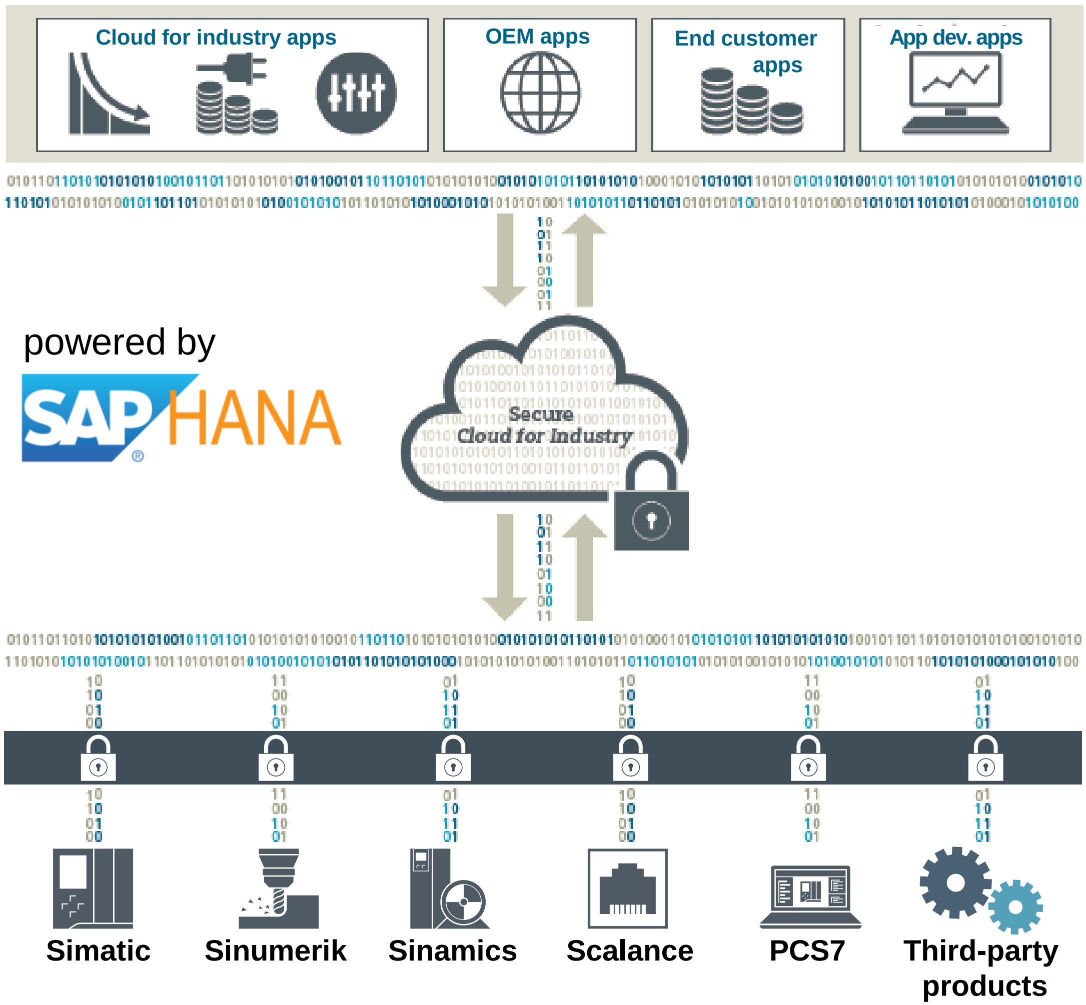
Siemens-SAP Cooperation on Manufacturing Cloud Platform



Optimization of plants and machines as well as energy and resources

- **Open standard (OPC)** for connectivity of Siemens und third-party products
- **Plug and play connection** of Siemens products (engineering in the TIA Portal)
- **Cloud for industry** with open application interface for individual customer applications
- Optional **cloud infrastructure** – public cloud, private cloud or on-premise solution
- Transparent **pay-per-use pricing model**
- Opportunities for completey new **business models** (e. g. selling machine hours)

2x5 New National Competence Centers for Industrie 4.0

Federal Ministry for Economic Affairs and Energy

Core Centers selected In First Round in 2015

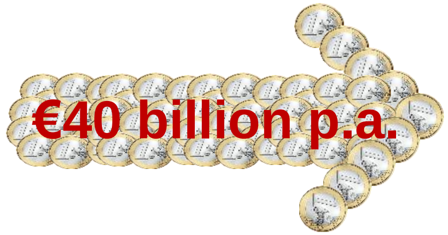
Secondary Centers selected in 2016

After the Seed Investment in Germany the Roll-Out of Industrie 4.0 in Europe has been started

"We are in the middle of a true revolution…the fourth industrial revolution: It will change all our industries, it will change our economy and it will change our lives"

EU Digital Economy & Society Commissioner Günther Oettinger

Funding



The German Platform for Realizing Industrie 4.0

Platform Industrie 4.0

Ministry of Economics, Ministry of Research

Decision Making, Technological Competence

Political and Societal Coaching

Market Activities

Steering Board

- Industry Leaders
- Working Group Leaders
- Ministry of Economics & Ministry of Research

Strategy Board

- Politics
- Trade Unions
- Industry Associations
- Academies

Competence Centers of Academia

Testbeds of Industry

Working Groups

- Reference Architecture
- Security

⋮

Scientific Advisory Board

International Standardization

Service Office

Standardization as a Key Success Factor for Industrie 4.0

Standardization through Semantic Meta Description Languages

Intefaces between Digital Enterprise and Digital Factory Layer

Semantic Service Description and Semantic Product Memory

OWL OWL-S OMM++
USDL WSDL

DIN EN 62264

VDI 2860

Standardization through Interoperability

Communication Standards

7	SOA Services	SoA ✓
6	OPC UA	OPC-UA
5	OPC UA	
4	IP	TCP/IP ✓
3	IP	
2	Ethernet	RJ45, WiFi… ✓
1	Ethernet	

Mechatronic Base Standards

HAN-Modular® ✓

The Race for Industrie 4.0 Standards

- Leading Provider of Internet Hardware, Software and General ICT
- No Leading Manufacturing Industries

- Leading Manufacturing Industries
- Leading Provider of Enterprise Software

- Leading Provider of Internet Hardware
- Giant Market for Manufacturing Industries

Research Cooperation Potential

1. Collaborative Robotics: Hybrid Teamwork of Robotic Team and Human Teams
2. Semantic Technologies: Product Memories for Service Orchestration in Smart Factories
3. Intelligent Industrial Assistance Systems: Proactive and Situation-aware Worker Assistance based on wearable AI
4. Production Planning: Advanced Multiagent Planning and Dynamic Plan Revision for Industrie 4.0
5. Security Technologies: Intelligent Intrusion Detection for Smart Factories

Wolfgang Wahlster is a member of the International Advisory Board of CIIRC, the Czech Institute of Informatics, Robotics and Cybernetics, headed by Prof. Marik

Conclusions

- **Industrie 4.0 is a success story of a strategic public-private partnership and secures Germany's economic power as a leader in manufacturing.**

- **Industrie 4.0 brings the Internet of Things to the job floor of factories and allows mass customization of smart products for a reasonable price based on semantic technologies and semantic service matchmaking.**

- **Cyber-Physical Production Systems and Semantic Product Memories enable Plug&Produce and Multiadaptive Smart Factories. DFKI is a key driver of these technologies.**

- **A new generation of Factory Workers is essential for Industrie 4.0 and will be assisted by a new generation of collaborative robots and intelligent industrial assistance systems using multimodal dual and augmented reality.**

- **Industrie 4.0 and Smart Service Welt are large-scale future projects between industry and academia that are the basis for a data-driven economy.**

Thank you very much for your attention.

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