EMO Hannover
September 18, 2019

Künstliche Intelligenz in der Industrie 4.0: Hürden und Chancen in der realen Produktion

Artificial Intelligence in Industrie 4.0: Hurdles and Opportunities in Real Production

Dr. Anselm Blocher

Research Department Cognitive Assistants

Deutsches Forschungszentrum für Künstliche Intelligenz GmbH - German Research Center for Artificial Intelligence
Stuhlsatzenhausweg 3, Saarland Informatics Campus D3 2
D-66123 Saarbrücken
Phone: +49 681 857 75-5262
E-mail: Anselm.Blocher@dfki.de
WWW: http://www.dfki.de/~blocher

Worldwide Megatrend: Industrie 4.0

The concept of Industrie 4.0 was created in 2010 and first published in 2011 by Wahlster, Kagermann and Lukas

In 2018 more than 80.000 papers have been published on Industrie 4.0

Total Investment in R&D for Industrie 4.0: 140 Billion € per year in Europe

© W. Wahlster

Artificial Intelligence for the Second Wave of Digitalization

First Wave:
Digital Data
- Record
- Store
- Transmit
- Process

Second Wave:
Digital Data
- Understanding
- Refining
- Active Usage
- Monetize

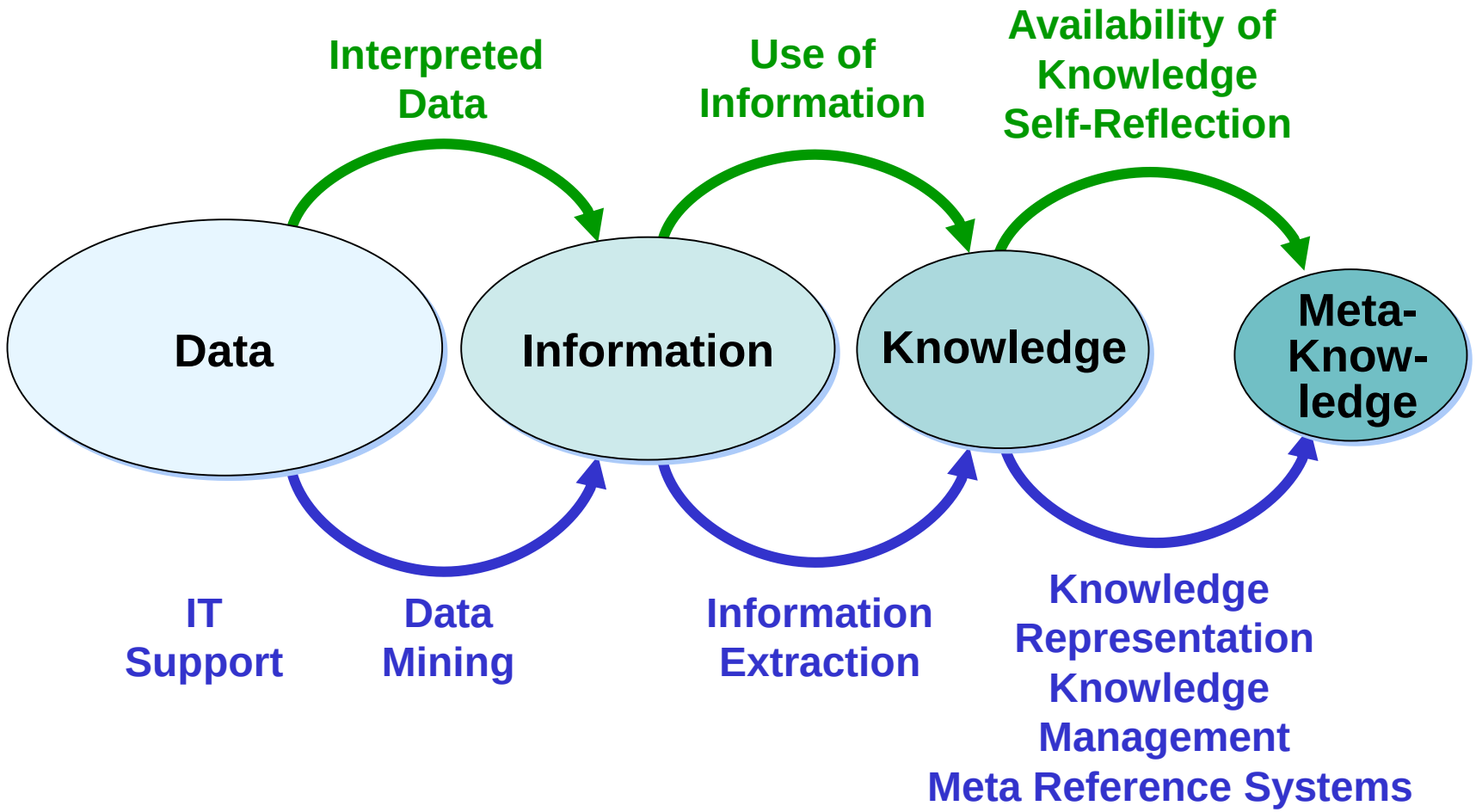
Machine-*readable* Data:
Internet and Cloud Technologies

Machine-*understandable* Data:
Artificial Intelligence and Machine Learning

Digitalization "with Rhyme and Reason"

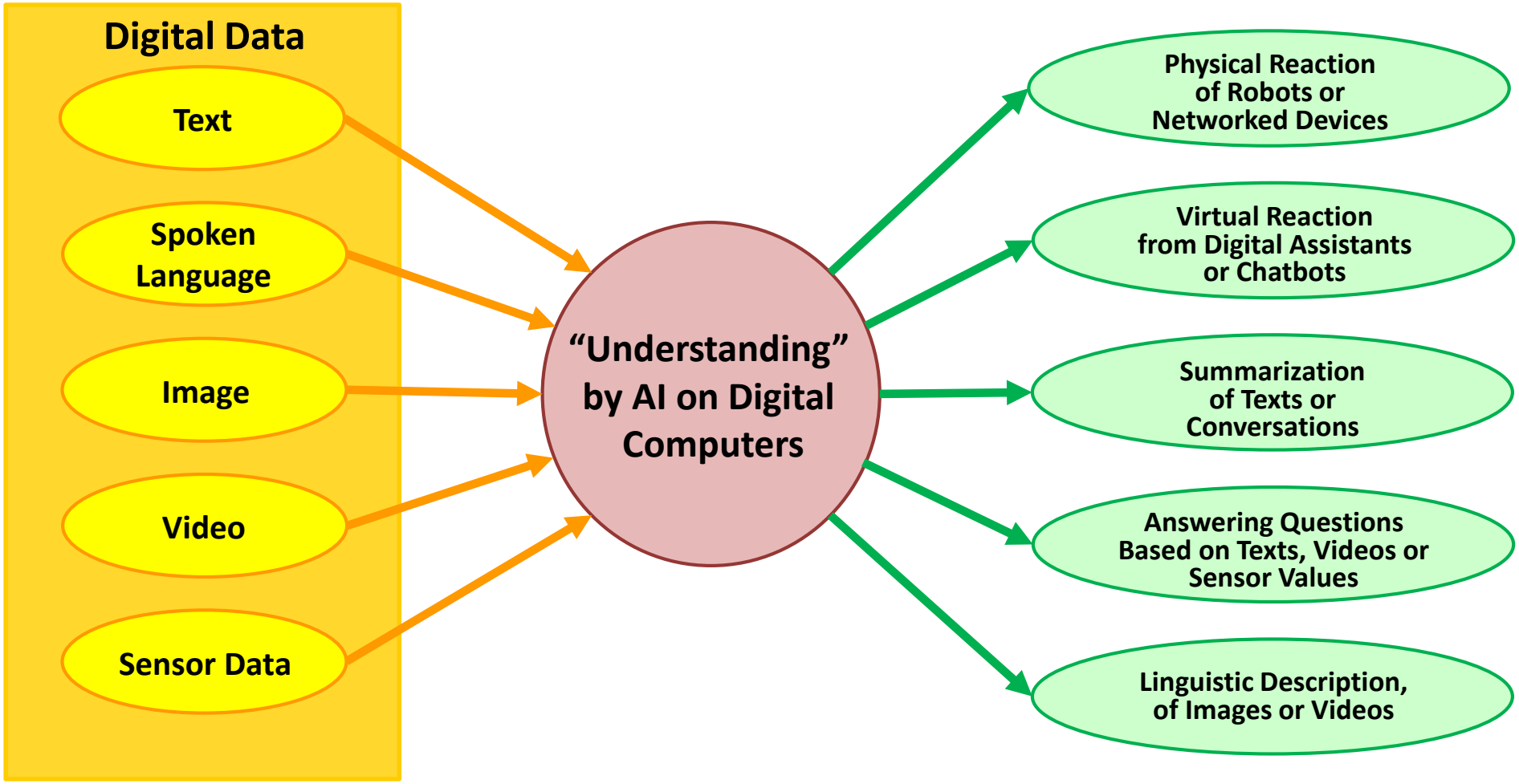
© W. Wahlster

From Data to Meta-Knowledge: From Big Data to Smart Data as Useful Data for Smart Services



© W. Wahlster

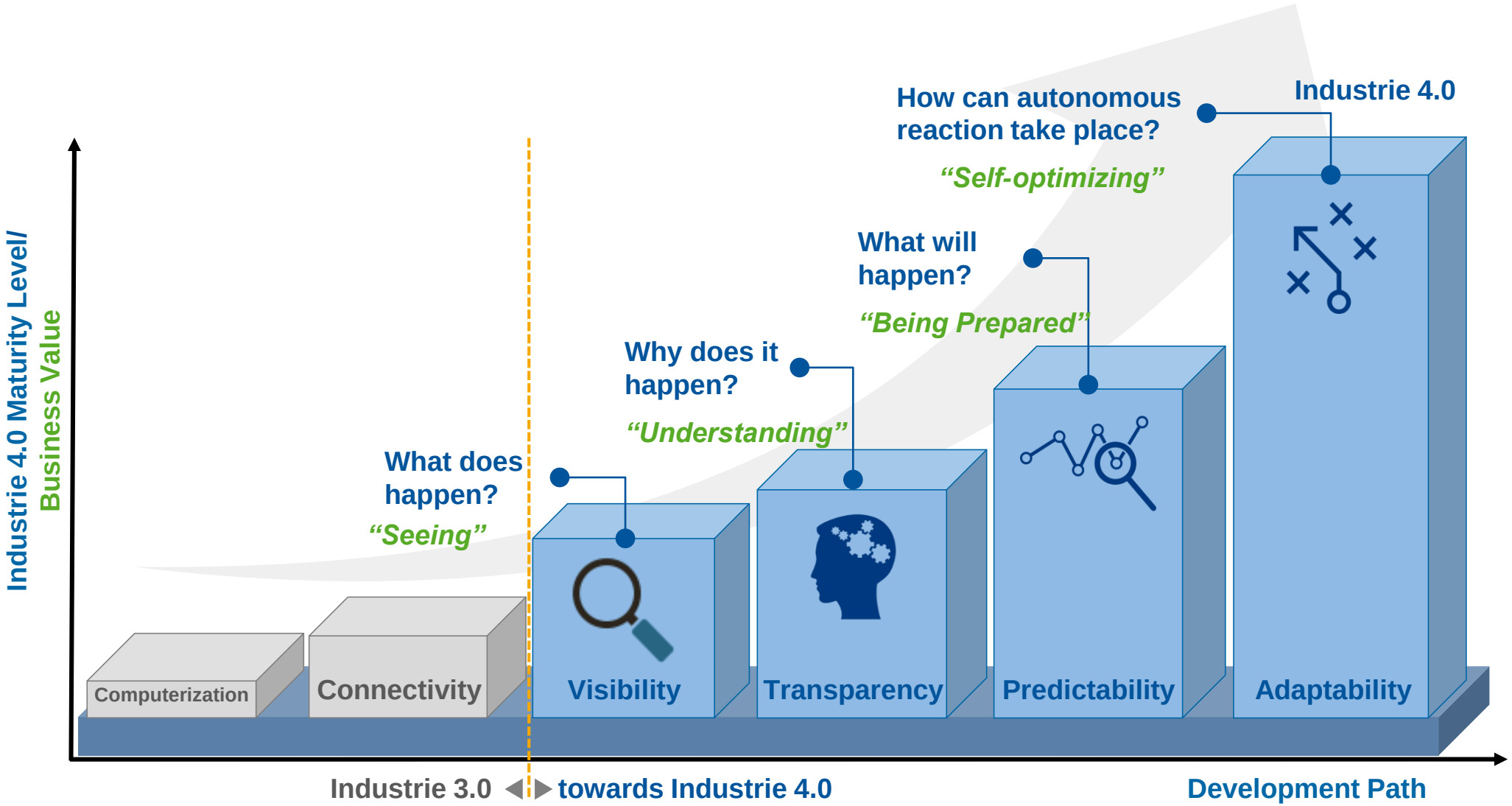
Digital Understanding: Understanding Digital Data and Understanding with the Help of Digital Systems



Understanding Test: Adequate System Reaction

© W. Wahlster

Companies Can Leverage Diverse Potentials on the Development Path to Industrie 4.0 by Choosing a Stepwise Approach



The Maturity Index Follows an Assess and Assist Approach That Enables Companies to Set Up Specific, Benefit-oriented I4.0 Roadmaps

Approach

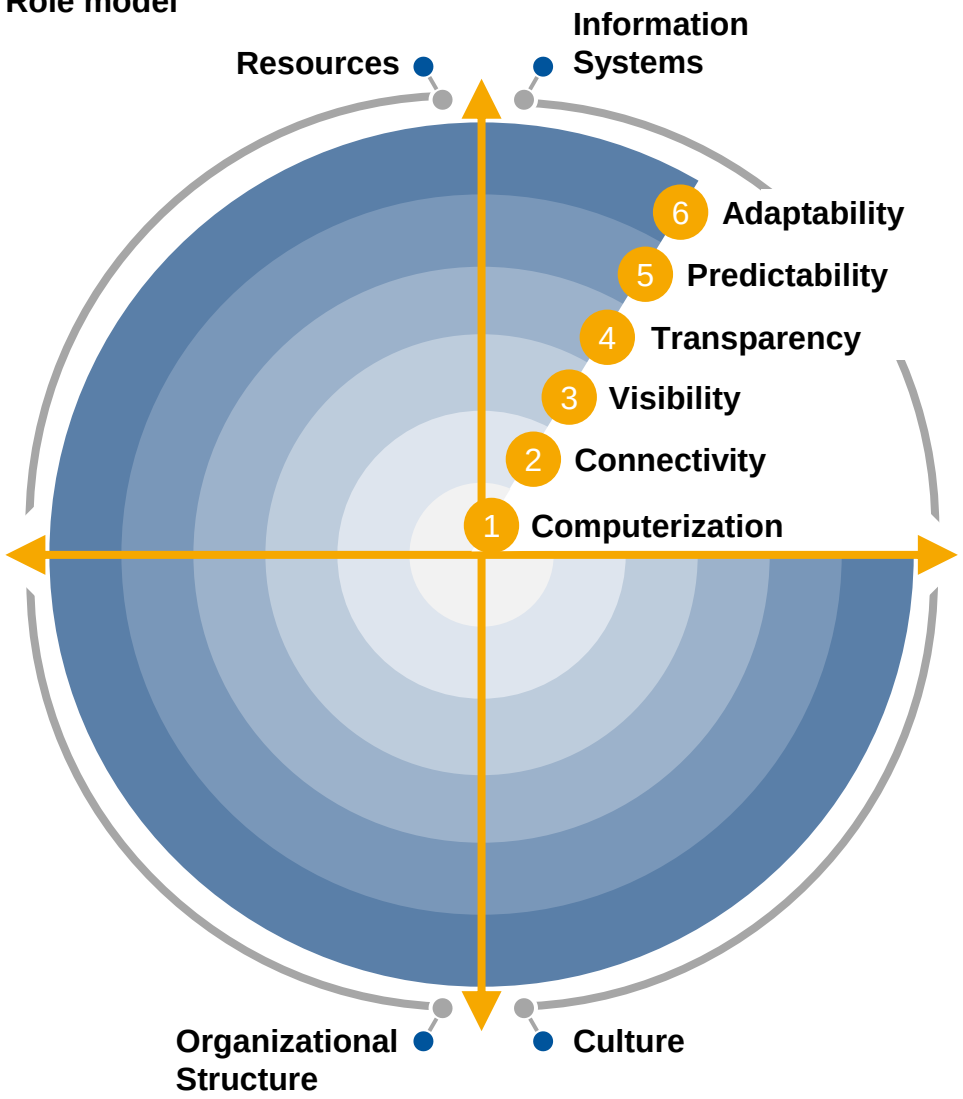
Step 1: Enterprise-wide assessment

- Assessment of the status quo of an enterprise regarding the Industrie 4.0 maturity level based on data from ERP- and PLM systems and a survey
- For this purpose a holistic overview is required to identify the status quo of the Industrie 4.0 maturity
- The assessment developed in the project is based on relevant core processes of a company

Step 2: Company-specific Industrie 4.0 roadmap

- A defined implementation roadmap is required to stay focused on the overall goal
- Derived action items represent necessary projects that should be conducted to reach the next level of Industrie 4.0 maturity
- The approach developed in this project measures the reached maturity level and helps to outline the business value

Role model



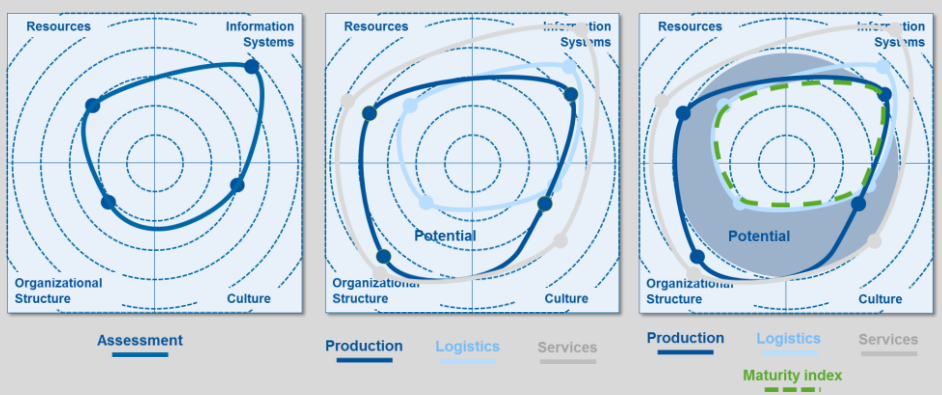
The Assessment Consists of Three Phases. Evaluation and Recommendation Are Based on Surveys Conducted at the Enterprise

Survey

- Questionnaire for each function
- Survey tool

Evaluation

Evaluate | **Combine** | **Analyse**



- **The current Maturity Level of a single process** is evaluated on the four different Structuring Forces
- Maturity Level of different processes are **combined**
- The **biggest possible fit** equals the current Maturity Level

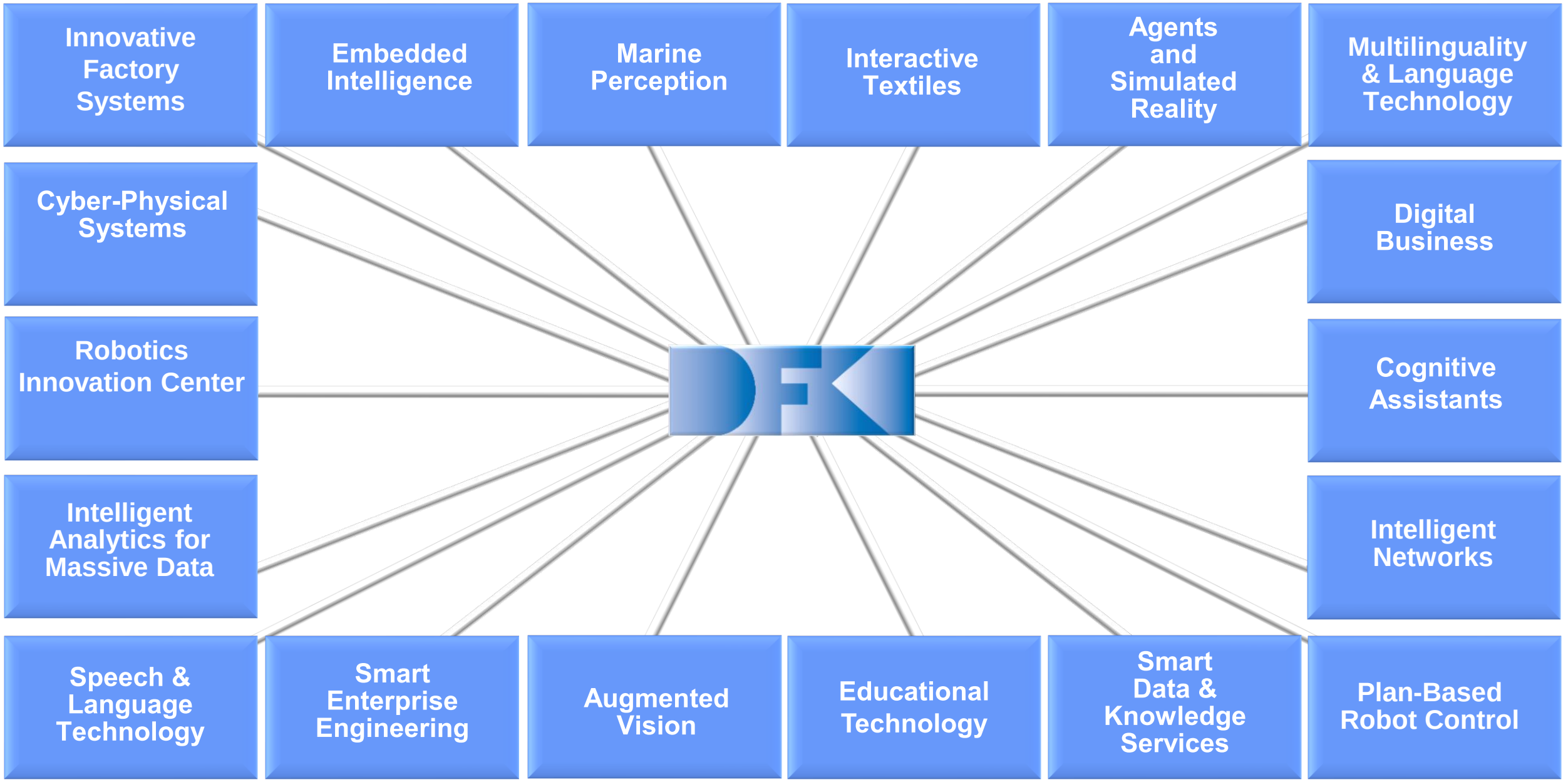
Recommendation

- Identify potential in processes and structuring forces
- Identify potential benefits
- Derive Action Items

DFKI, Germany's Center for Research and Application in AI

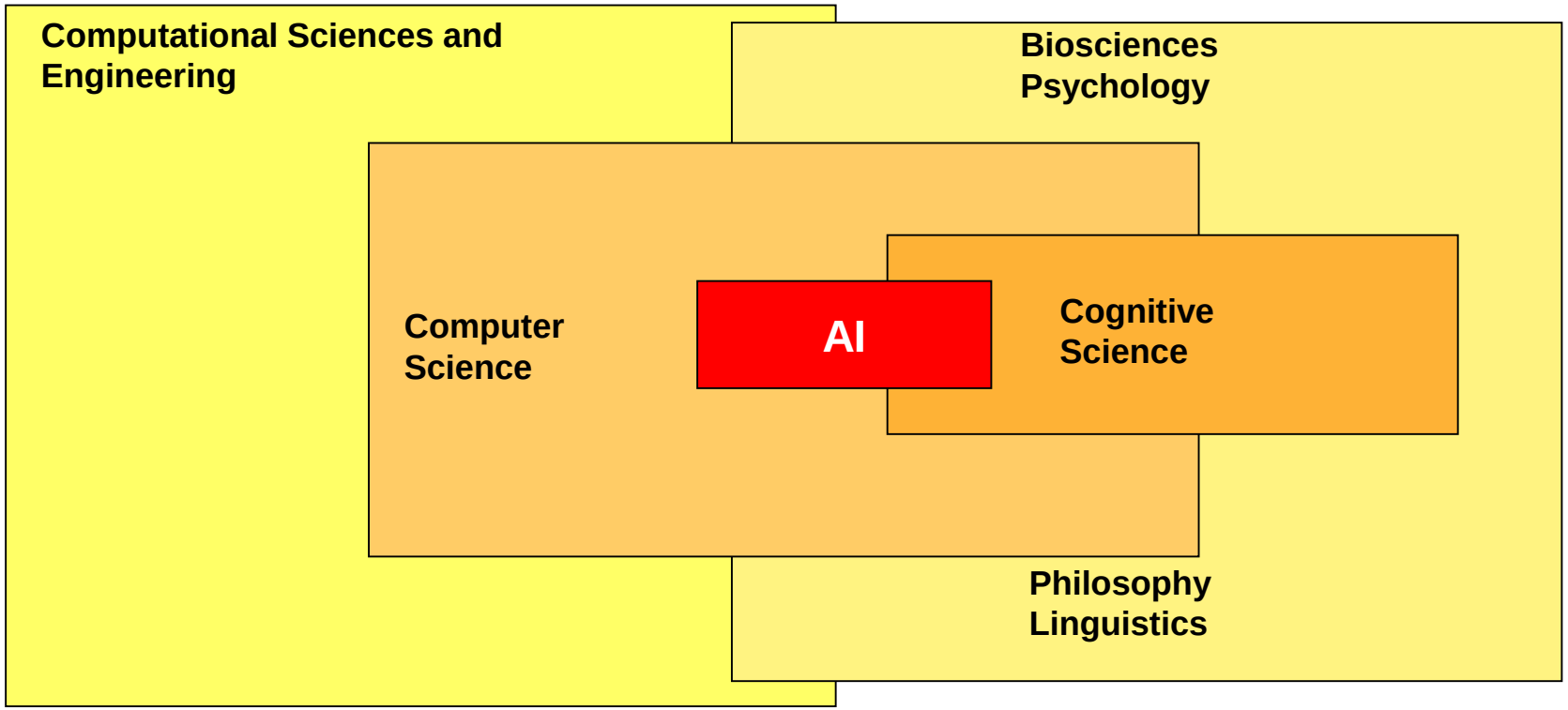
© W. Wahlster

The R&D Departments and Groups of DFKI



© W. Wahlster

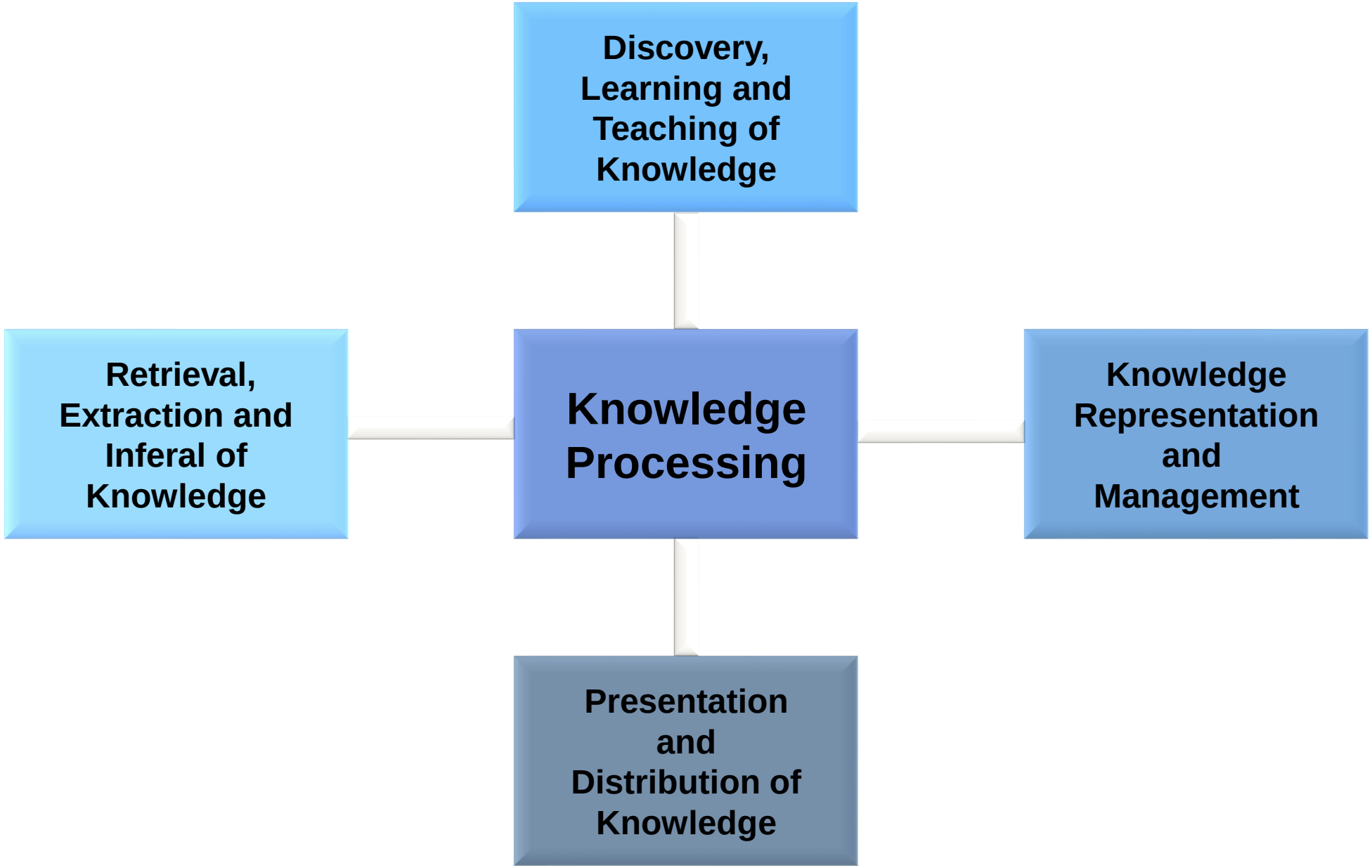
Artificial Intelligence (AI) as Avantgarde Informatics



Artificial Intelligence: realize intelligent behavior and the underlying cognitive abilities on computer systems.

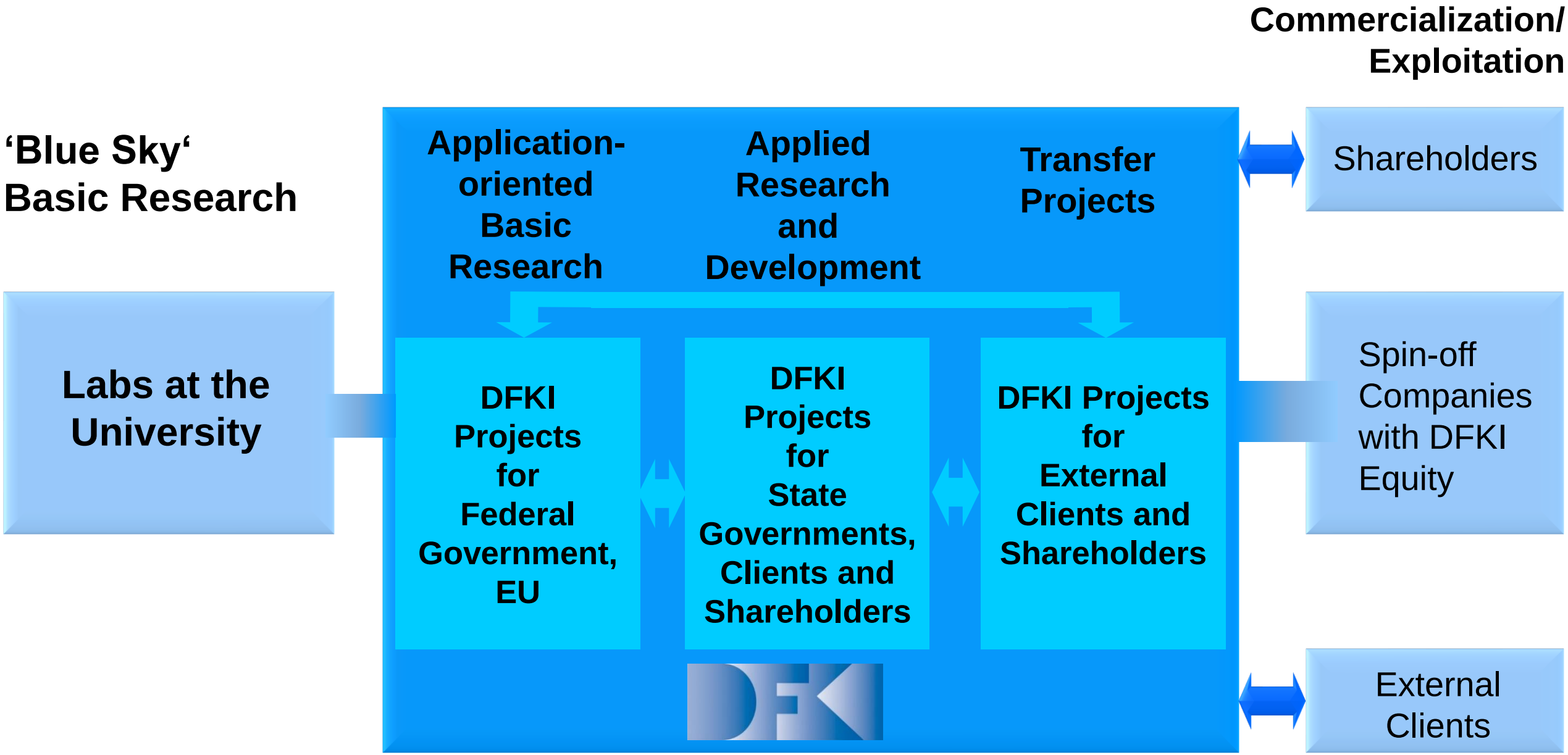
© W. Wahlster

Intelligent Software Systems Based on Knowledge Processing



© W. Wahlster

DFKI Covers the Complete Innovation Cycle



© W. Wahlster

End-to-End Demonstration Systems: 7 Living Labs of DFKI

Innovative Retail Lab (IRL)

Advanced Driver Assistance Systems Lab (ADAS)

Bremen Ambient Assistance Living Lab (BAALL)

Smart Factory

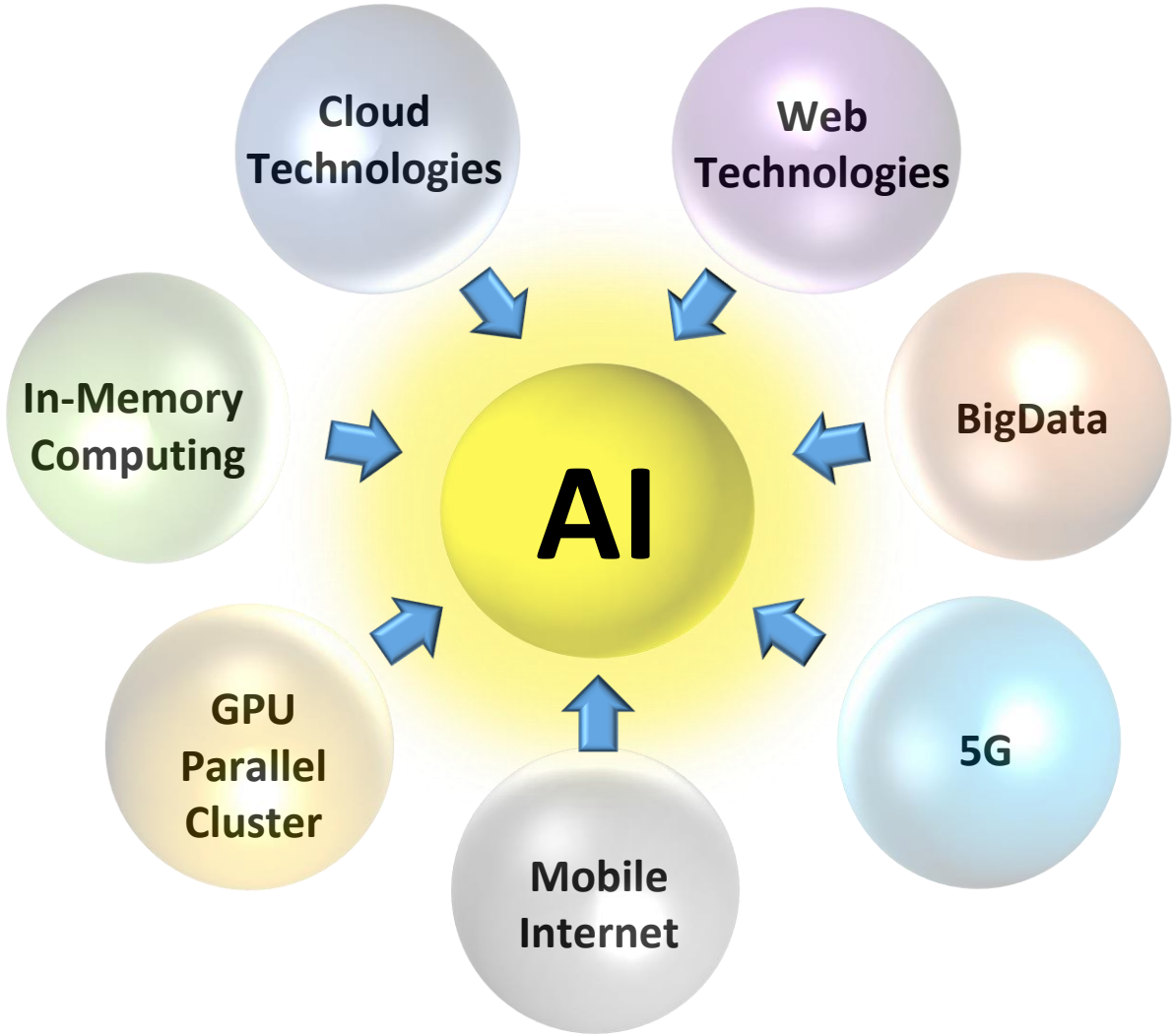
Robotic Innovation Center (RIC)

Smart City Living Lab

Smart Office Space

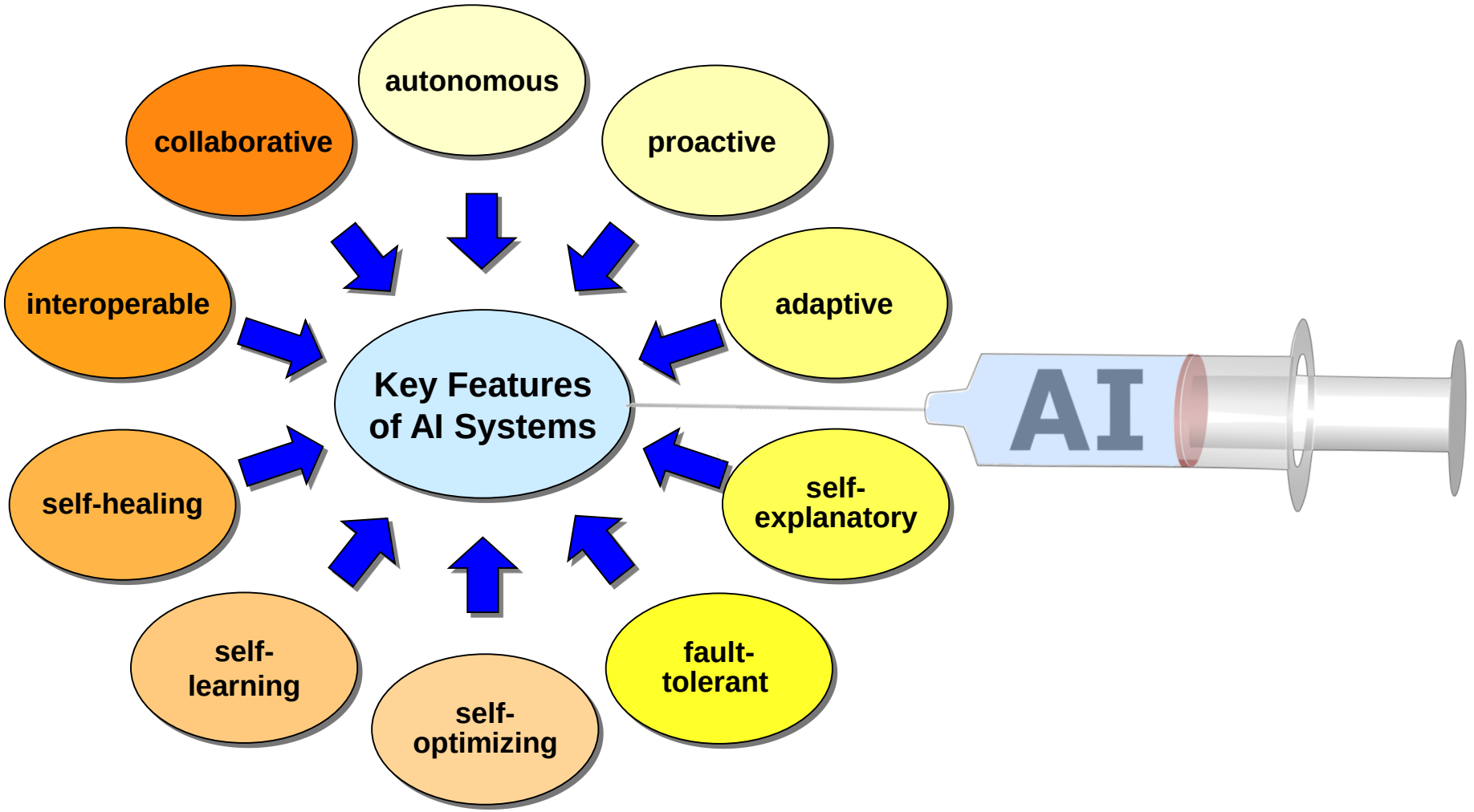
© W. Wahlster

Today‘s IT-Environments Boost AI Solutions



© W. Wahlster

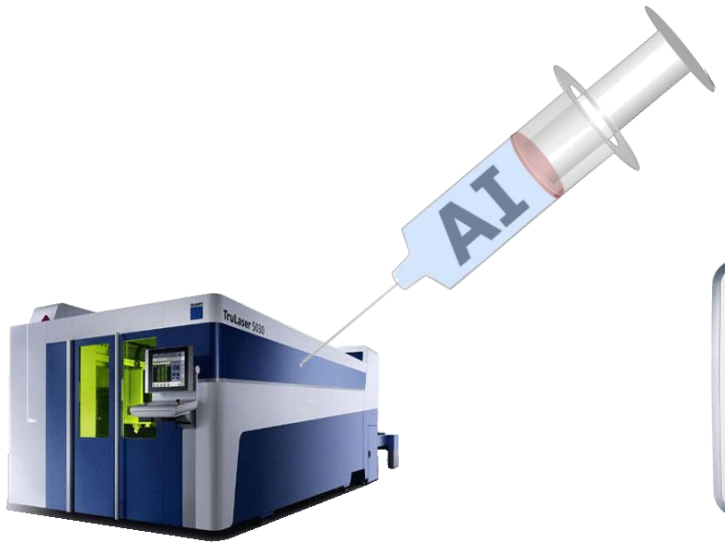
Injecting AI: AI + Smart Data = Smart Products & Services



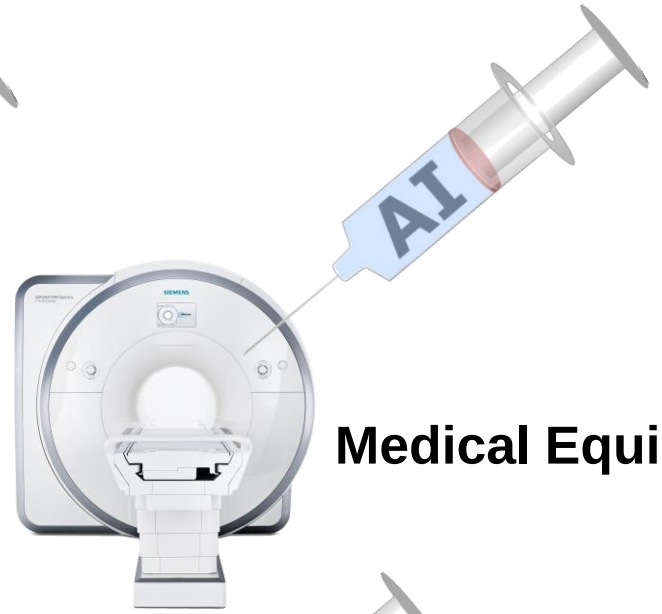
© W. Wahlster

Disrupting German Economy by Injecting AI: Transforming Premium Products Into Smart Products and Smart Services

Cars



Manufacturing Equipment



Medical Equipment

Home Appliances

Agricultural Machinery

© W. Wahlster

Key Aspects of Industrie 4.0 Based on AI for the IoT

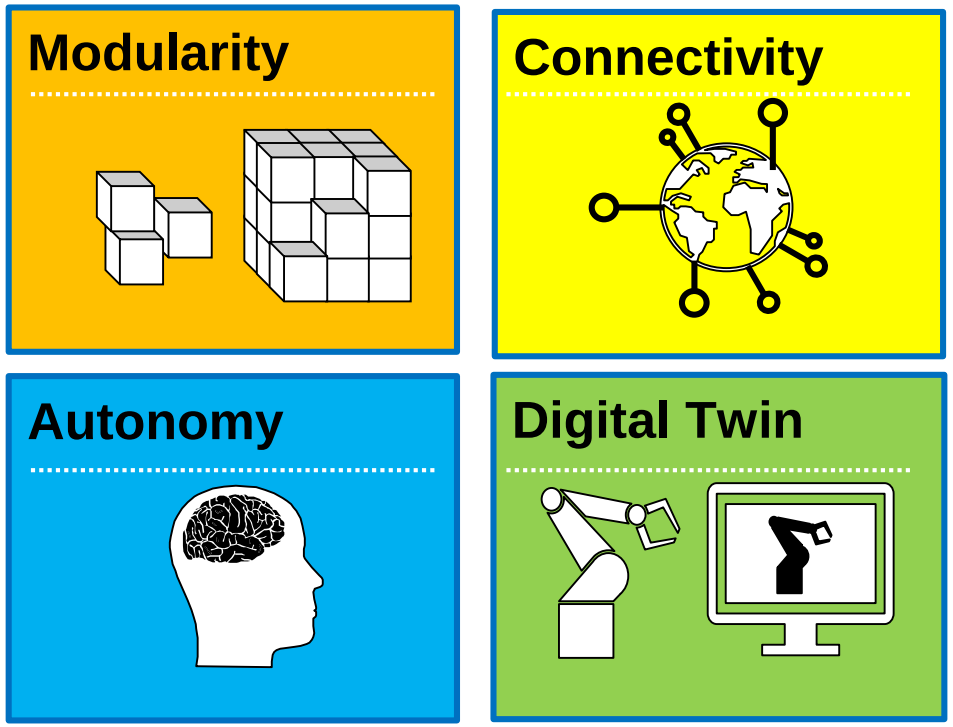
Needs of manufacturing industry …

Increased efficiency,
batch size 1, and
multidaptivity required

Smart Factories are defined by

- **Dynamic networks** of local controllers
- **Flexible production** configured in response to rapidly changing processes
- **Anytime planning** in realtime
- **Optimization** of production, e.g. **through Cyber-Physical Production Systems**
- **Self-organization,** e.g. product steers its own way through the production process
- **Digital Twins** of the entire process and its constituent elements

… can be clustered into four core aspects



Adapted from Siemens

© W. Wahlster

Building Blocks for Complex AI Systems: AI on Demand

Sense

- Signal-Symbol Transformation
- Multisensor Fusion
- Pattern Recognition
- Biosignal Analysis
- Attention Tracking
- Emotion Recognition
- User and Context Recognition

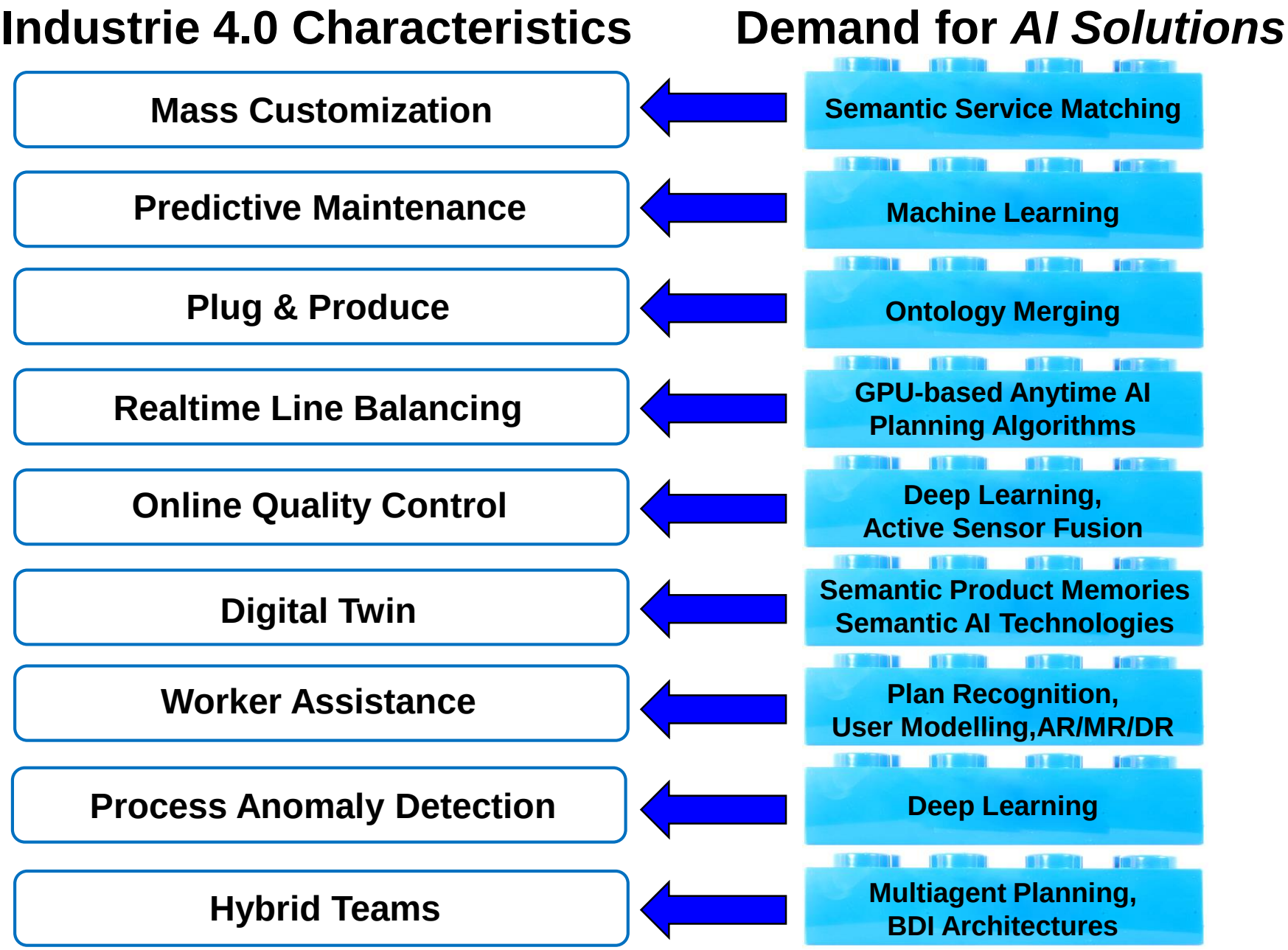
Understanding

- Text Understanding
- Image and Video Understanding
- Machine Learning
- Spoken Dialog Understanding
- Knowledge Processing & Reasoning
- Action Planing & Plan Recognition
- Information Extraction & Intelligent Search

Act

- Sensor Motoric Feedback
- Complex Motion and Object Manipulation
- Sensor Control
- Transfer of Control
- Explanation Component
- Multiagent & Collaboration Techniques
- Personalized Presentation

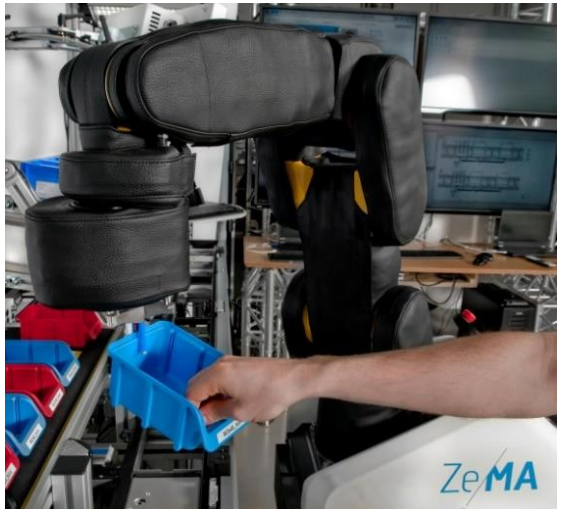
AI Technologies for Industrie 4.0 Characteristics



Connecting Workers, Robots, and Tools
(ZeMA and DFKI in SmartF-IT, Müller/Wahlster 2015)

- **The Collaborative Robot APAS provides the worker with the right screw type according to the workflow.**
- **The use of the screw driver (which is connected via Internet to the CPS middleware) is monitored by ultrasonic sensors.**

Collaborating APAS Robot

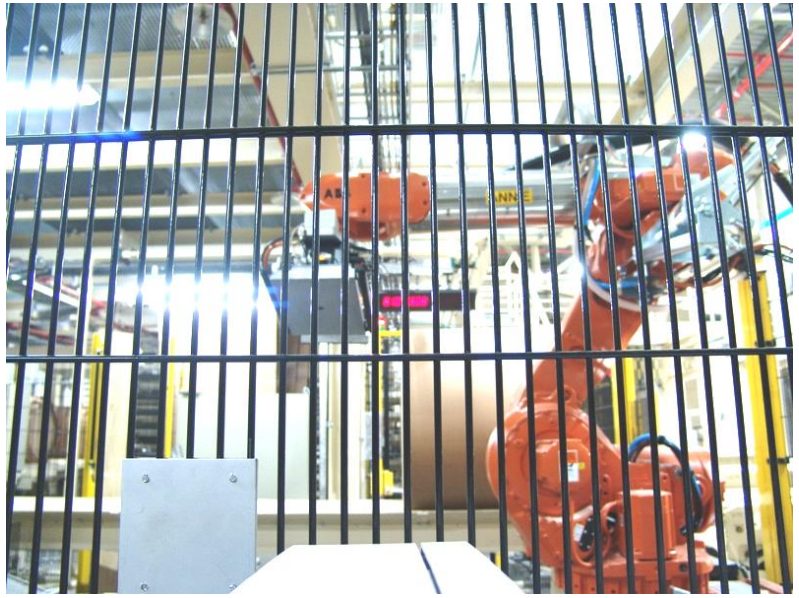


Monitoring of Screwing

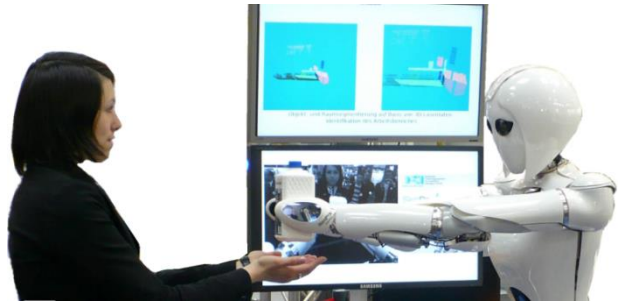
© W. Wahlster

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

Yesterday



Today

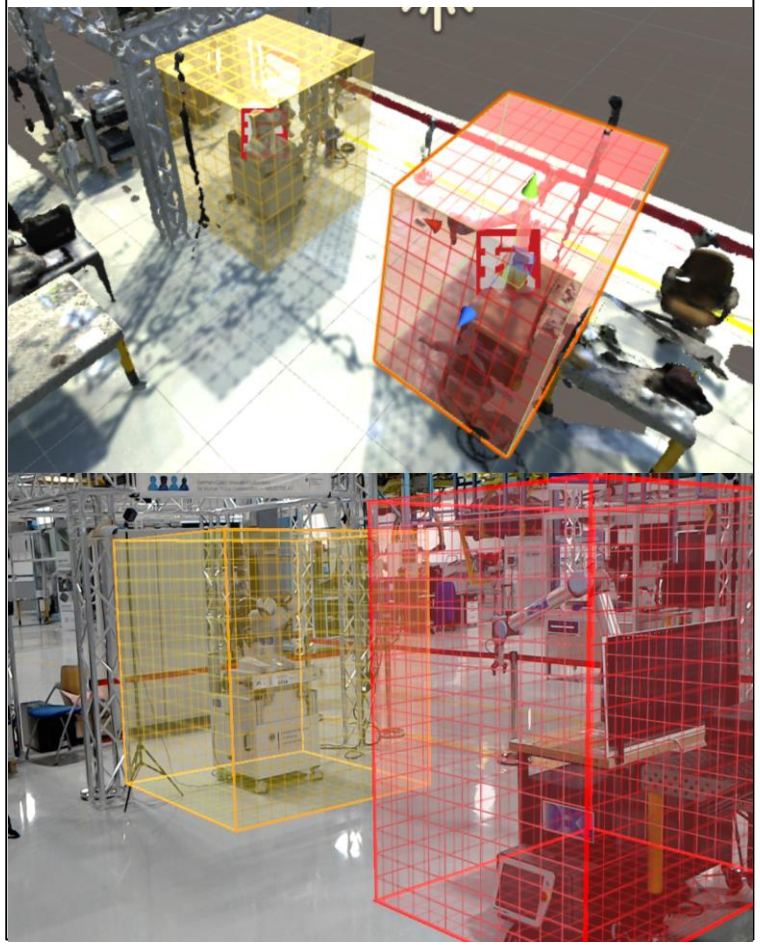


A new generation of light-weight, flexible robots collaborate with humans in the smart factory

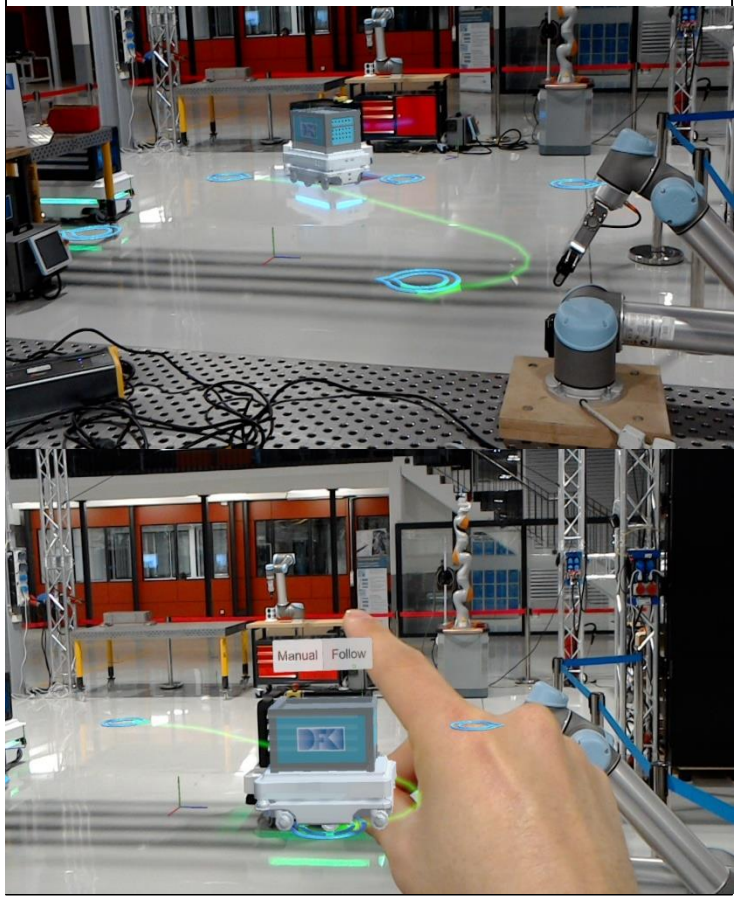
© W. Wahlster

HRC-Modules as Assistance Systems

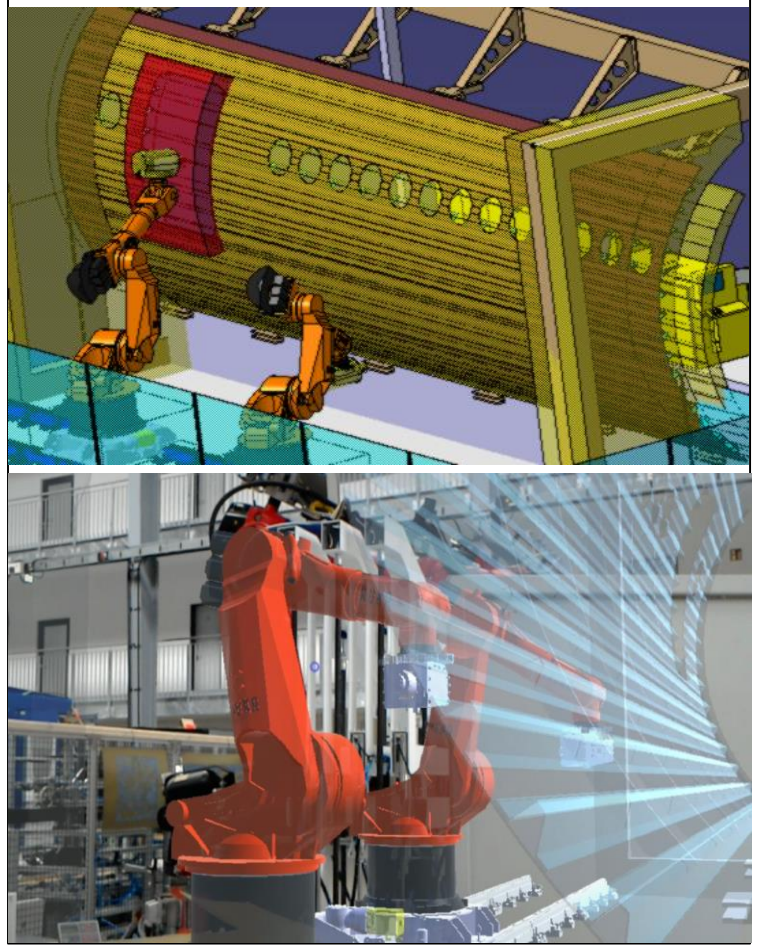
- **Dynamic security zones with multi-modal notification**



- **Manual selection of target positions and automatic “Follow-Me” mode for mobile robots**



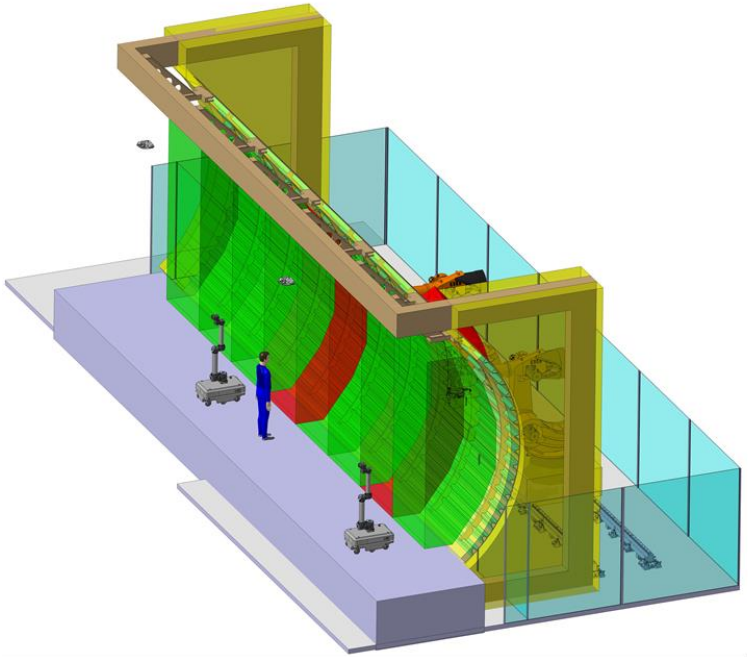
- **“X-Ray vision” supporting HRC**



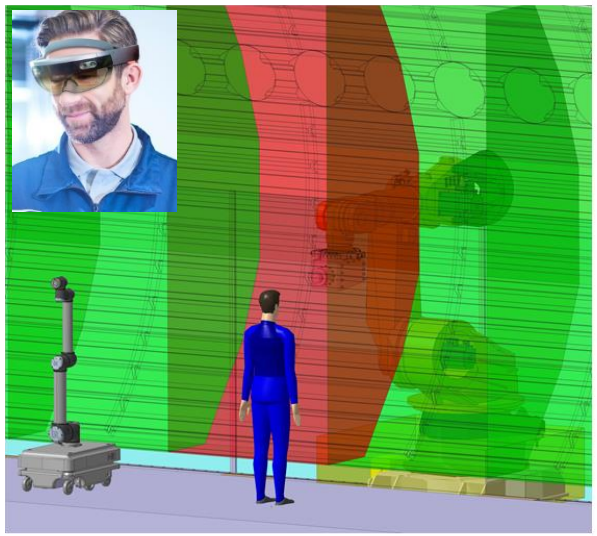
Hybr-iT
Mensch Roboter Kollaboration

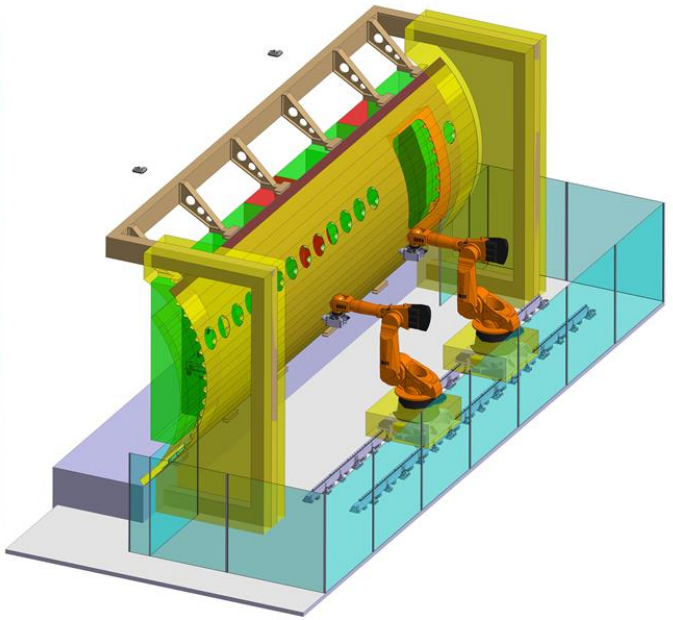
© W. Wahlster

AI for an „X-Ray“ View Through the Worker‘s HoloLens for Tracking Dangerous Actions of Occluded Heavy-Weight Robots



Collaborative ligth-weight robots working together with humans on the interior sideof the fuselage





Heavy-weight robots working on the exterior side of the fuselage

© W. Wahlster

Smart Factory for the Production of Cars and Aircrafts

Power 4 Production

Saarbrücken

2400 m², 20 Robots in a hybrid team cell (140 m²)

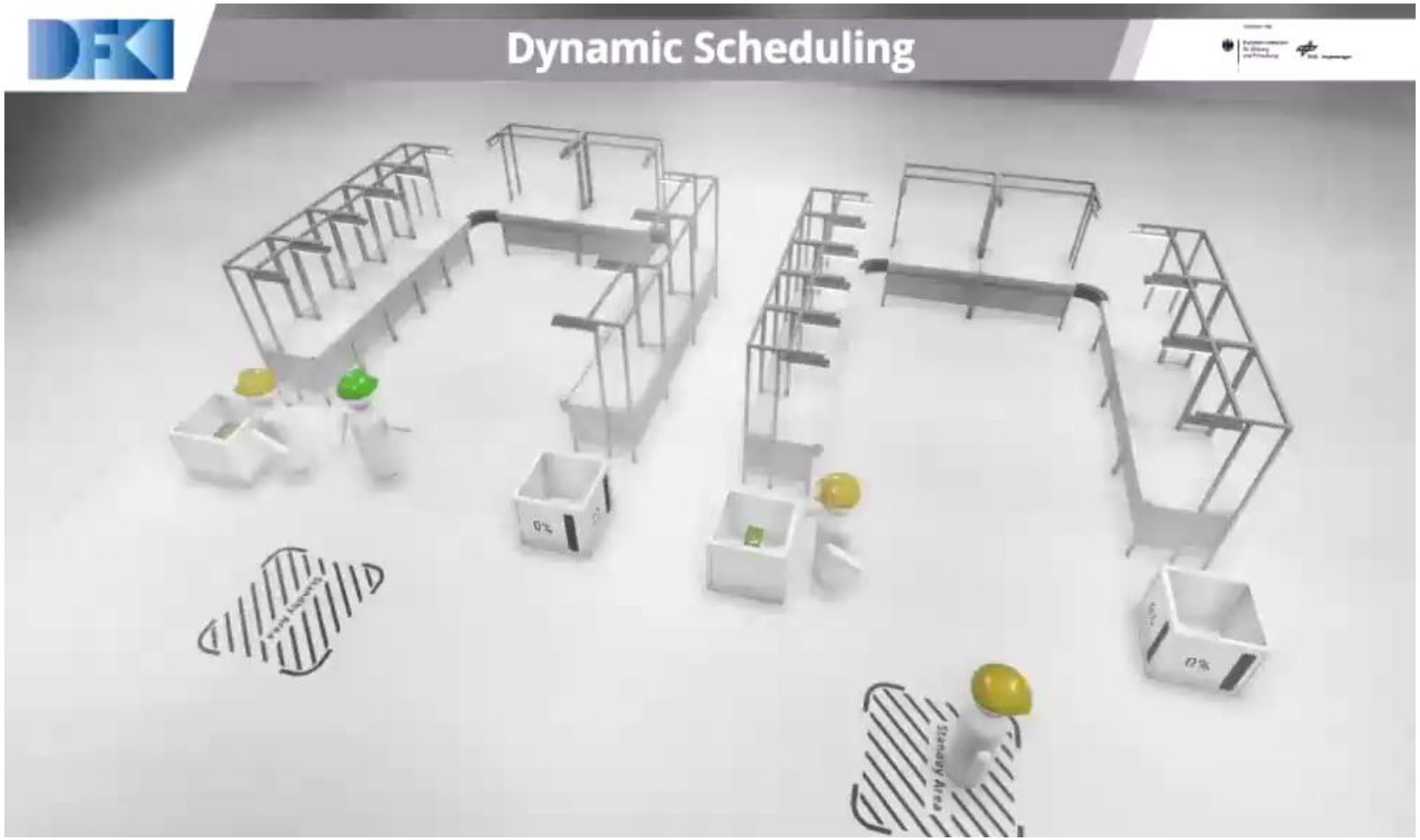
ZeMA
Zentrum für Mechatronik und Automatisierungstechnik

DFKI German Research Center for Artificial Intelligence

Team Robotics for Multiadaptive Manufacturing Tasks

© W. Wahlster

AI-Based Real-time On-the-fly Planning of Hybrid Production Teams

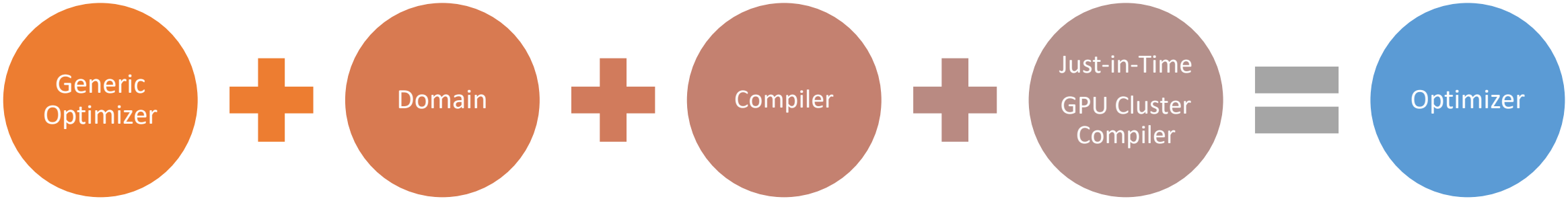


Based on GPU Computing for Extremely Large State Spaces

Funded by BMBF
in the
SmartF-IT project

© W. Wahlster

Optimization Approach



- Generic Optimizer Library
  - Designed for GPUs
  - Generic functionality required by all optimizers
- Domain (or domain model)
  - Domain-specific knowledge
  - State description, optimization goals, exploration heuristics
- Optimization Compiler
  - Generates specialized optimizers
  - E.g. determines optimal memory layout, execution order, optimization strategy …
- Generated Optimizer
  - High-performance optimizer
  - Tuned for GPUs

Conclusions

1. AI Technologies are a key success factor for Industrie 4.0.
2. Semantic Technologies guarantee interoperability in multi-vendor factories and are the basis for a disruptive SOA production logic.
3. Anytime, GPU based automated production planning in realtime is a breakthrough for flexible automation.
4. User Modeling, Plan Recognition as well as intelligent multimodal interfaces are the basis for a new generation of worker assistance systems.
5. Hybrid teams of cobots, softbots and people are a challenge for basic research in multiagent coordination, e.g. with an acceptable solution of the transfer of control problem.
6. Industrie 4.0 brings many AI subfields together in one of the most important fields of industrialized countries like Germany.

Thank you very much for your attention

EMO Hannover 2019 Preview
03. Juli 2019

Künstliche Intelligenz in der Industrie 4.0: Hürden und Chancen in der realen Produktion

Dr. Anselm Blocher

Forschungsbereich Kognitive Assistenzsysteme

Deutsches Forschungszentrum für Künstliche Intelligenz GmbH
Stuhlsatzenhausweg 3, Saarland Informatics Campus D3 2
66123 Saarbrücken
Tel.: 0681 857 75-5262
Fax: 0681 857 75-5485
E-mail: Anselm.Blocher@dfki.de
WWW: http://www.dfki.de/~blocher

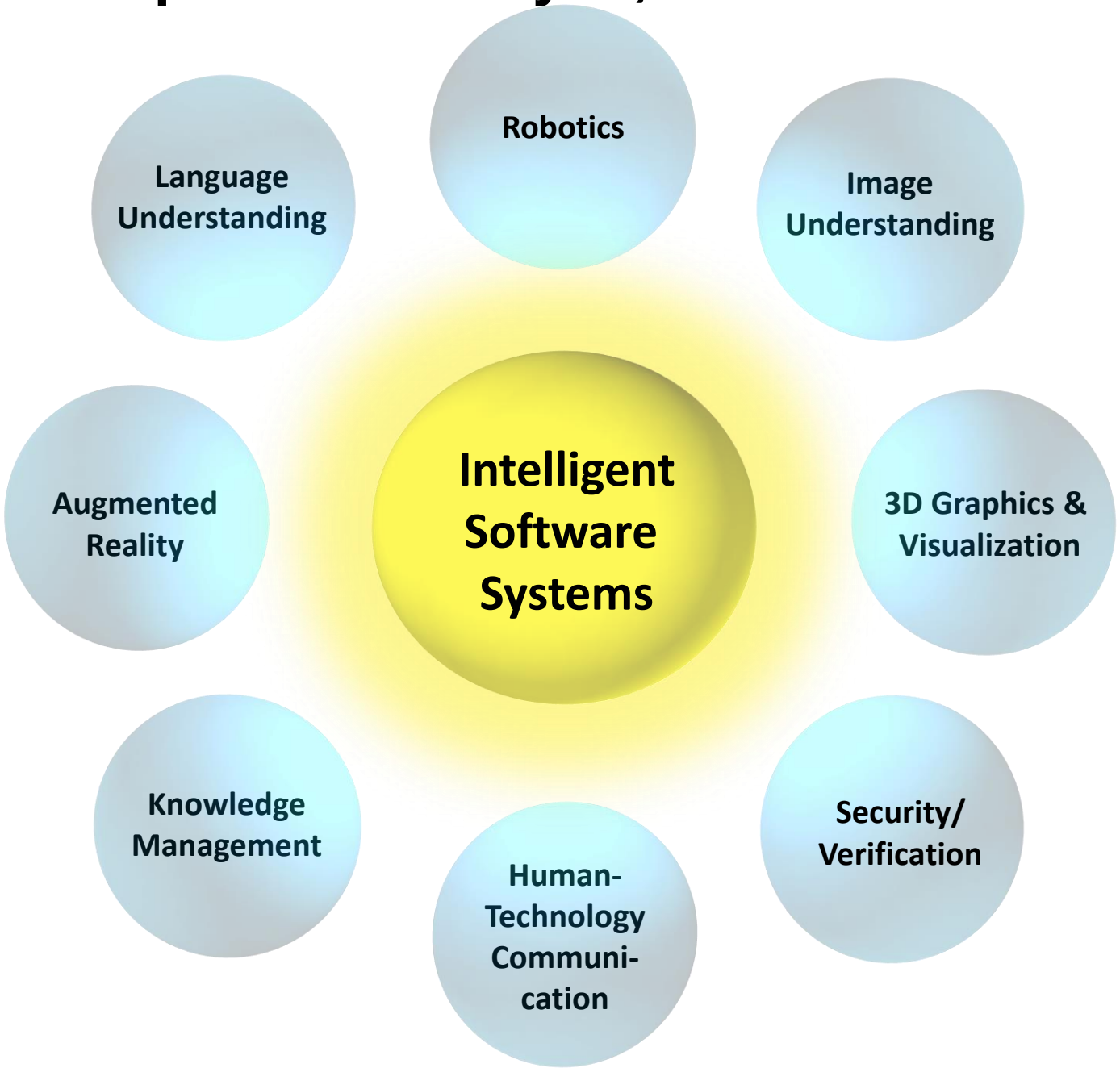
Outline

1. Introduction: DFKI
2. Introduction: Digit(al)ization,
   Industry 4.0, BaSys4.0, Maturity Index
3. AI in general
4. AI in Industry 4.0
5. Manufacturing Engineering and Production:
   Some Use Cases and Labs
6. An outlook into the Future of AI
7. Conclusions, Final Words

DFKI Is the World‘s Largest AI Research Center with >1000 Employees, 28 Shareholders and >90 Spin-Off Companies

© W. Wahlster

DFKI Approach: Computers with Eyes, Ears and Common Sense



© W. Wahlster

Our Service Offering

As an internationally renowned Center of Excellence for innovative software systems based on Artificial Intelligence (AI) methods we are offering the following services with more than 30 years of experience in basic and applied R&D:

Technology transfer of award-winning research results of DFKI

Design, construction and operation of Living Labs

Innovation coaching and start-up consulting in the Public-Private-Partnership sector

Technical and organisational support for the standardisation in the IT sector (including W3C, ISO)

Individual design, development and implementation of innovative application solutions

Strategic and technical due diligence consulting for companies in the ICT sector

Market studies, expert surveys, feasibility analysis and empirical user studies

Innovation coaching and turnaround management

Component development with AI-functionality enhancing performance of complex software systems

Business engineering: Process analysis and development

Scientific advice on the selection and implementation of complex software solutions

Scientific monitoring of data collections and their evaluation

Customization, implementation, deployment and maintenance of our AI-solutions

Technology workshops, training and practice

Scientific evaluation and benchmarking of software solutions

Independent assessment of IT-security and privacy

Application-oriented basic research

© W. Wahlster

DFKI‘s First 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

smartFactory KL®

Members of SmartFactory KL e.V.

The Paradox of Artificial Intelligence

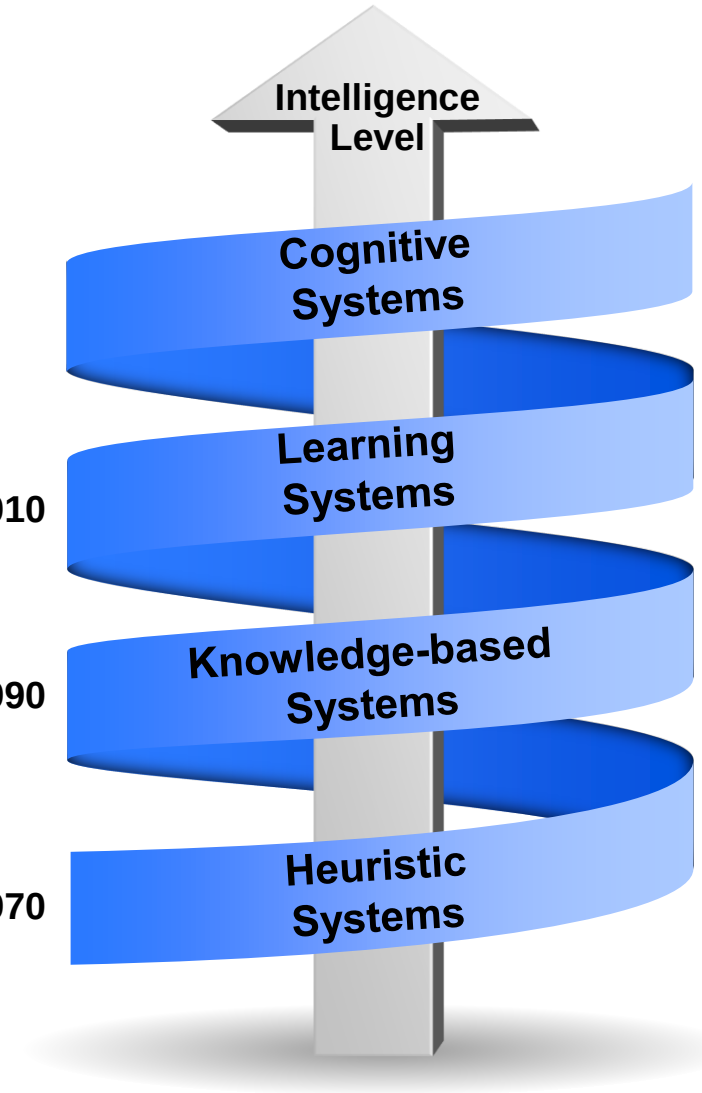
In AI-Research the rule is:

Difficult Problems are easy,
easy Problems are difficult.

Expert‘s intelligence Cognitive and knowledge-intensive capabilities	Daily routine intelligence Sensorimotor & socio-emotional capabilities
– Find flaw in computer-chip	– Recognize a face
– Beat chess-master	– Catch a ball
– Optimize steel production	– Console a kid

© W. Wahlster

The Four Phases of AI Research: 60 Years of AI



Phase 4 – 2010 -

Hybrid Architectures: Knowledge Bases combined with Machine Learning (in Embodied Systems)

Phase 3 – 1990 - 2010

Machine Learning based on Mass Data and Probalistic Peasoning

Phase 2 – 1970 - 1990

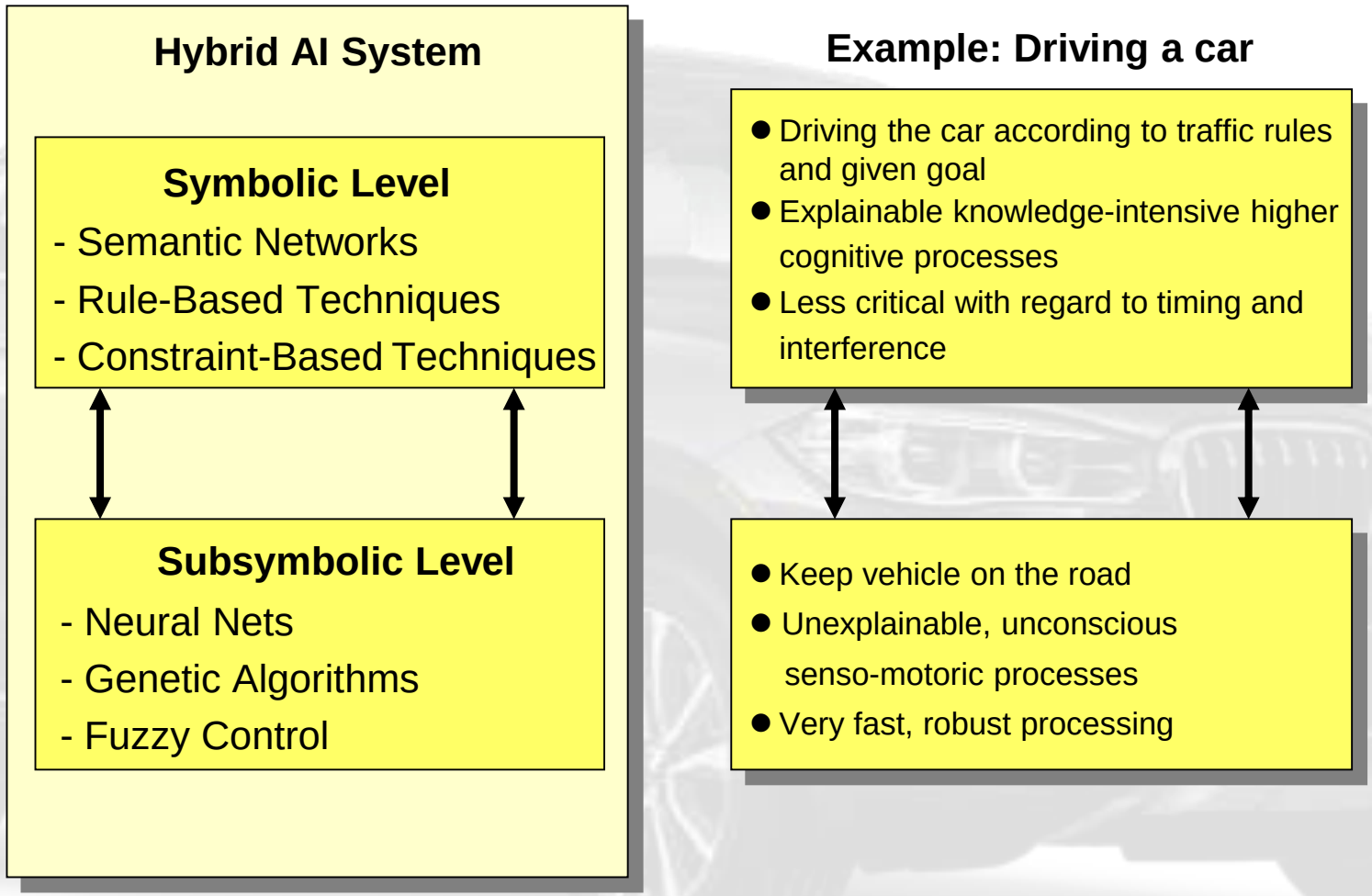
Hand-crafted Knowledge Bases and Rule-based reasoning

Phase 1 – 1950 - 1970

General Problem Solving Methods

© W. Wahlster

The Need for Hybrid AI Systems



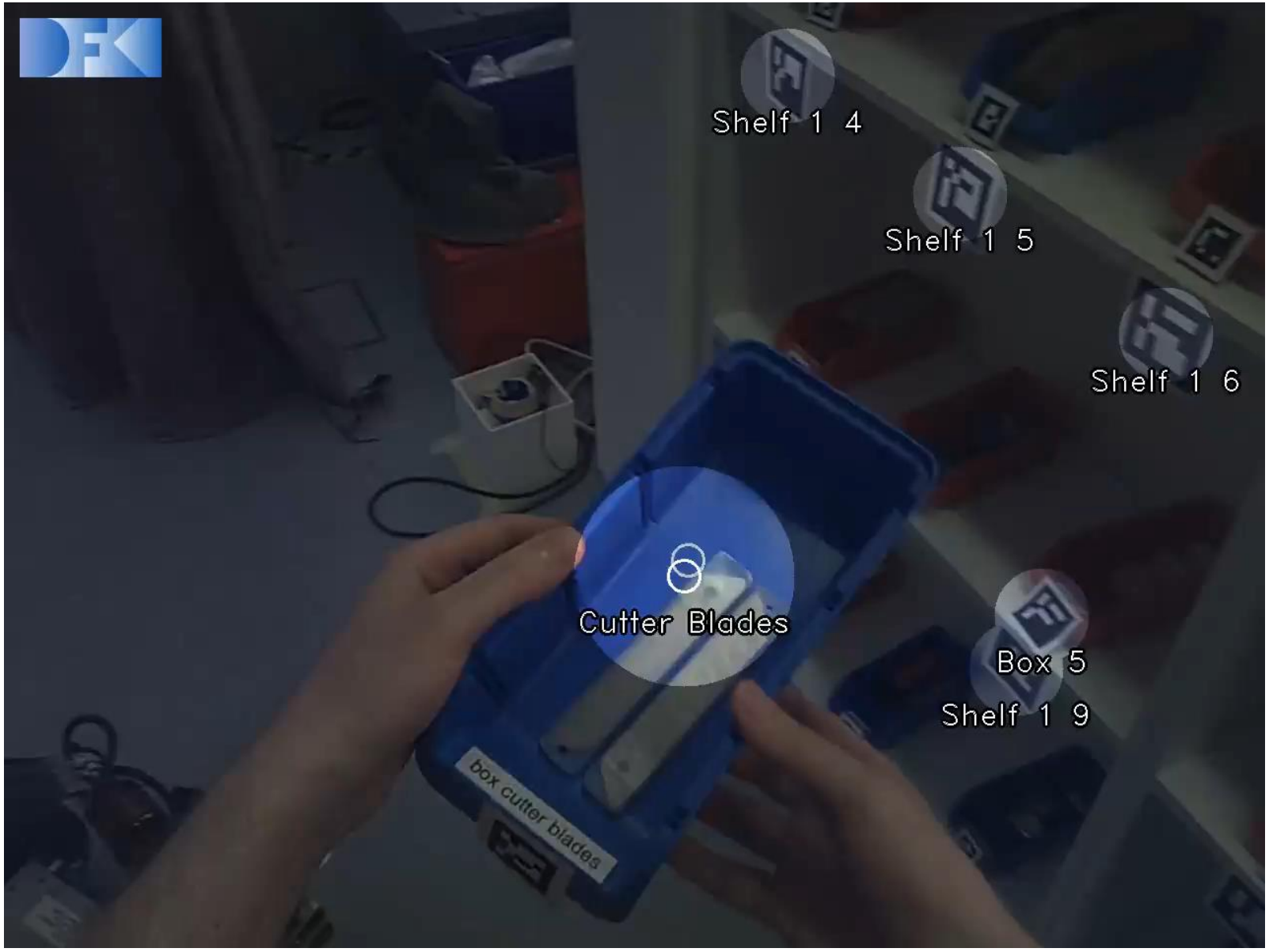
Example: Driving a car

- Driving the car according to traffic rules and given goal
- Explainable knowledge-intensive higher cognitive processes
- Less critical with regard to timing and interference

- Keep vehicle on the road
- Unexplainable, unconscious senso-motoric processes
- Very fast, robust processing

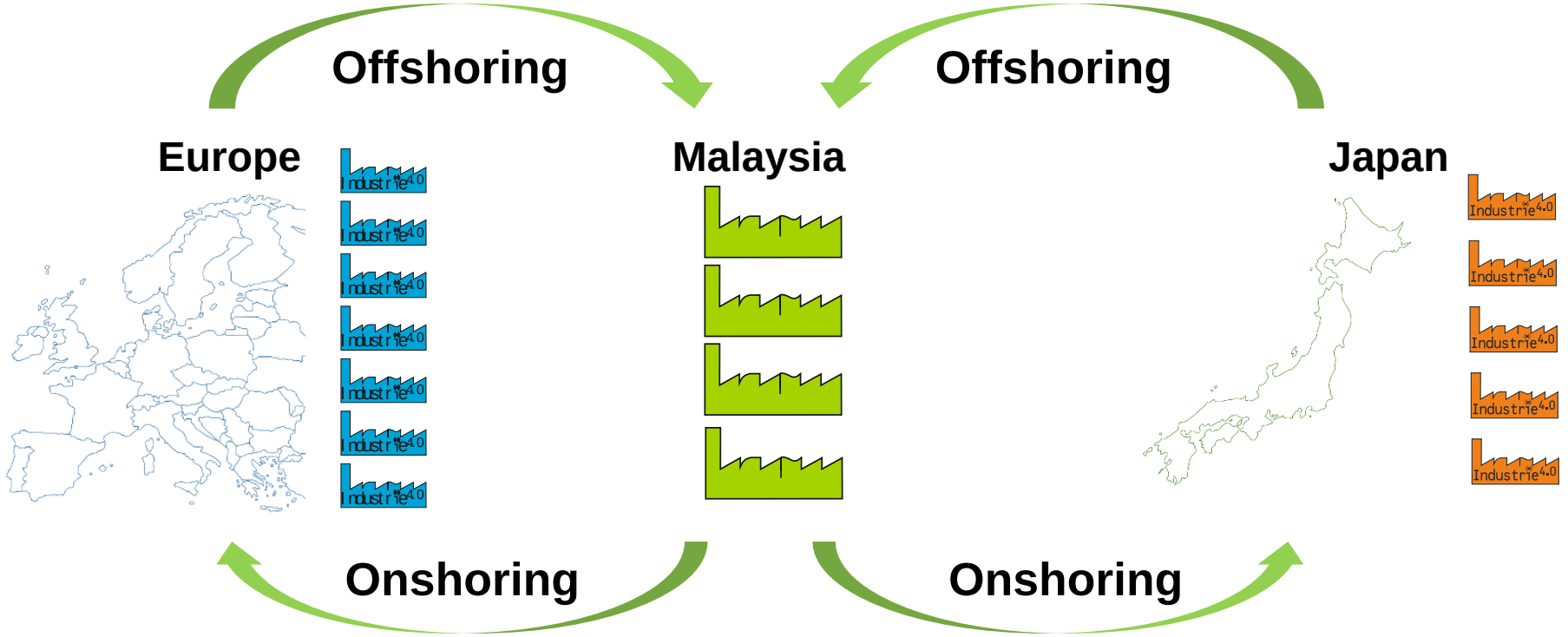
© W. Wahlster

Deep Learning-based Object Recognition on the Shop Floor



HYSOCIATEA
HYBRID SOCIAL TEAMS

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

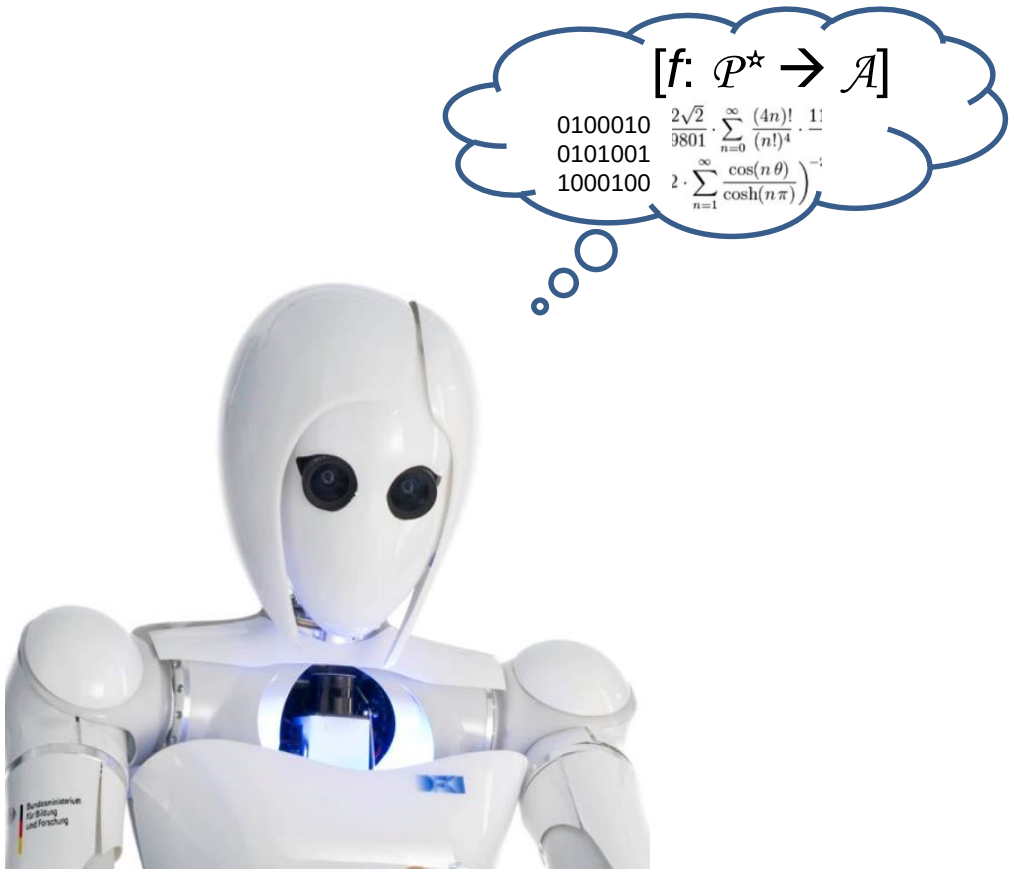
- High-wage Country
- Industrie 4.0
- Mass Customization
- Short and Mobile Chains to Consumers in Japan
- Small Networked Smart Factories

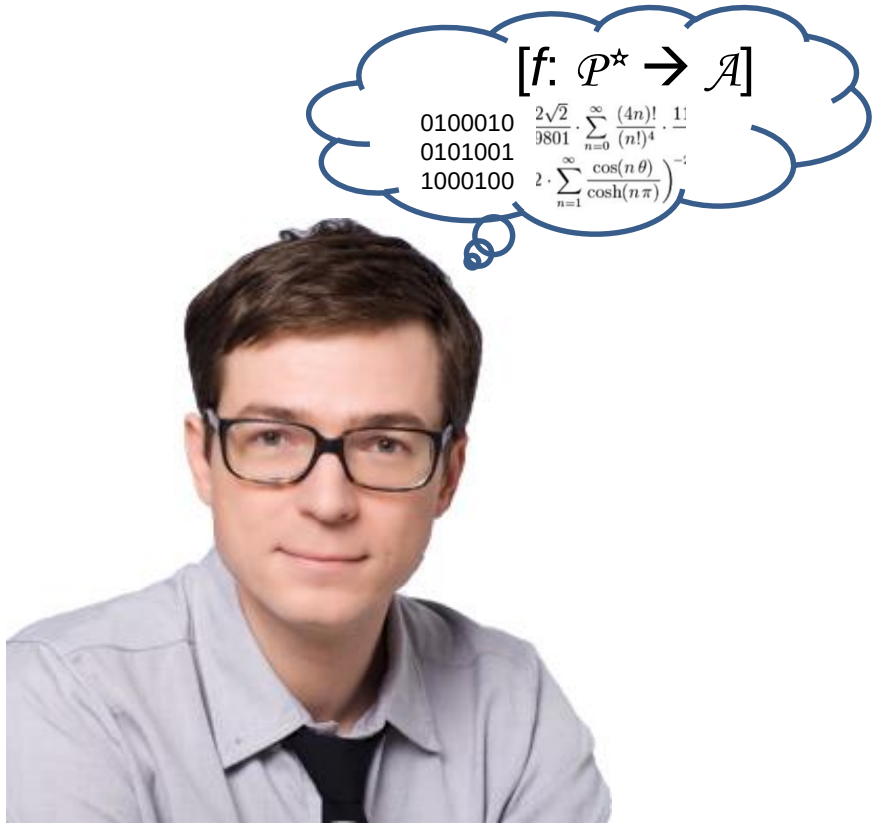
For example: sport shoes, clothes, kitchens, appliances, consumer electronics, toys, bikes…

Final Words

© W. Wahlster

Is Artificial Intelligence better than our brain?



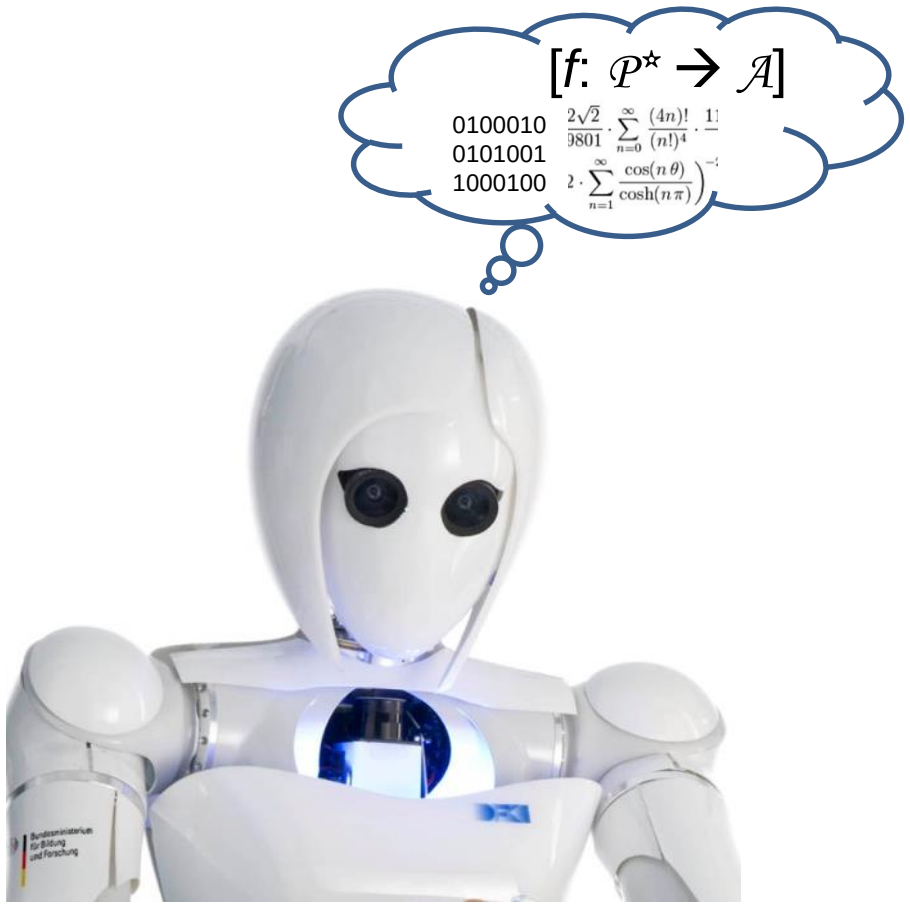


Answer : No – and still for a long time!

But:

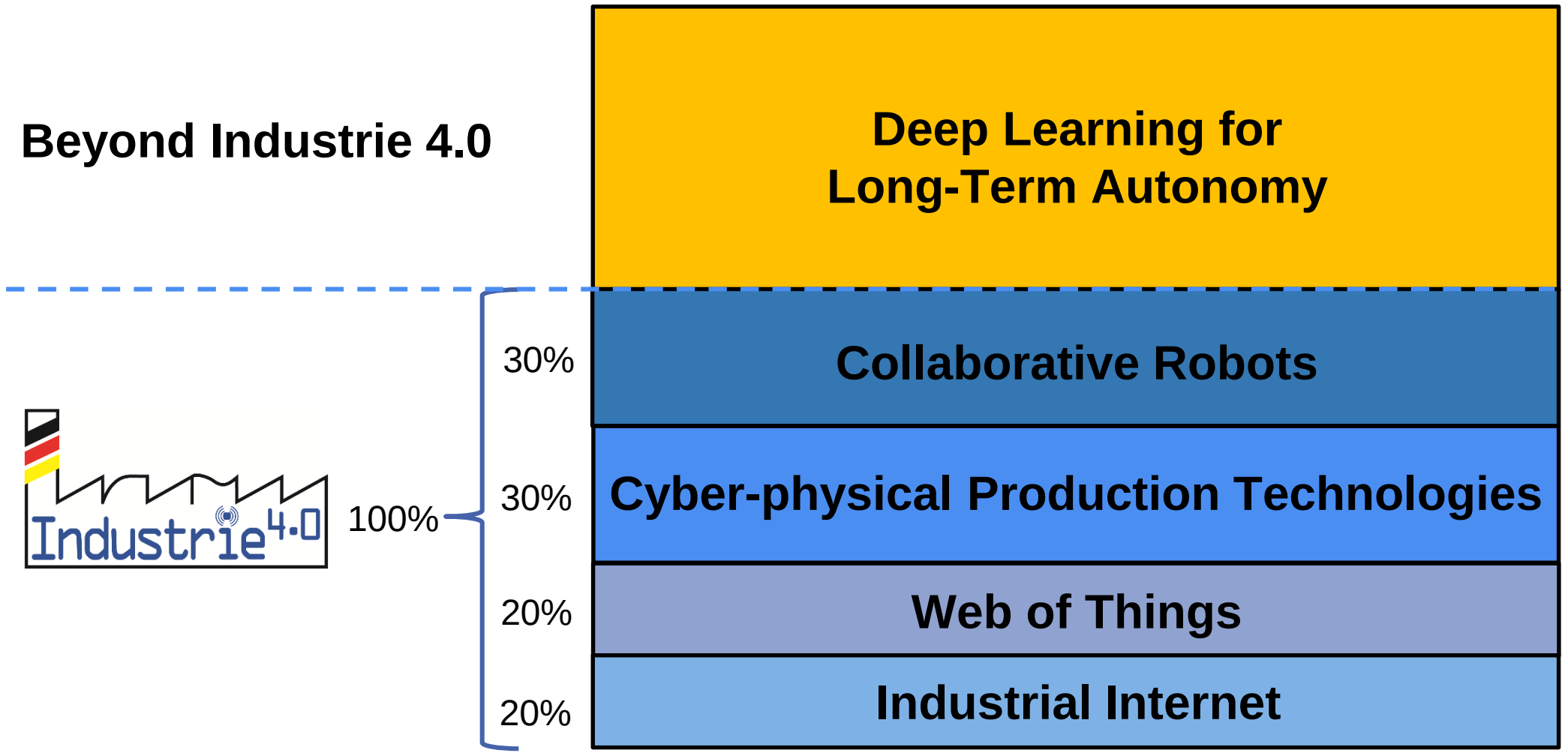
© W. Wahlster

Artificial Intelligence is better than natural stupidity.



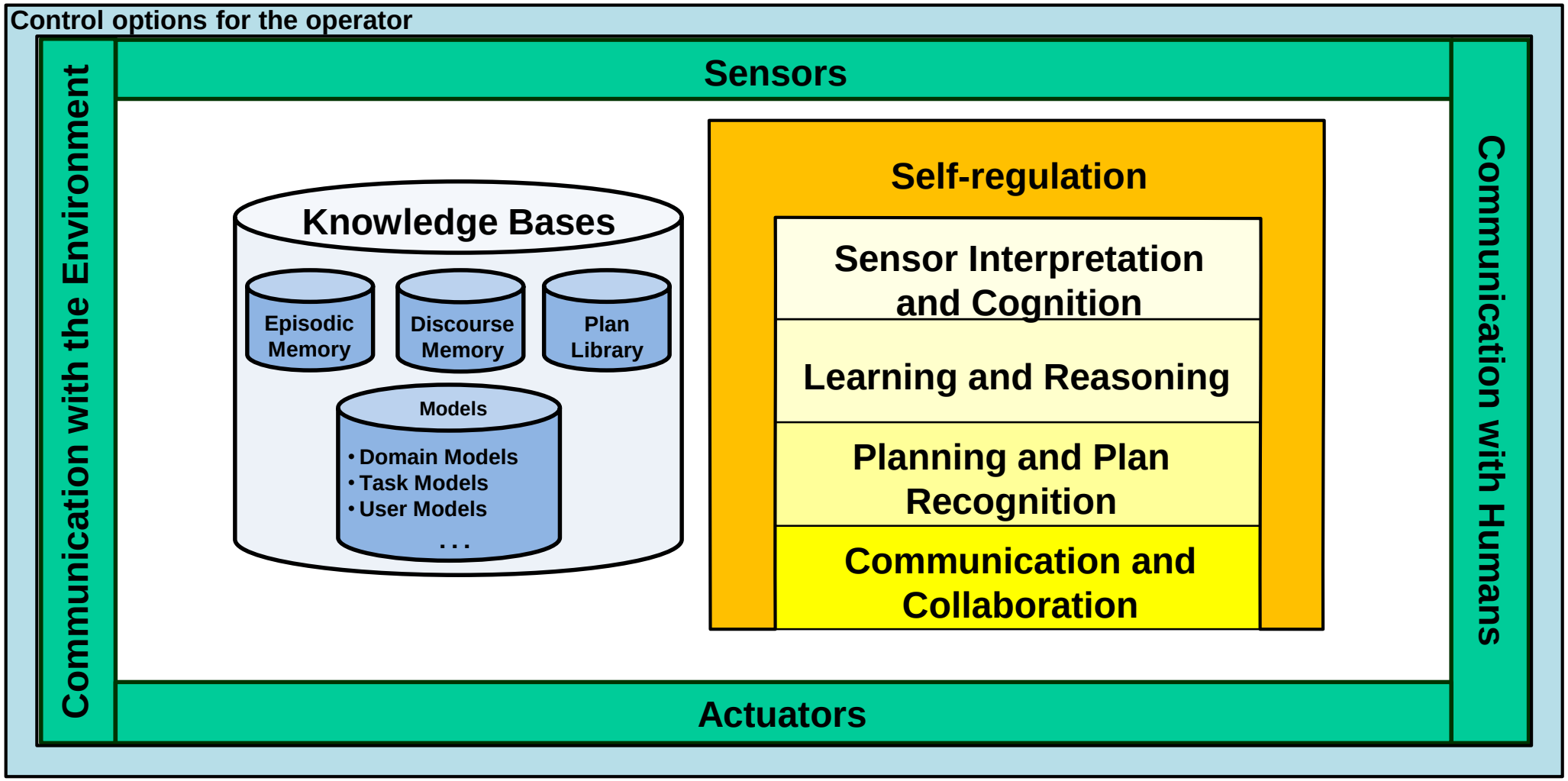
© W. Wahlster

Beyond Industrie 4.0: Long-term Autonomy



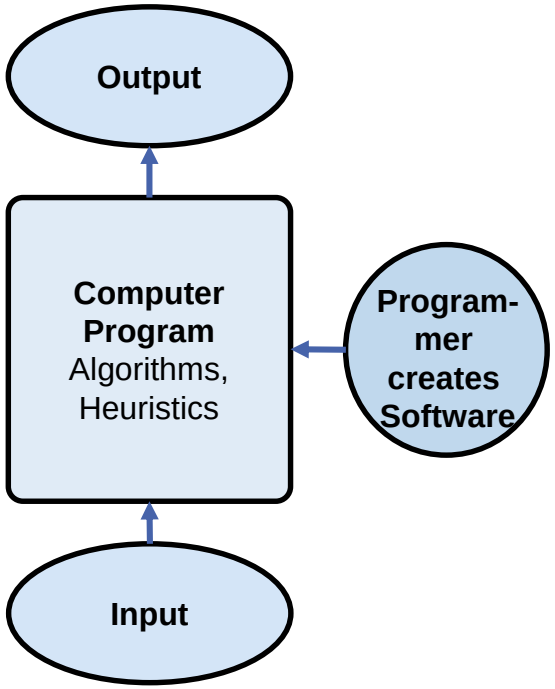
© W. Wahlster

Reference Architecture for Autonomous Systems



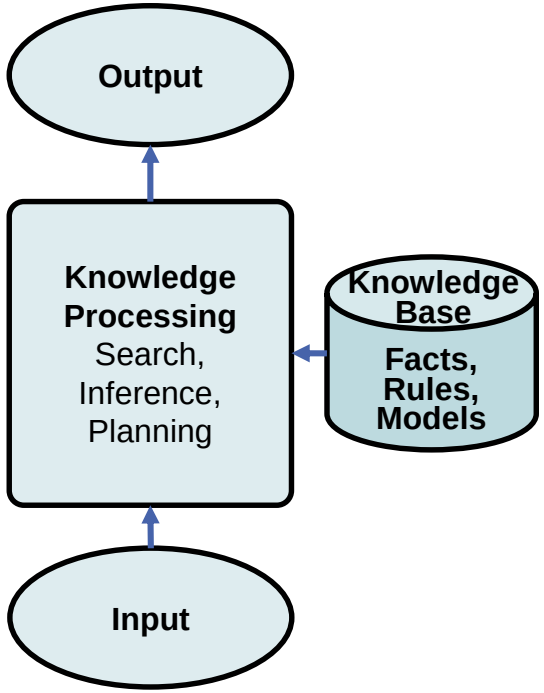
© W. Wahlster

Towards Self-Learning Systems



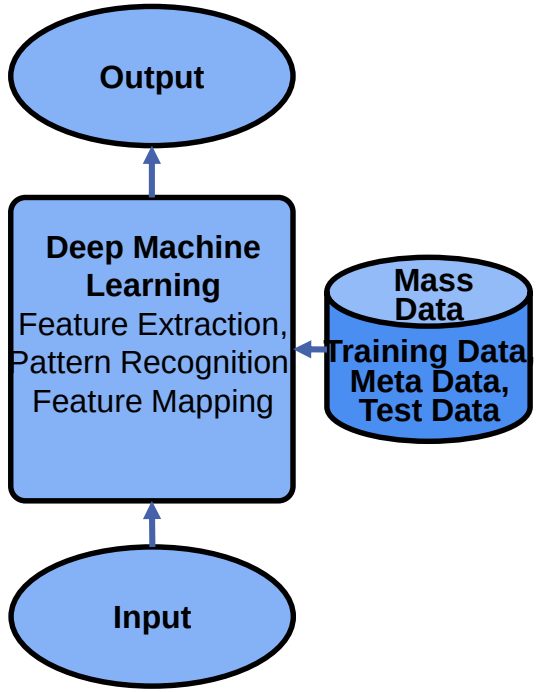
Bottleneck: Programmer

- high development costs
- restriced adaptability
- weak explanation capabilities



Bottleneck: Knowledge Base

- huge development effort
- high maintenance costs
- good explanation capabilities



Bottleneck: Training Data

- minimal development effort
- good adaptability
- no explanation capabilities

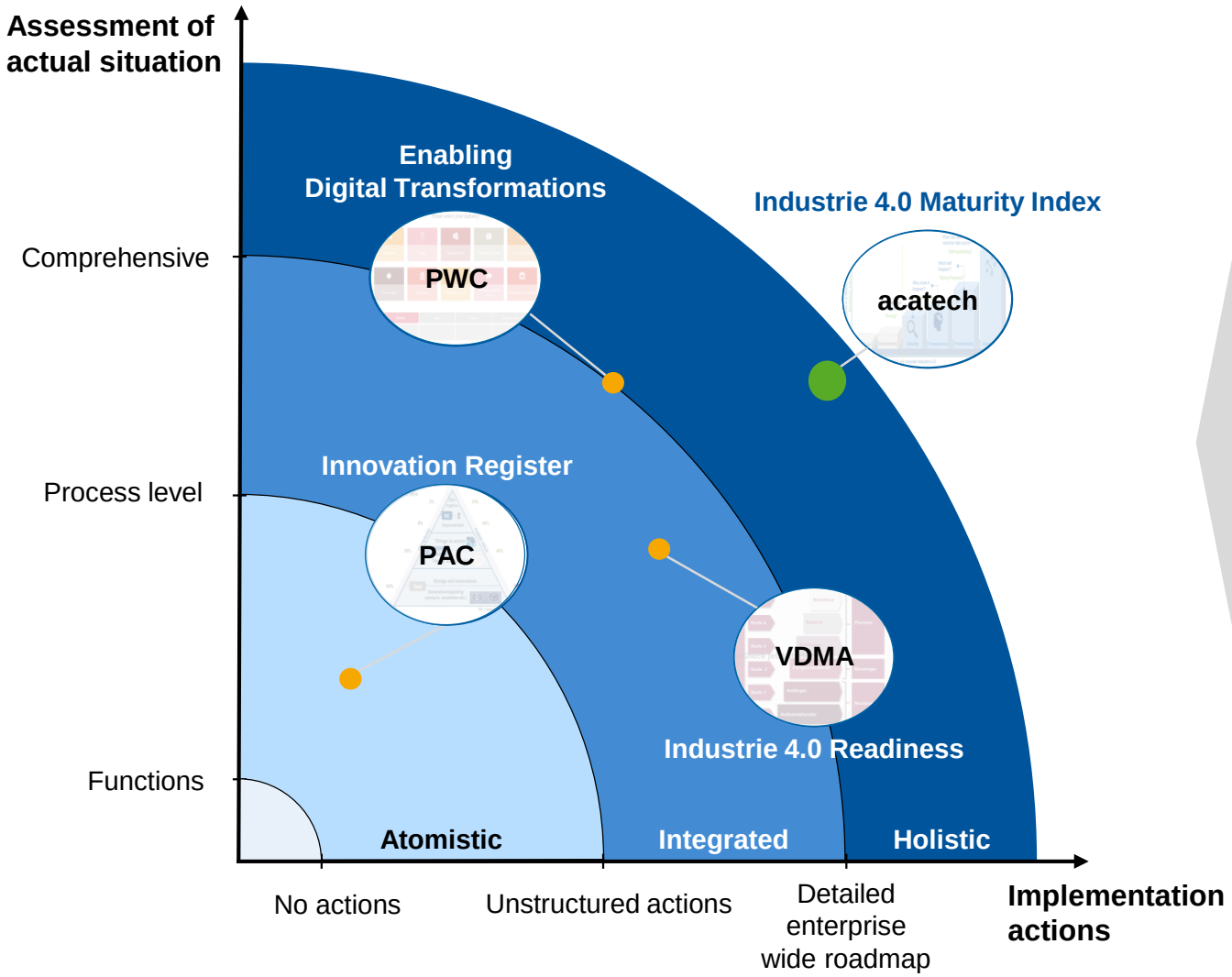
© W. Wahlster

Artificial Intelligence Compared with Human Intelligence

	Dimensions of Intelligence	 versus 
	Sensomotoric Intelligence	+ ++
	Cognitive Intelligence	++ +
	Emotional Intelligence	− ++
	Social Intelligence	− ++

© W. Wahlster

The Industrie 4.0 Maturity Index provides complete assessment of the actual situation and derives actions for implementation

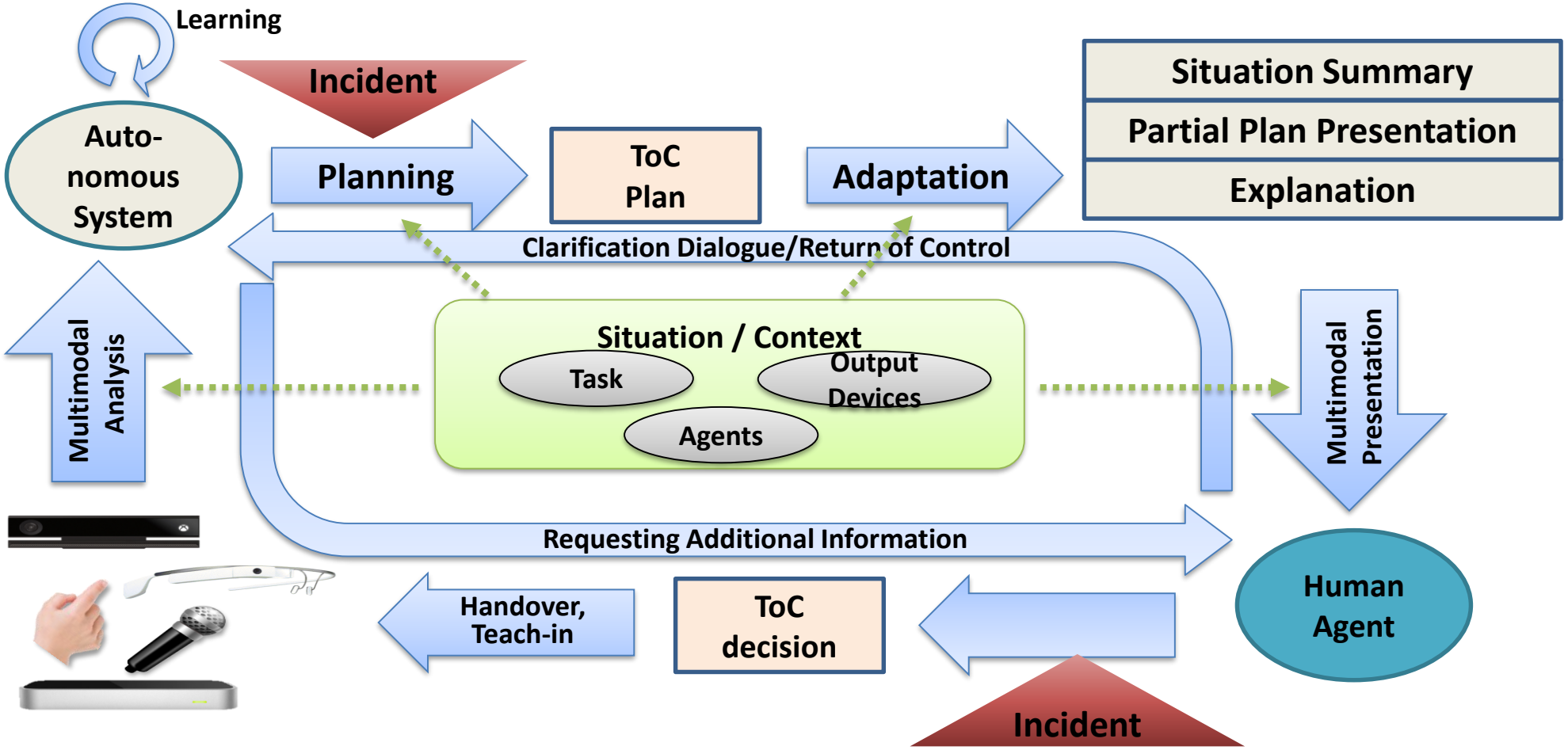


- Enterprises require a model that comprehend-sively assesses the actual situation
- Implementation actions have to follow the individual assessment
- Existing models do not provide a holistic, compre-hensive assessment.
- In most approaches, implementation roadmaps are missing

Industry 4.0 Maturity Assesment

Organization	Tool	URL
BMWi	Industrie 4.0 – Checkliste	http://www.bmwi-unternehmensportal.de/SharedDocs/Downloads/DE/PDF-Checklisten-Uebersichten/Checkliste-Industrie-4-0.pdf?__blob=publicationFile
HNU, minnosphere	Digitaler Reifegrad – Analysetool	http://reifegradanalyse.hs-neu-ulm.de/
DeutscheTelekomAG	Digitalisierungsindex	http://www.digitalisierungsindex.de
VDMA, IMPULS-Stiftung	Industrie 4.0-Readiness-Modell	http://www.industrie40-readiness.de
Connected Production	Industrie 4.0-Reifegrad-Test	http://www.connected-production.de/industrie-4-0-reifegrad-test
IHK München und Oberbayern	Leitfaden Industrie 4.0	https://ihk-industrie40.de/
VDMA	Werkzeugkasten Industrie 4.0	http://www.vdma.org/article/-/articleview/8617794 ?inheritRedirect=true
H&D International Group	Industrie 4.0-Readiness	http://www.hud.de/industrie-4-0
OÖ Wirtschaftsagentur GmbH, FH OÖ	Reifegradmodell Industrie 4.0	http://www.mechatronik-cluster.at/fileadmin/user_upload/Cluster/MC/MC-Downloads/Reifegrad.pdf
BostonConsultingGroup	DigitalAccelerationIndex	https://www.bcg.com/expertise/capabilities/technology-digital/digital-acceleration-index.aspx
acatech	Industrie 4.0 Maturity Index	http://www.acatech.de/de/projekte/projekte/industrie-40-maturity-index.html
WZLderRWTHAachen	„4i“-Reifegradmodell	http://www.ingenieur.de/VDI-Z/2016/Ausgabe-06/Forschung-und-Praxis/Industrie-4.0-Audit
Kompetenzzentrum Mittelstand NRW	Quickcheck Industrie 4.0 Reifegrad	https://indivsurvey.de/umfrage/53106/uHW7XM

Transfer of Control: From Autonomous System to Humans & from Humans to Autonomous System



Autonomous systems need **to plan when to transfer control** to other agents and give them a **summary of the current situation** and an explanation.

Human agents need to decide when to transfer control back to the system and give further instructions on how to proceed or what to do.

© W. Wahlster

Industrie 4.0 Maturity Assessment of Production

Production					
Data processing in the smart factory	*No processing of data*	*Factory memory*	*Data mining for process monitoring*	*Streaming data analysis*	*Automatic process planning / control*
M2M Communi-cation	*No communication*	*Field bus interfaces*	*Industrial ethernet interfaces*	*Machines have access to internet*	*Web services (M2M software)*
Company-wide production network	*No networking of production with other business units*	*Information exchange via mail / tele-communication*	*Uniform data formats and rules for data exchange*	*Linked data across divisions*	*Ubiquitous production network*

Adapted from: VDMA Guideline Industrie 4.0

© W. Wahlster

Industrie 4.0 Maturity Assessment of Production

Production					
ICT infrastructure in production	information exchange via mail / telecommunication	Central data servers in production	Internet-based portals with data sharing	Factory cloud service	Suppliers / customers are fully integrated into the process design
Man-machine interfaces	No information exchange between user and machine	Use of local user interfaces	Centralized / decentralized production monitoring / control	Use of mobile & multimodal user interfaces	Augmented / mixed and dual reality
Efficiency with small batches	Rigid automation system for mass production	Use of flexible production systems and identical parts	Plug & produce production architecture	Service matchmaking architecture	Service oriented architecture for distributed mass customization

Adapted from: VDMA Guideline Industrie 4.0

© W. Wahlster

The BaSys 4.0 Approach for Digitalization

- Joint german reference research project
  - Started in 2016
- Main building blocks:
  - Asset administration shell (Digital Twin)
  - Structured (semantic) domain models
  - Service-oriented production concept

- Overall aim
  - Building a **software infrastructure for Industrie 4.0** which also **supports production-relevant change processes**
  - Provide an **open source reference implementation**

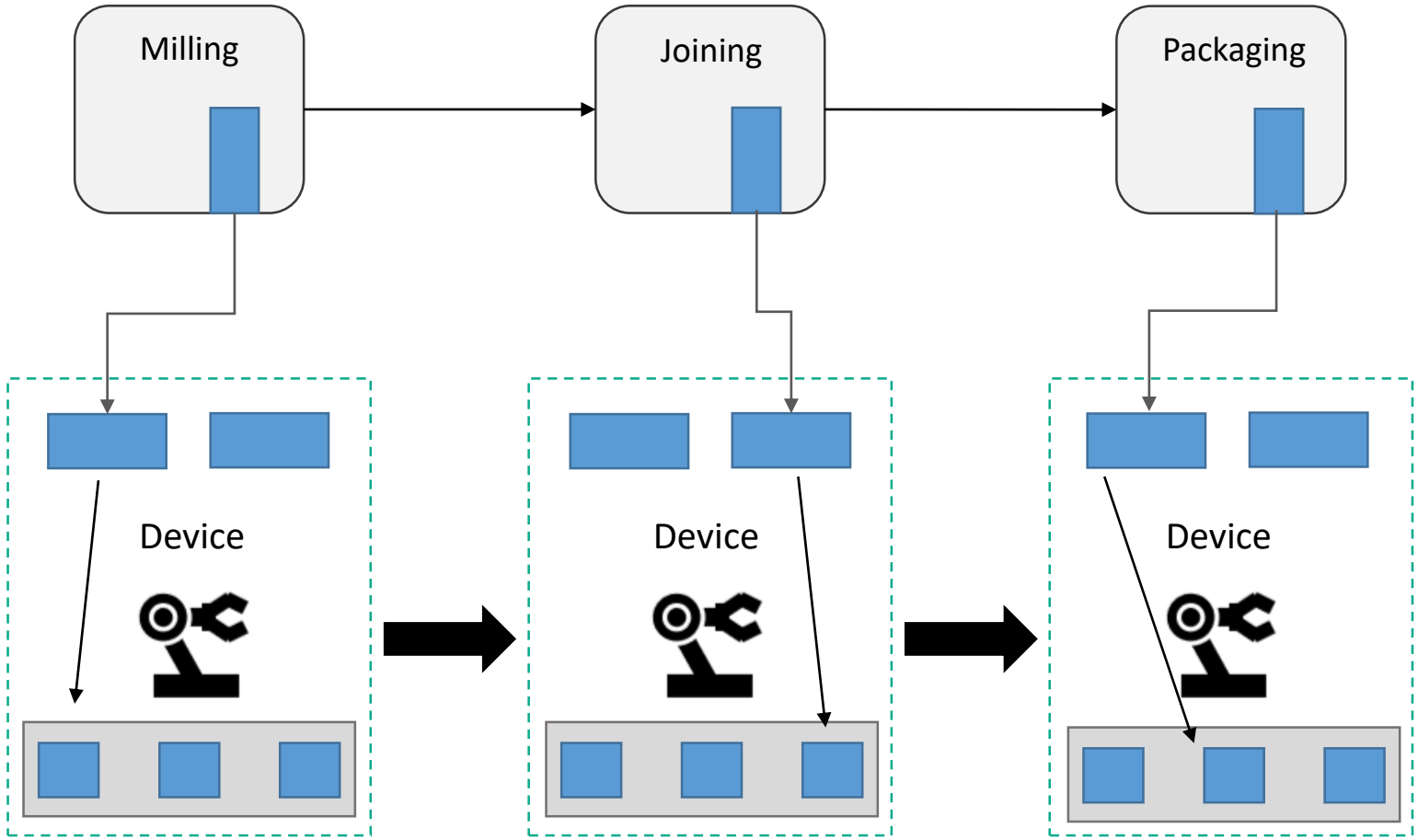
www.basys40.de

BaSys 4.0 – Service-oriented Production Approach

Orchestrated production process specifies required ressource capabilities

Asset administration shell of device provides uniform service interface for access to capabilities

Powerline Communication (PLC) functions realize the pure skills not the production logic



www.basys40.de

Technical Architecture – Big Picture

Order Management

Agent Management

Topology Management

Resource Management

Process Management

Service Registry

I4.0 Communication Middleware

AAS Management

Device Service „Pressing“

Integration

Proprietary

Device Service „Screwing“

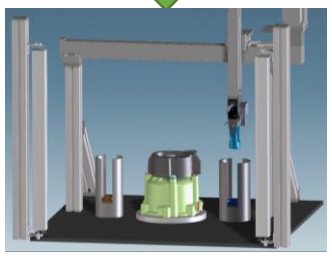
Integration

Proprietary

Device Service „Pressing“

Integration

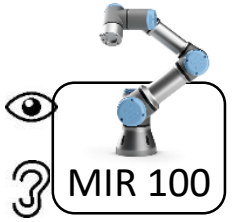
OPC-UA



Device Service „Pressing“

Integration

Proprietary



Worker Guidance

All services participate in the same distributed service platform

→ Communication API

→ Uniform service structure

www.basys40.de