TECHNISCHE UNIVERSITÄT
KAISERSLAUTERN

LRS

Collective cooperation of human-robot teams in the light of industry 4.0
工业4.0背景下的人与机器人的群体合作

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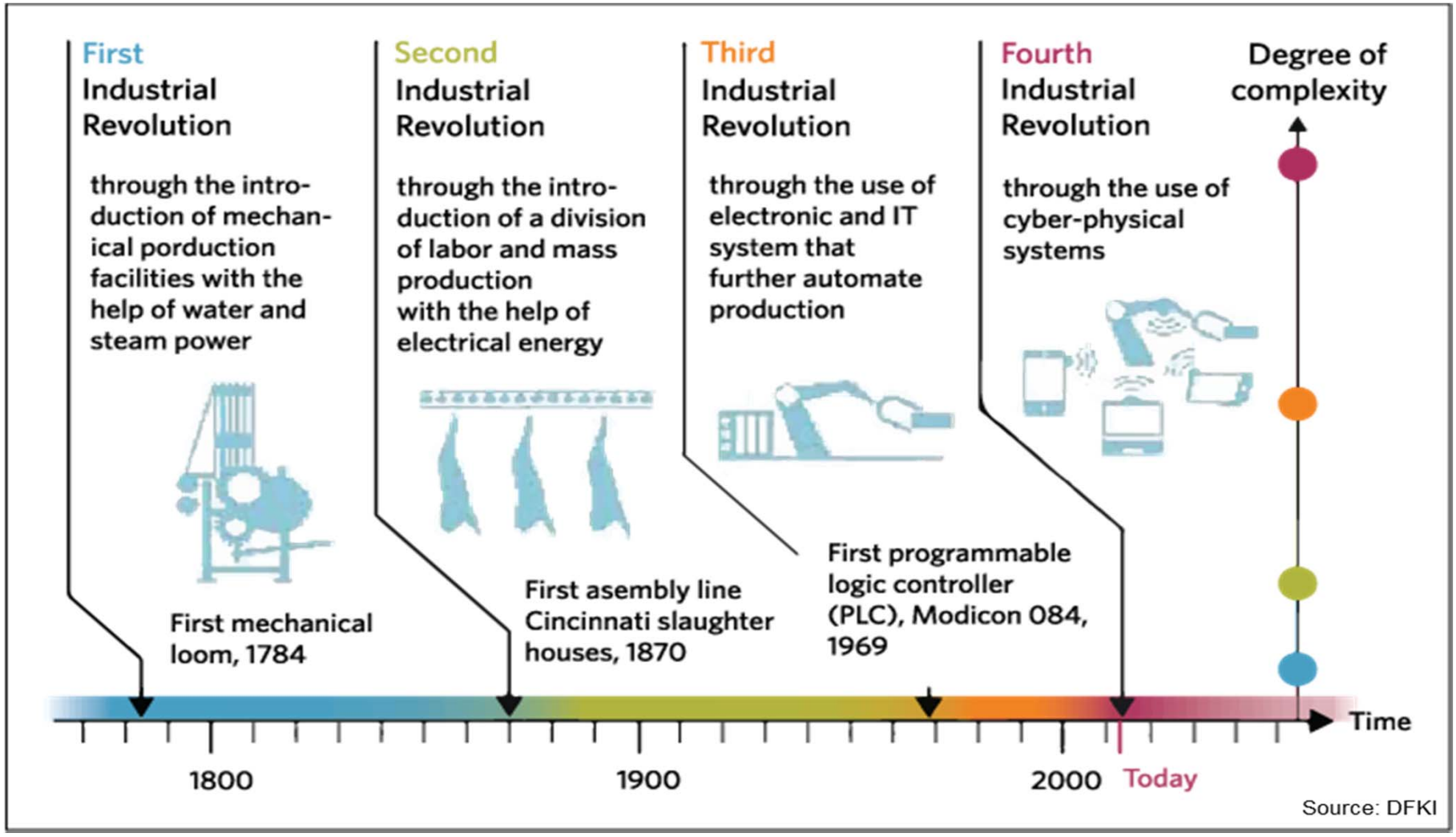
What is Industry 4.0?



Industry 4.0 and smart production

Smart Factory 2035 in the view of German industry

Factory 2035

autonomous production

Examples
- Pattern recognition in production and quality data
- Networked and cooperative mobile robots

personalized product

Example
- Smart in-line quality module for additive production

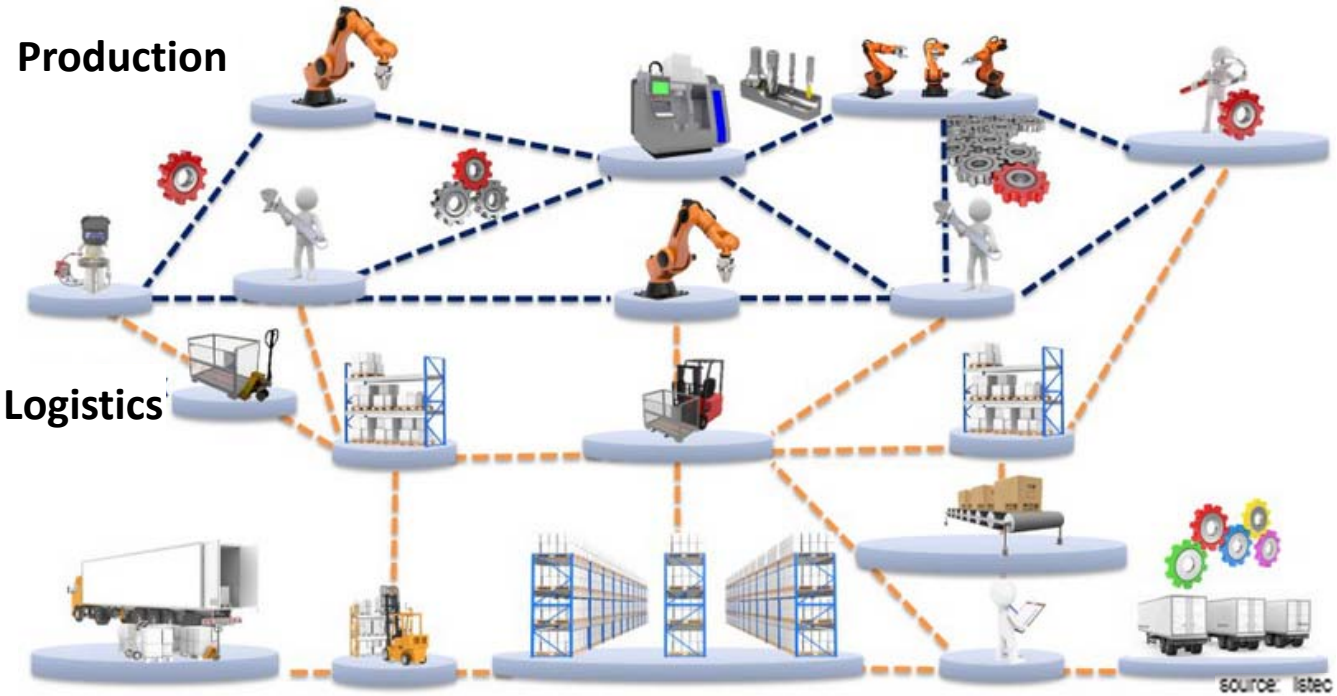
&

human as conductor

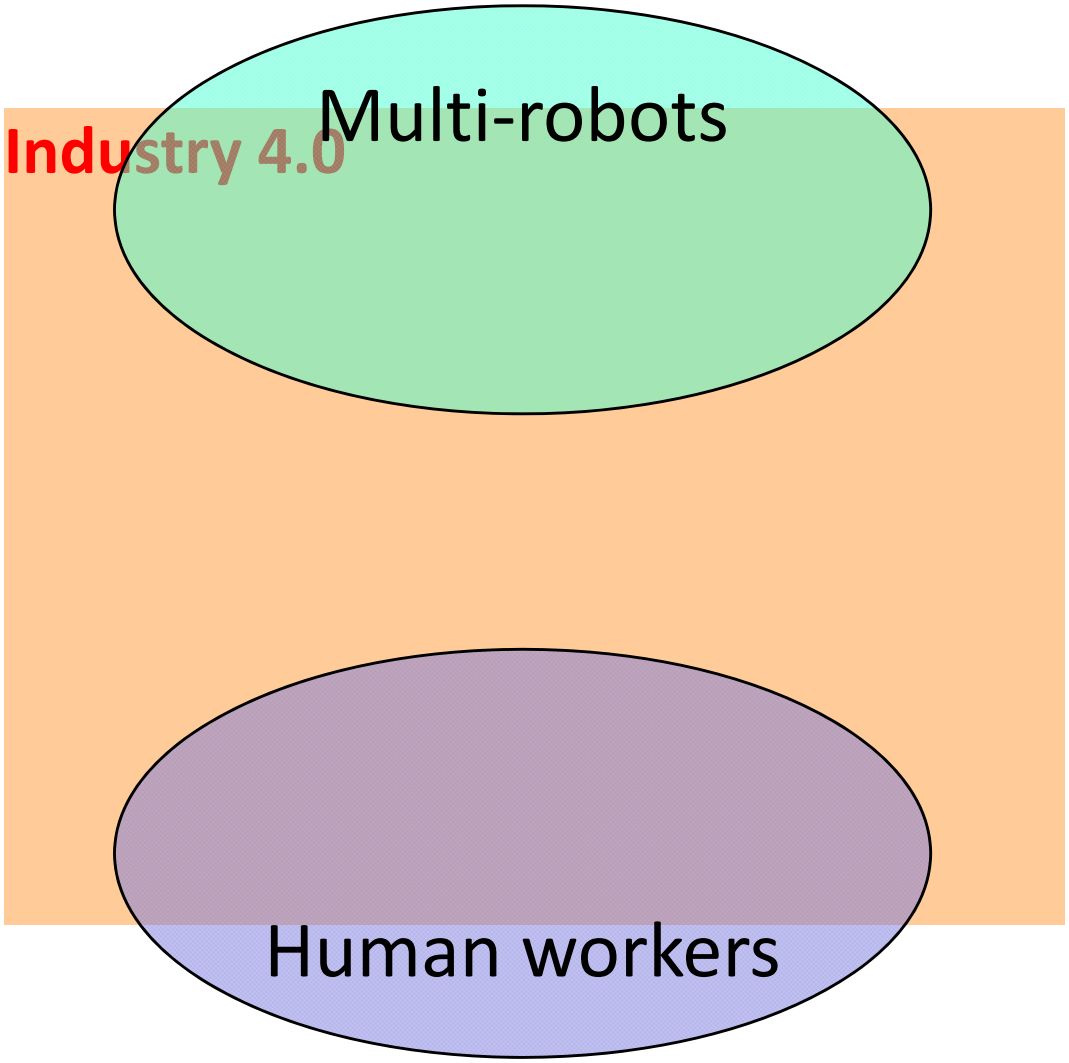
Example
- Augmented reality based system maintainance

Digitalization for added values

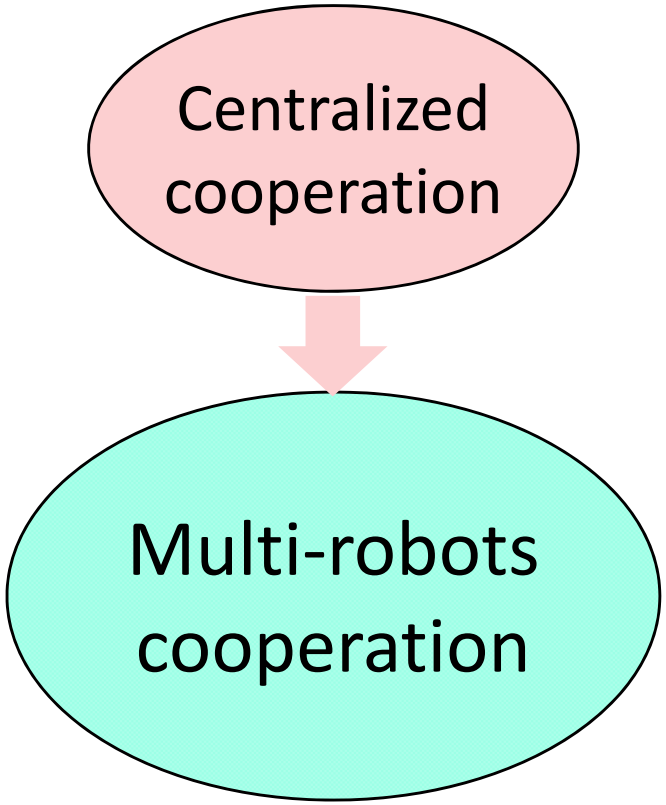
Examples
- Data-based process evaluation and configuration
- realtime data processing of all production units



Role of robot and human in industry 4.0



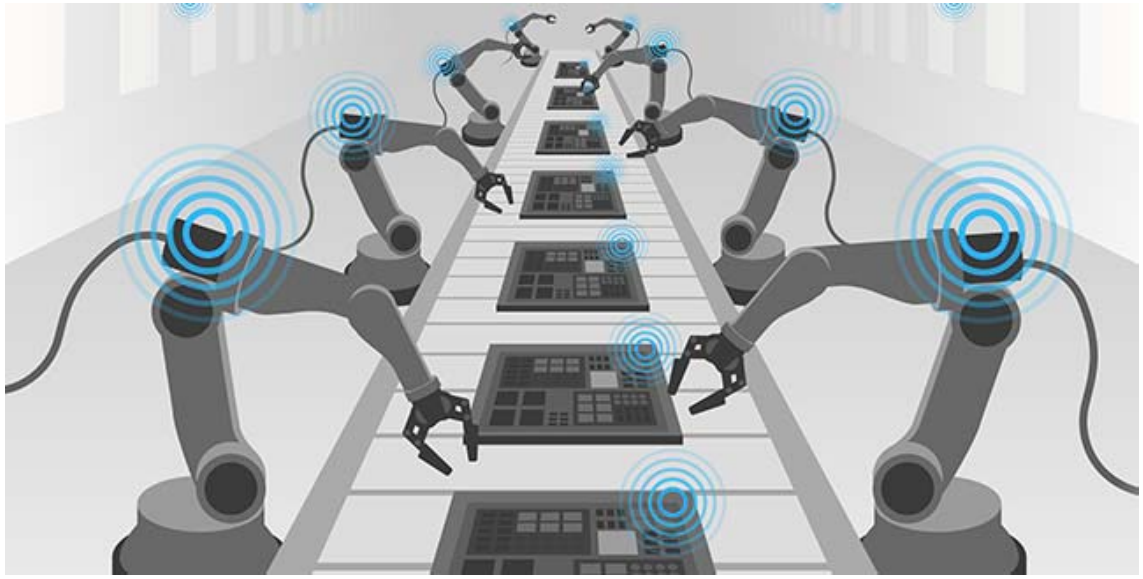
Today‘s state of art in multi-robot systems



Today‘s state of art in robot cooperation

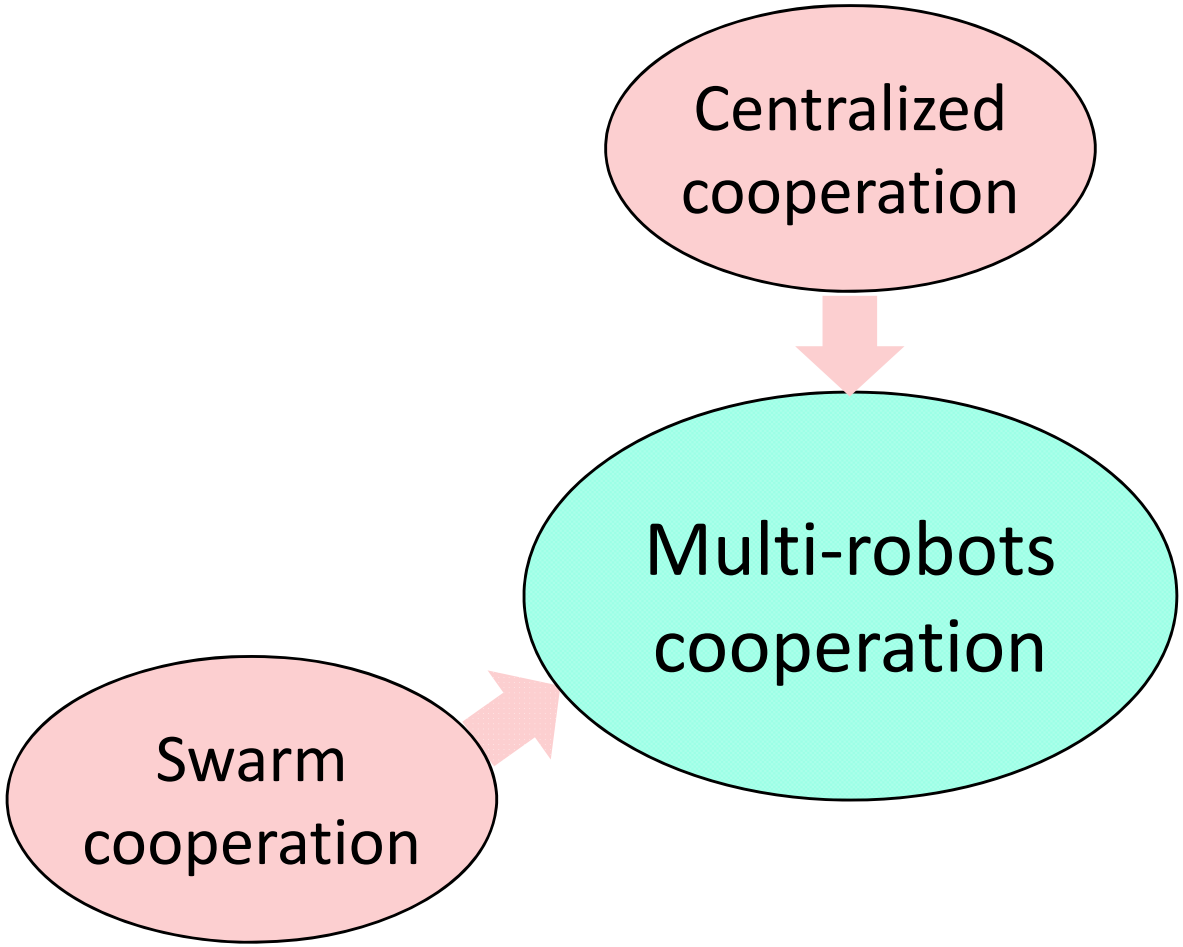
Centralized multi-robot cooperation

- Sequential/parallel cooperation
- Centralized communication and control
- Mostly stationary



Source: Iitians Technology

Today‘s state of art in multi-robot systems

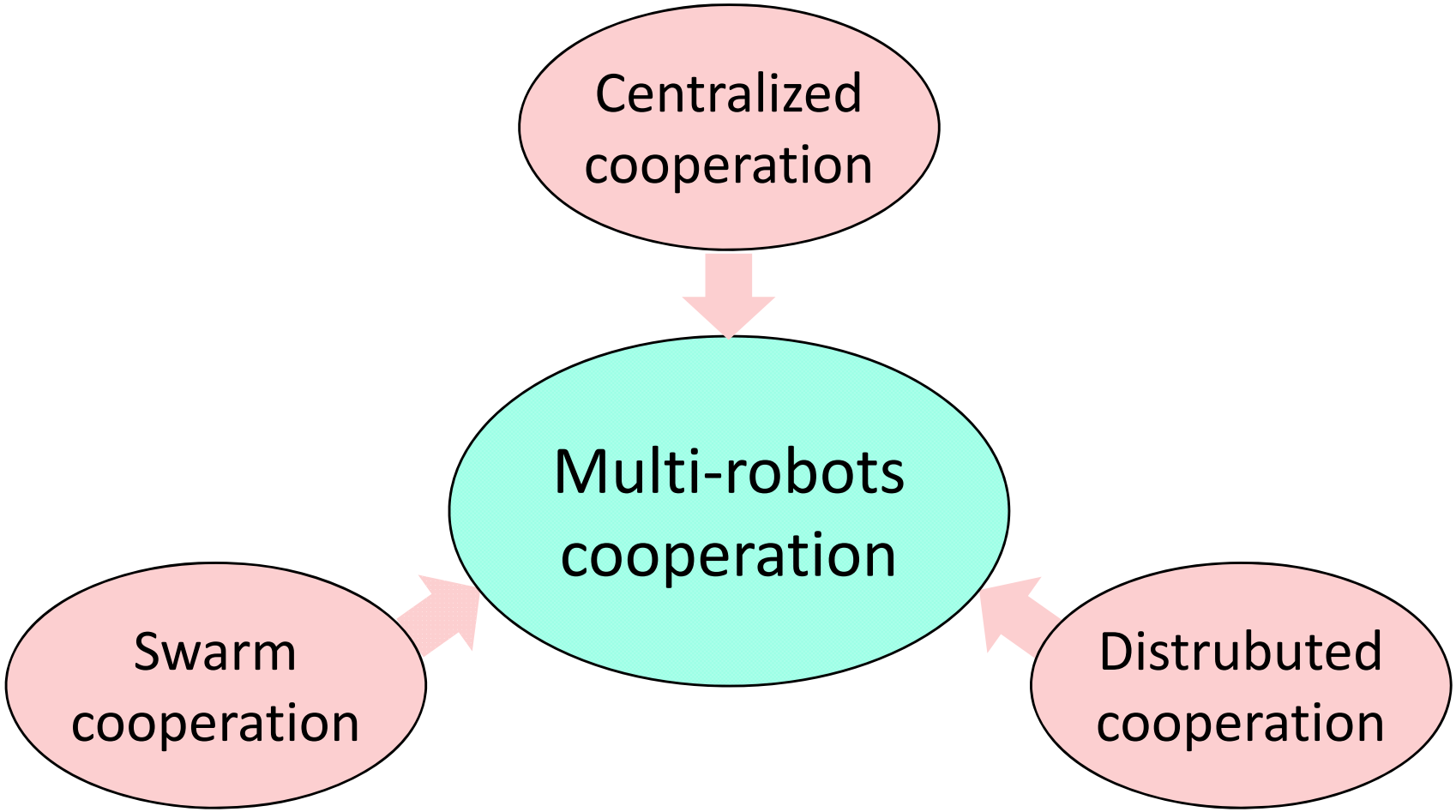


Today‘s state of art in multi-robot research

Swarm robotics

- Large number, simple robots
- Emulation of collective (swarm) behavior
- Artificial swarm intelligence, formation, consensus
- Local communication, local decision

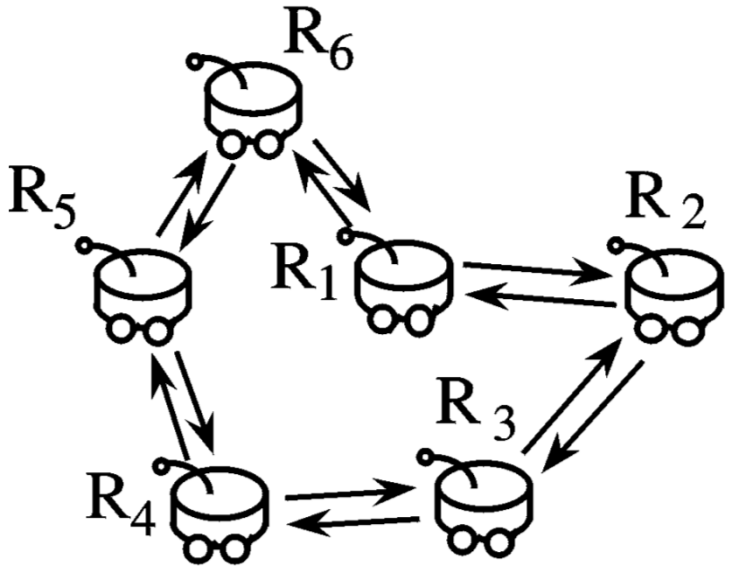
Today‘s state of art in multi-robot systems



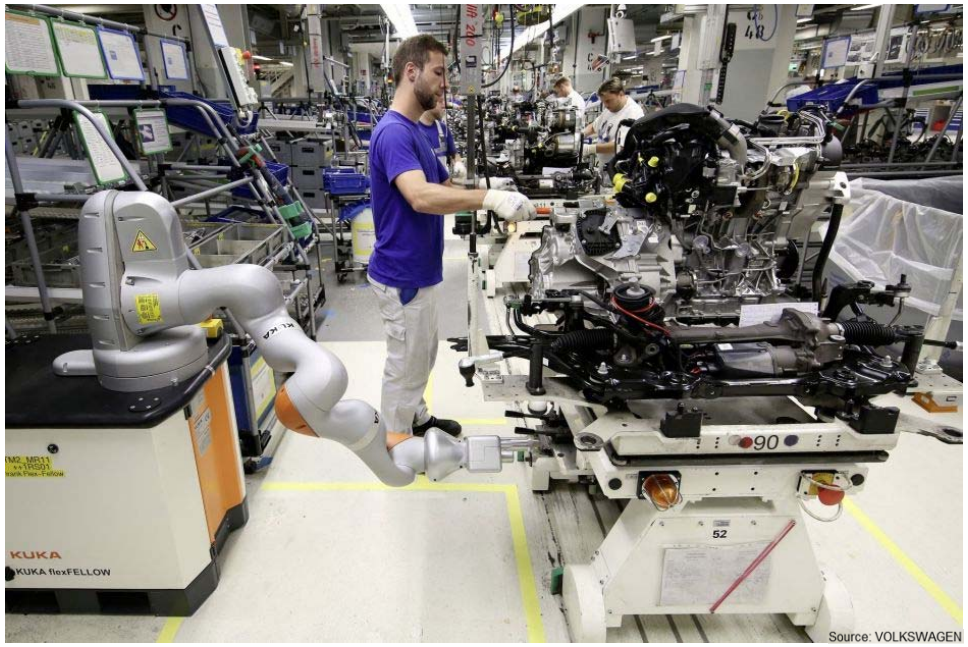
Today‘s state of art in multi-robot systems

Distributed Robotics

- Individual tasks, flexible configuration
- Distributed communication and control
- Special cooperation strategies



Today‘s state of the art in human-robot interaction



Isolated operation areas

- Wired bus-based communication
- No direct human-robot interaction
- Robot operation programmed by human

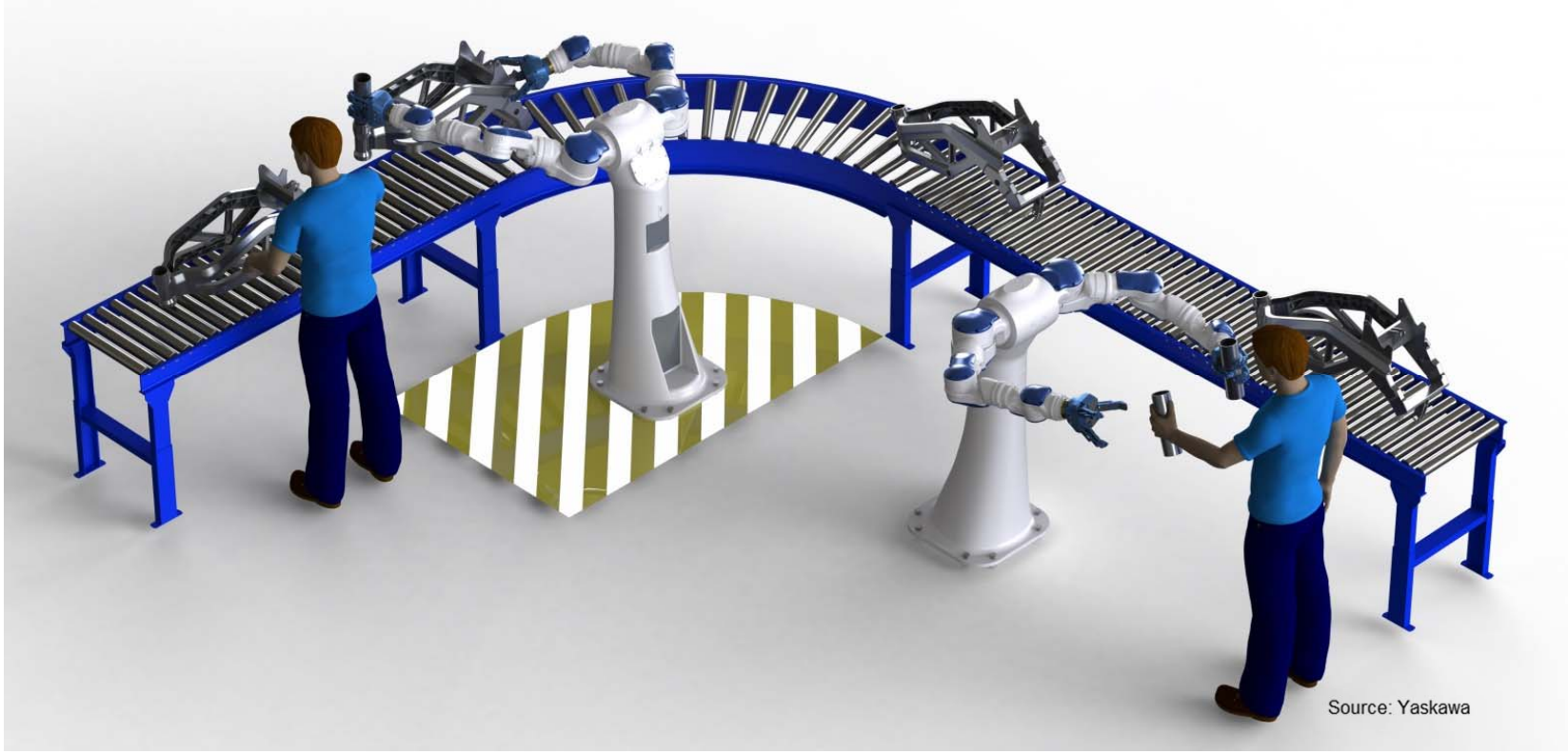
Fenceless operation units

- Human robot communication/interface
- Basic laws for safe interaction
- More proactive role of robot

New requirements from Industry 4.0

Human-Robot team in production process

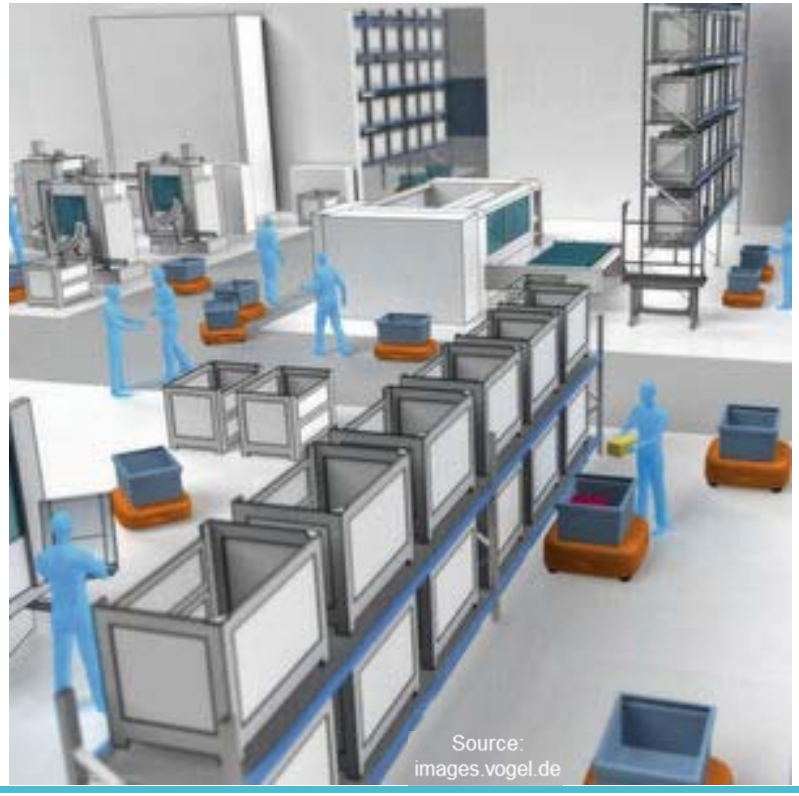
- Mixed human-robot teams
- Flexible cooperation for manipulation based on variable communication
- Changing formation



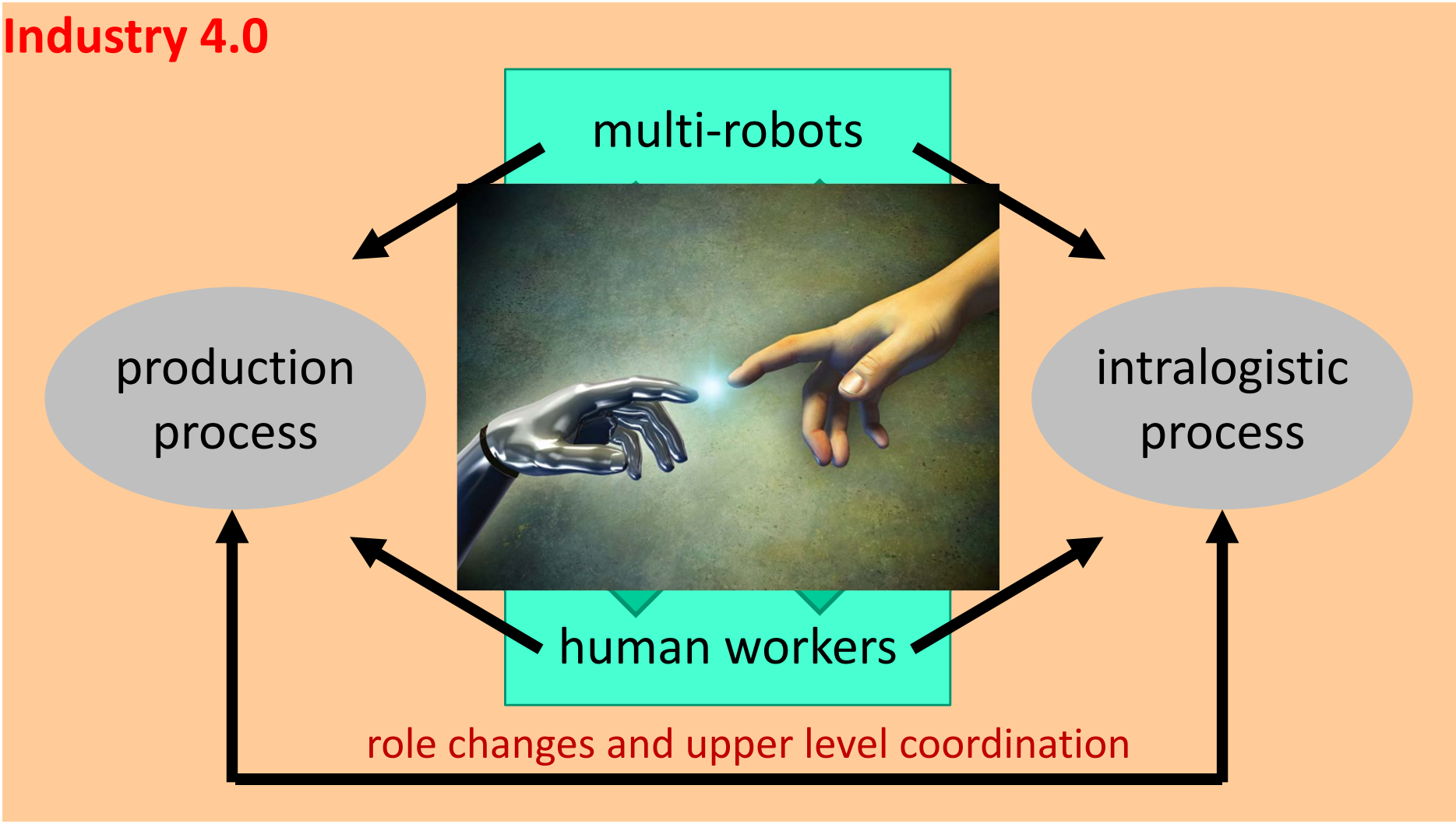
New requirements from Industry 4.0

Human-Robot team in intralogistic process

- Large number of autonomous mobile robots
- (Mainly) for transportation, but maybe equipped manipulator
- Special coordination integrated in optimized process

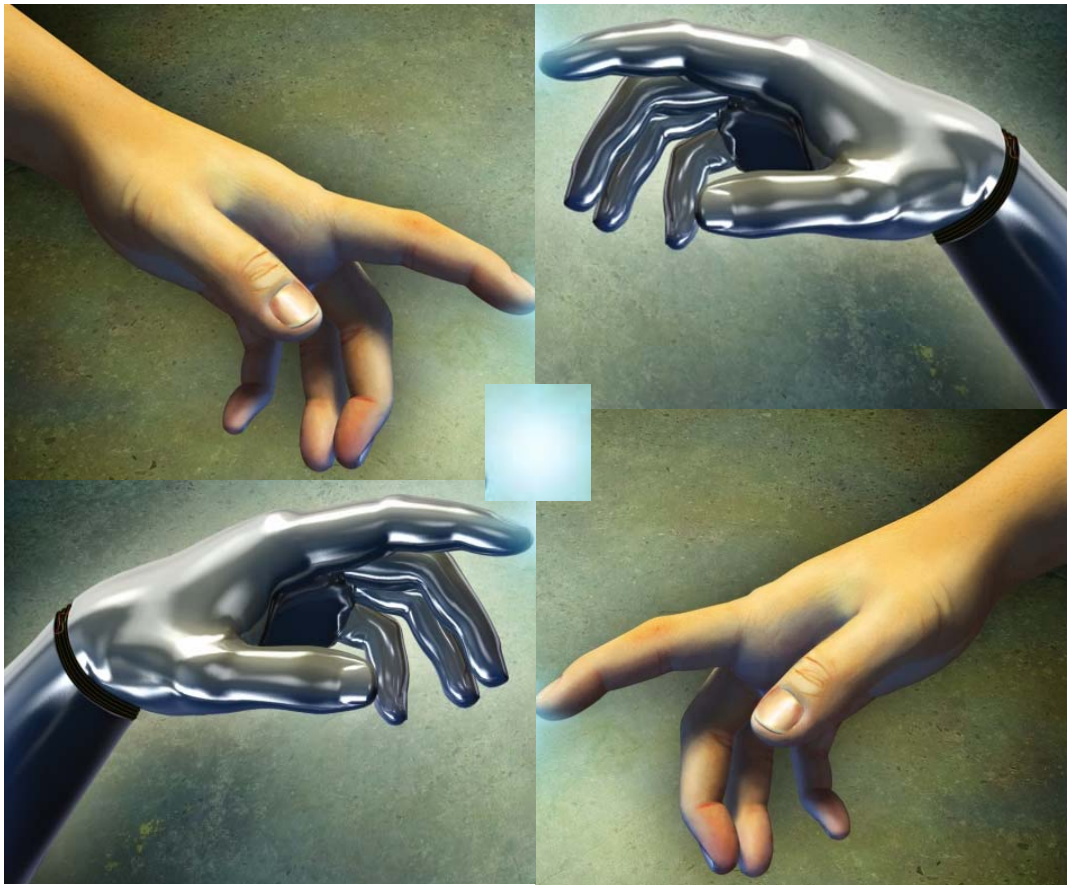


Position of human-robot teams in future factory

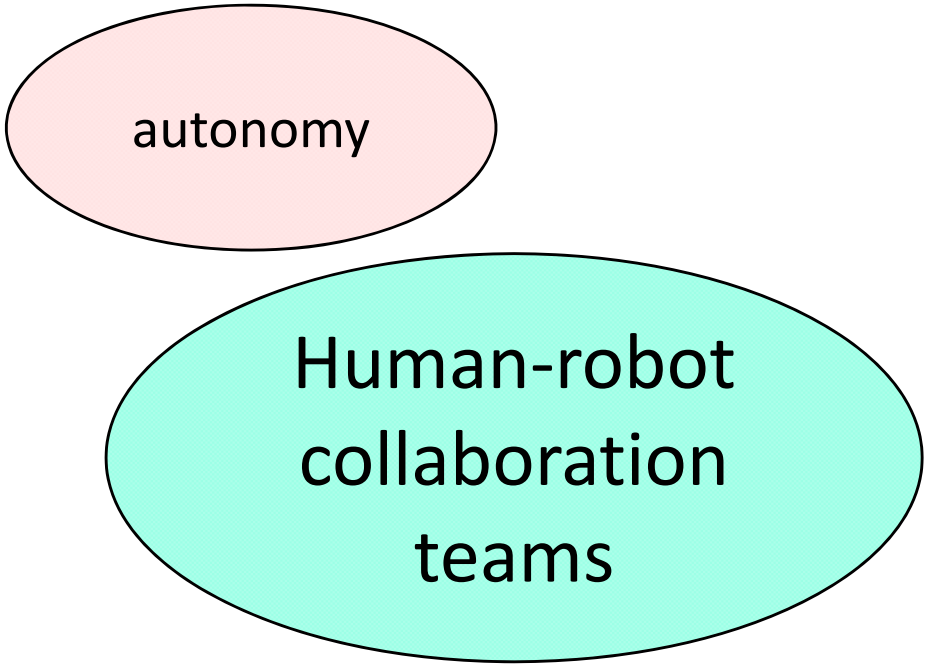


New requirements from Industry 4.0

From human-robot interaction to human-robot teams!



Challenges and chances

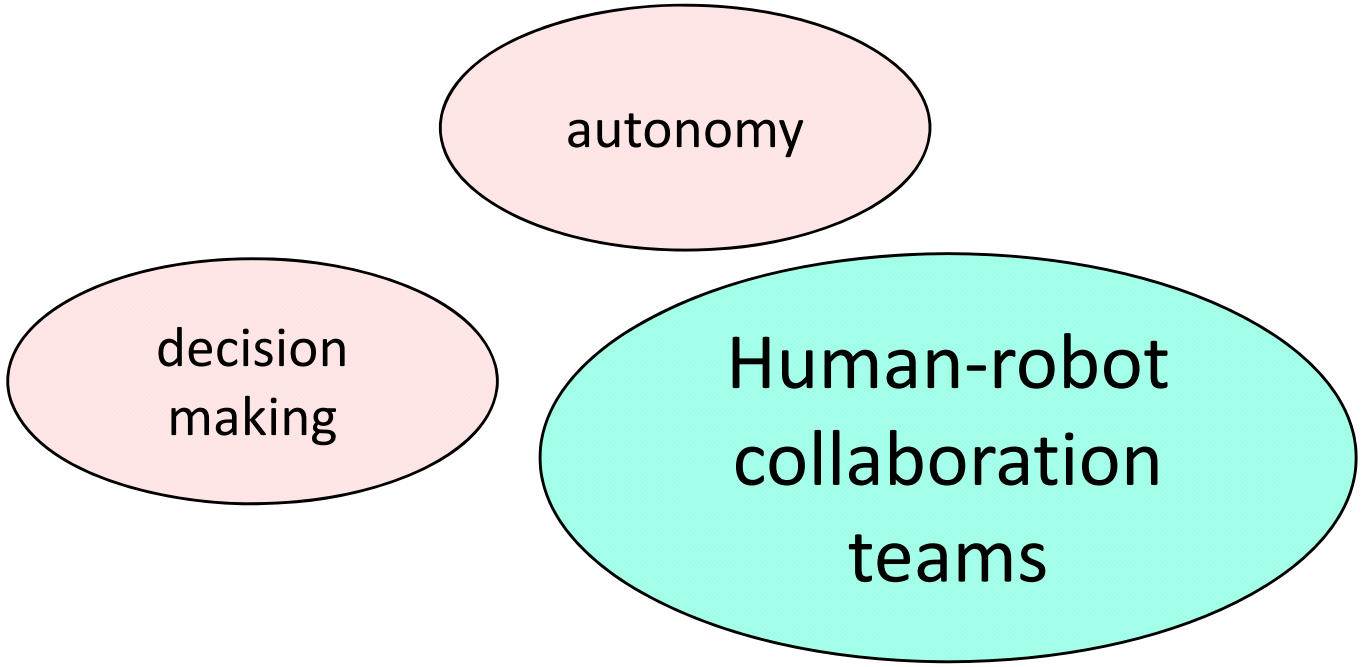


Challenges and chances

Autonomy

Every team member has the ability to autonomously move, localize, navigate, and execute manipulation tasks including safety guarantee (e.g. collision freeness)

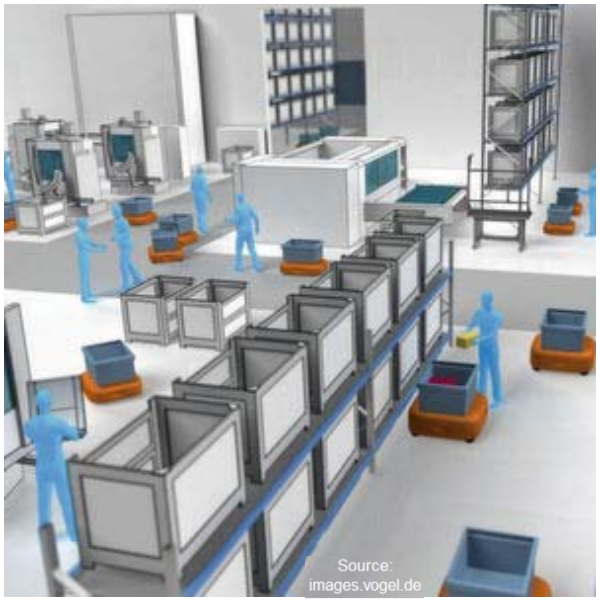
Challenges and chances



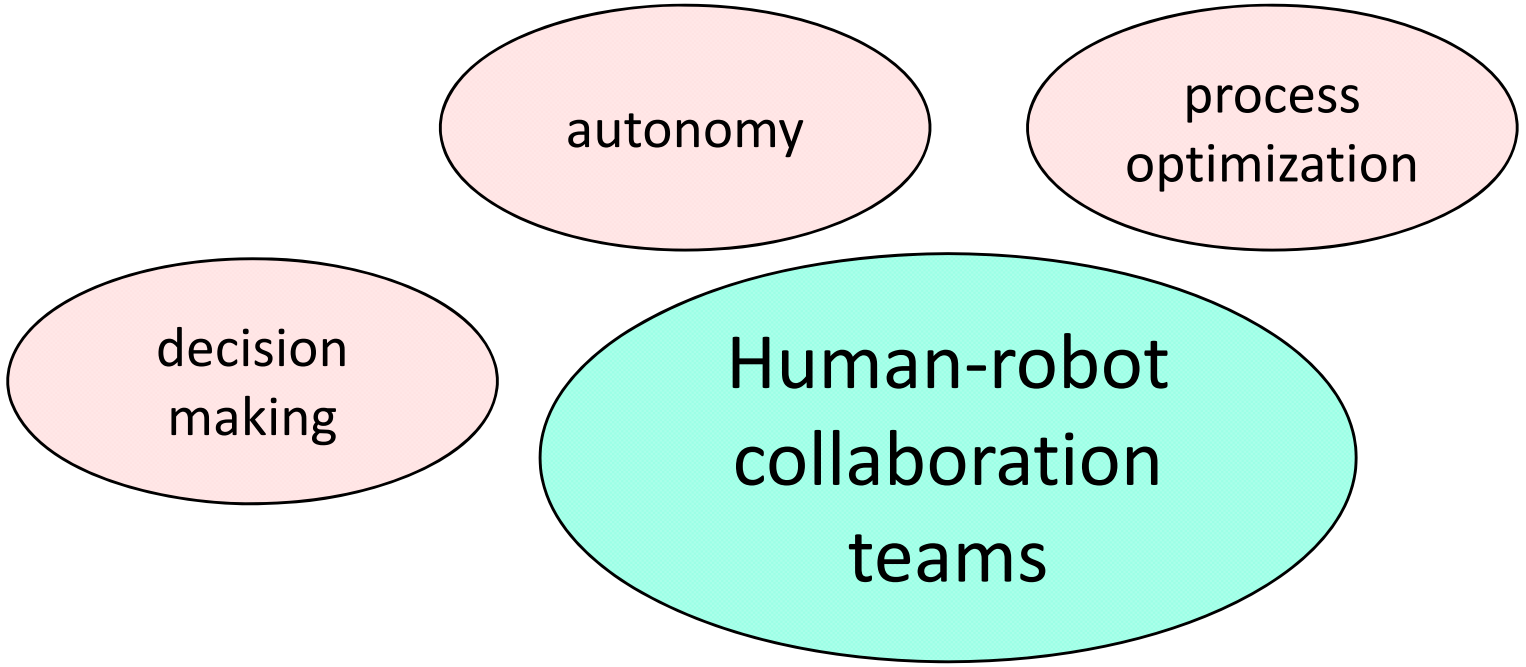
Challenges and chances

Distributed situation-dependent decision making

Local decision making roles in a human robot team are flexibly defined depending on the cooperation tasks (allocation, execution) and precision, confidence and trust. Very flexible configuration (e.g. plug-and-play)



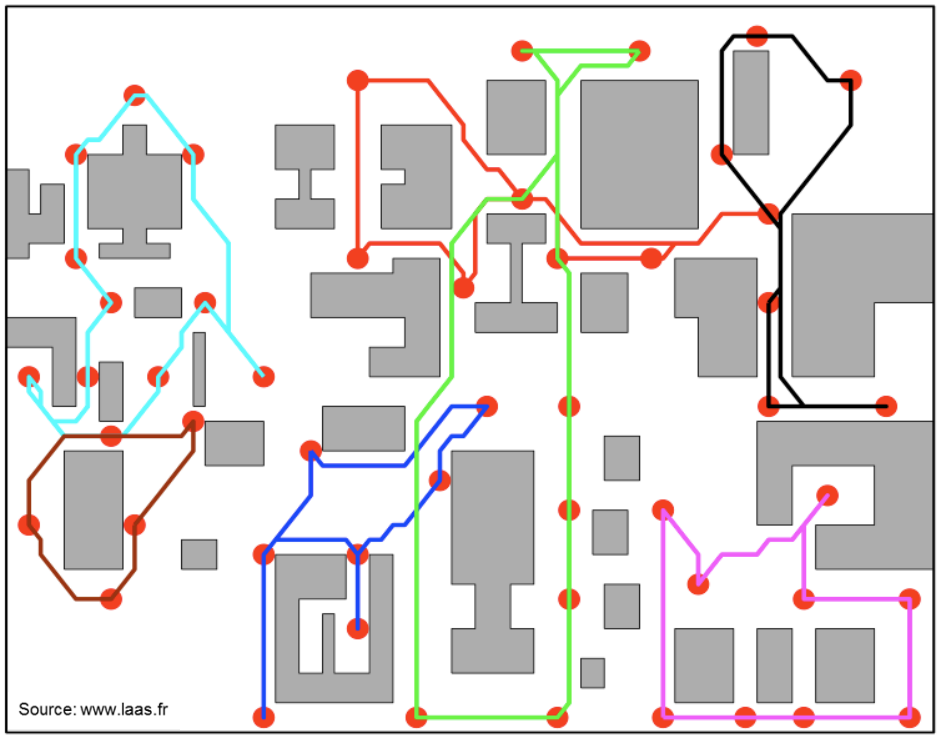
Challenges and chances



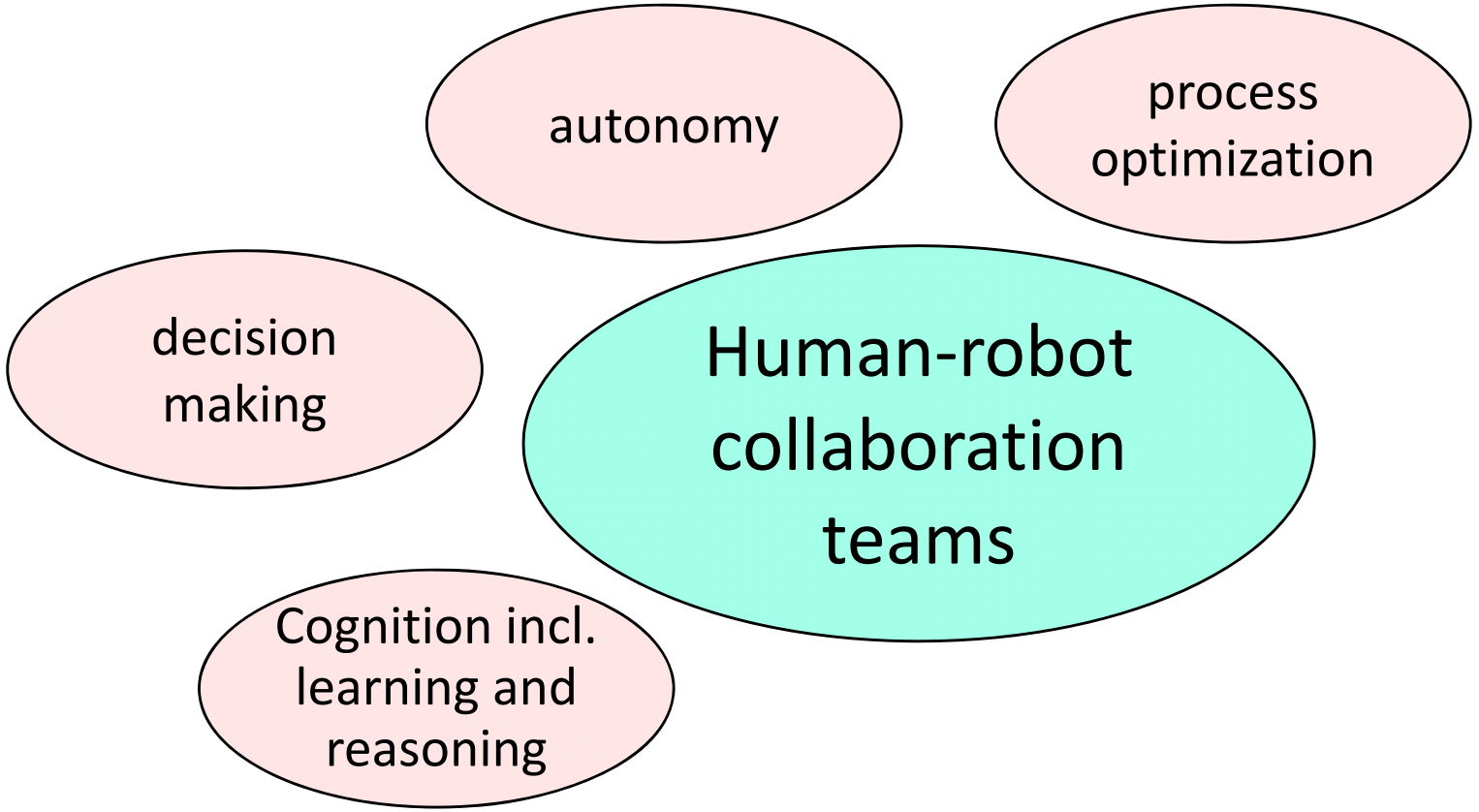
Challenges and chances

Integrated real-time motion planning and overall process optimization

Motion planning is not a task for a single robot anymore, but an integral part of the overall process optimization for efficiency achievement, in real time



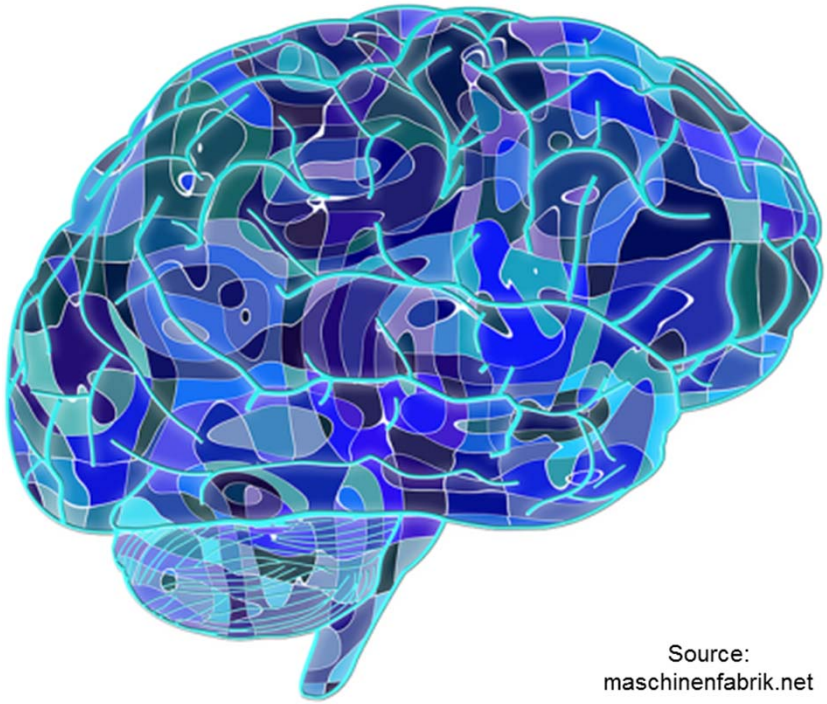
Challenges and chances



Challenges and chances

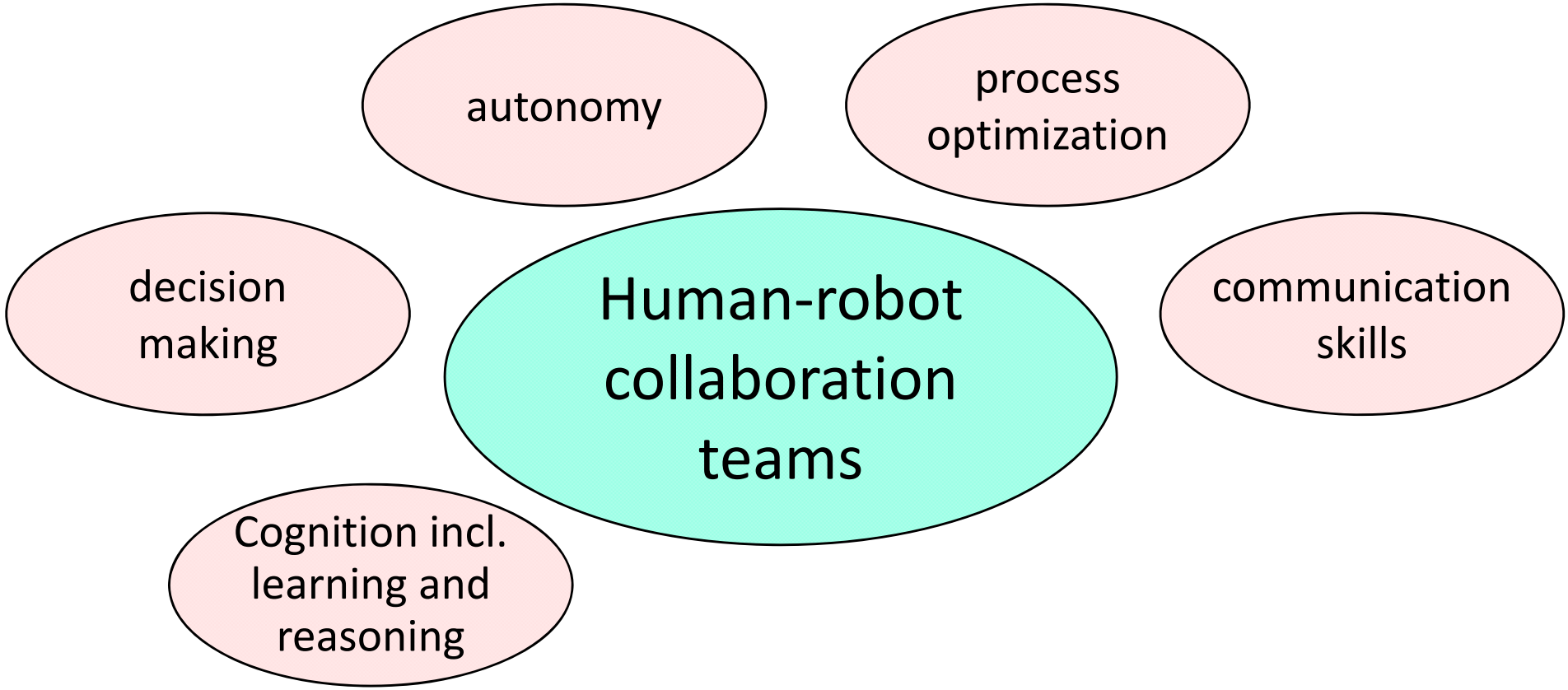
Cognitive capability (incl. learning and reasoning)

Cognition is based on sensors and perception, but integrated with AI techniques to learn and to reason, leading to a more holistic modeling of environment and (individual) human behavior.



Source:
maschinenfabrik.net

Challenges and chances

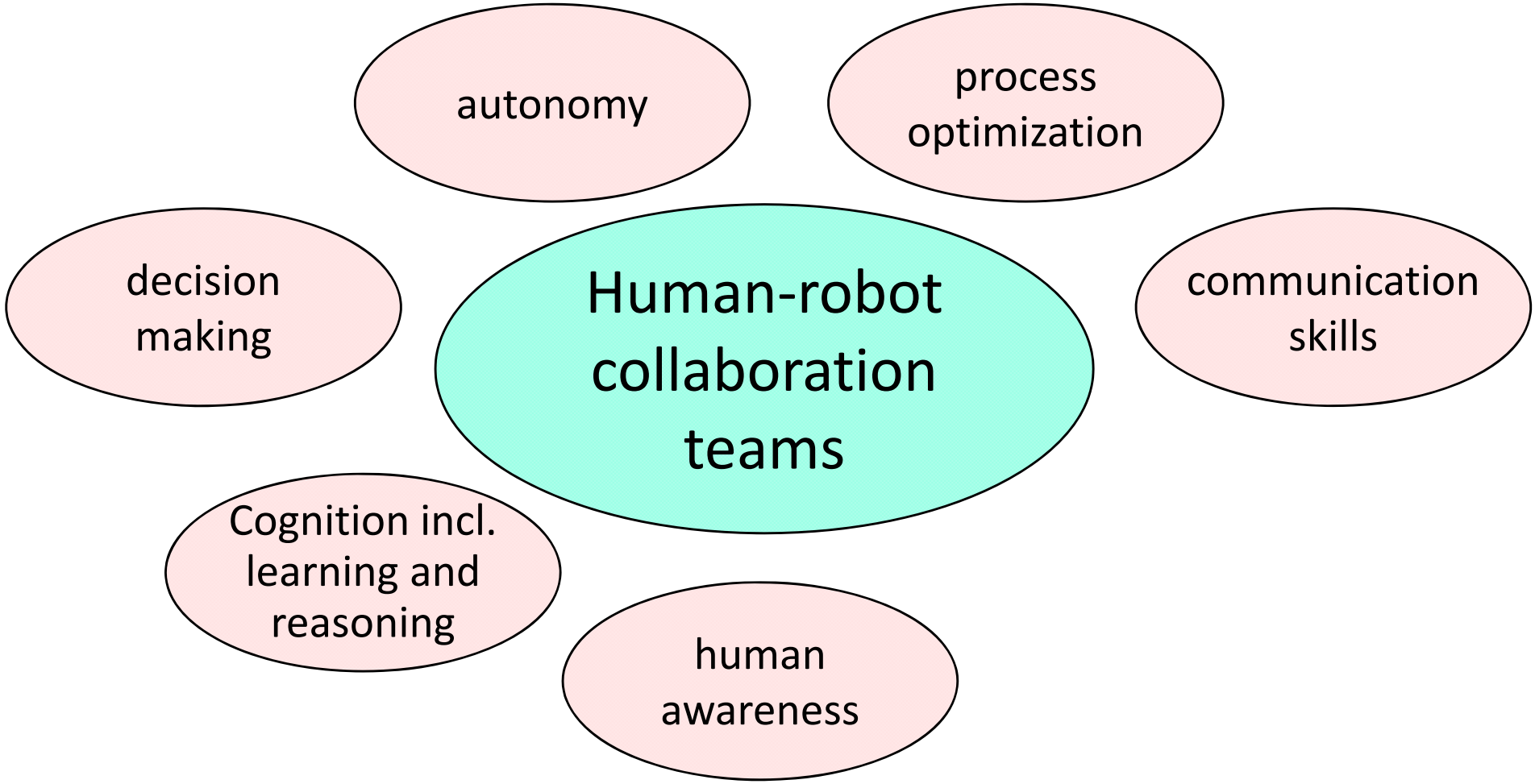


Challenges and chances

Communication skills

Verbal and silent communication, AI based interpretation, understanding of natural language, symbol and gesture grounding, meaning negotiation, inter-robot wireless communication.

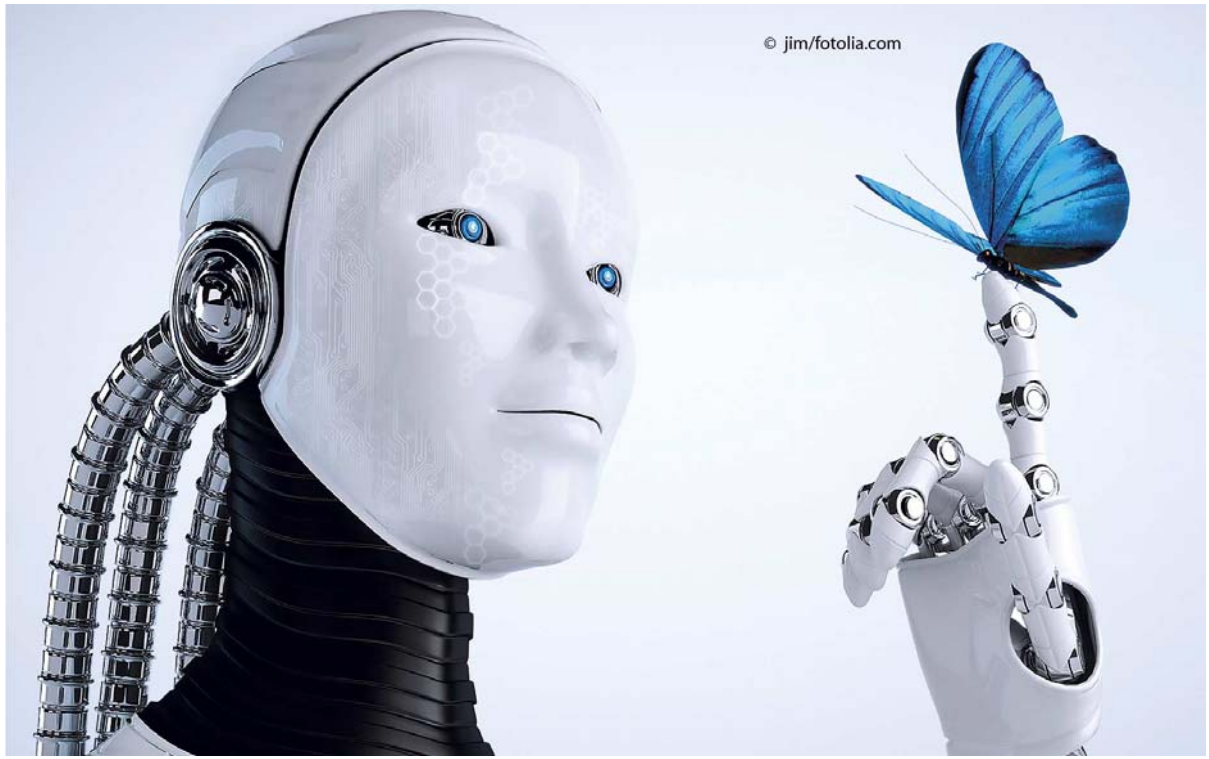
Challenges and chances



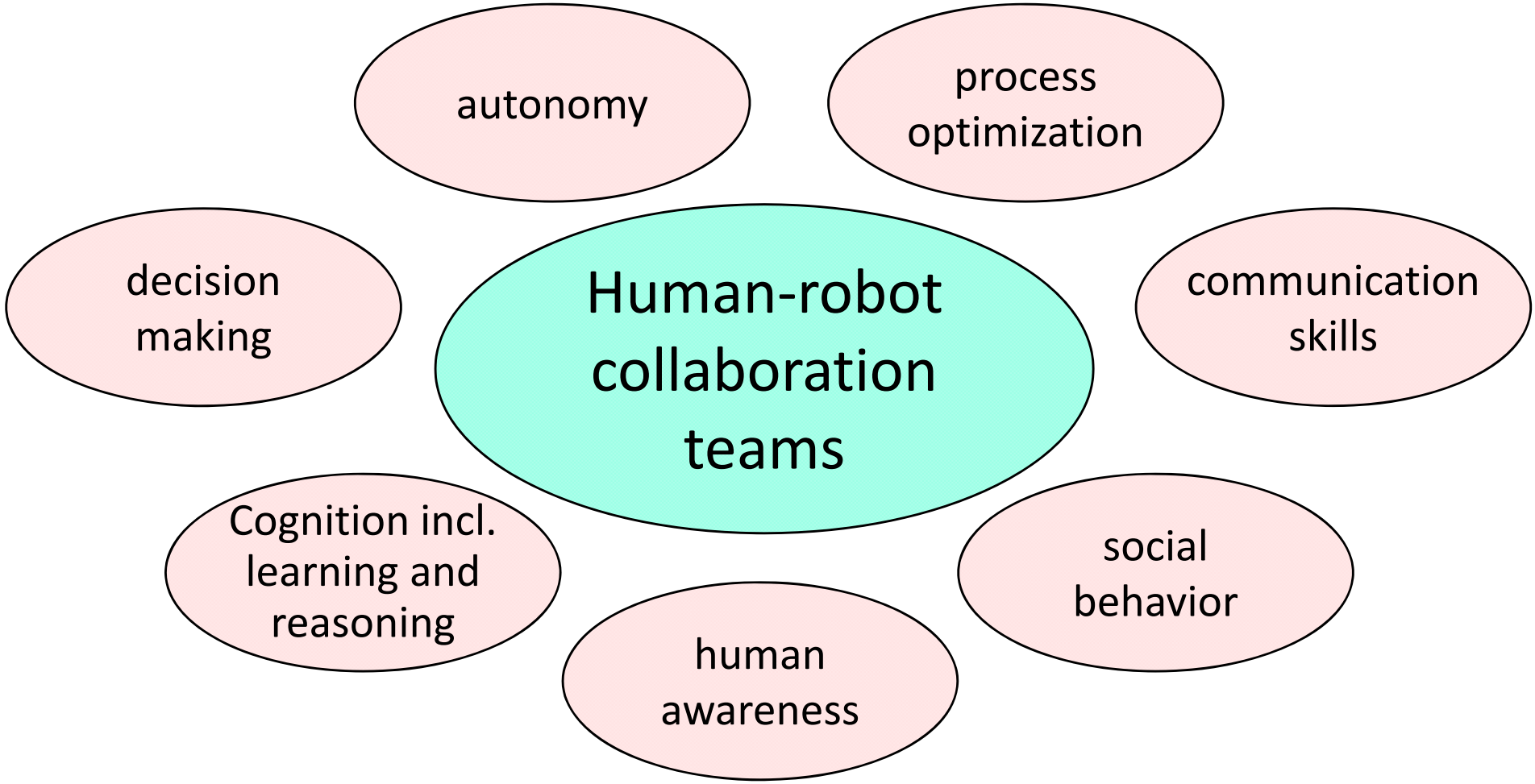
Challenges and chances

Human awareness

Constraint-based consideration of human-awareness for interaction, comfortable, natural motion and social rules, context-awareness, proactivity



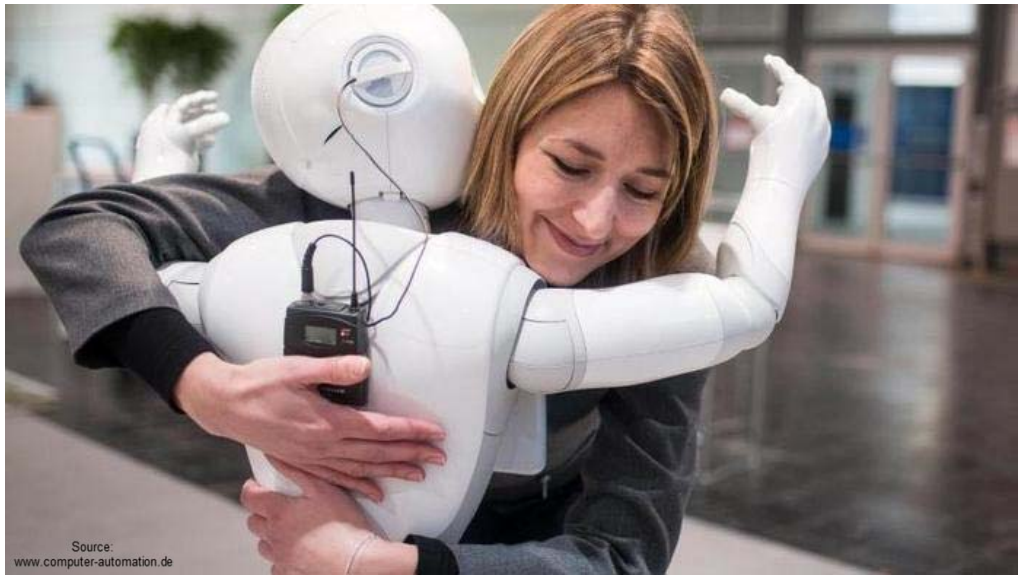
Challenges and chances



Challenges and chances

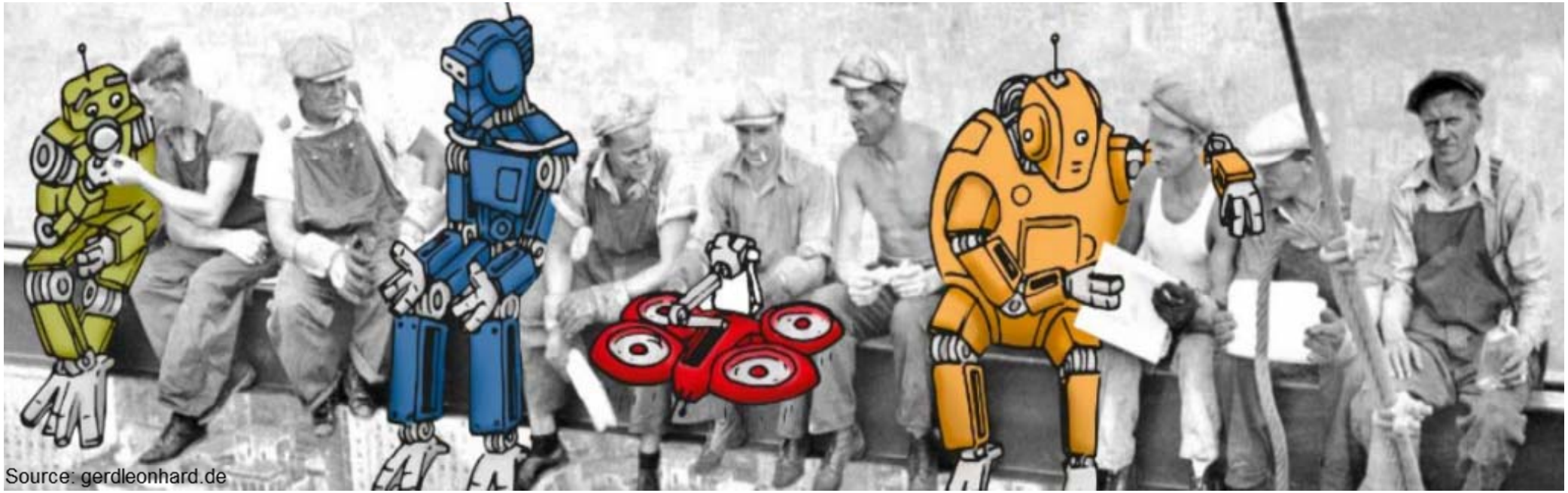
Social acceptance and social team behavior

Decision structure, team performance, and satisfaction, task understanding and role definition, team mental models

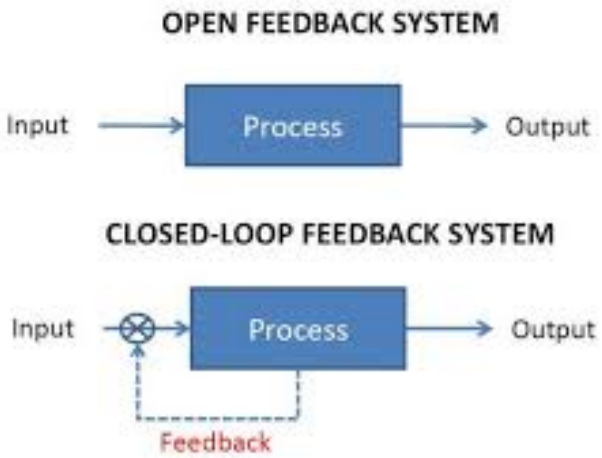


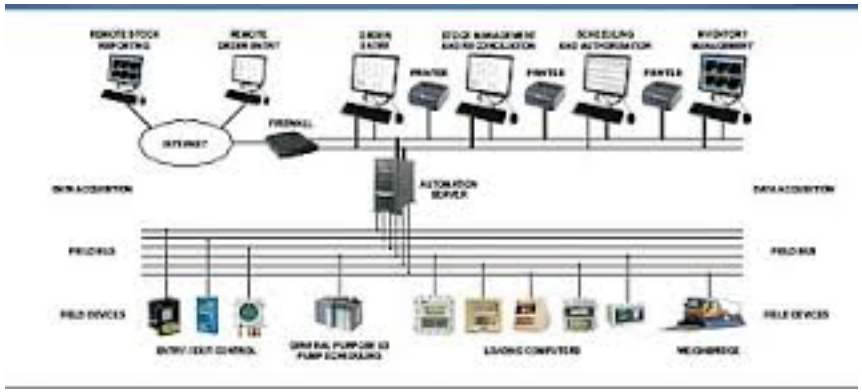
How can we master such complex systems and tough challenges?

Today‘s robot control methods are essential, but we need more „intelligence“ for cooperation!



Historical paradigm shifts in control



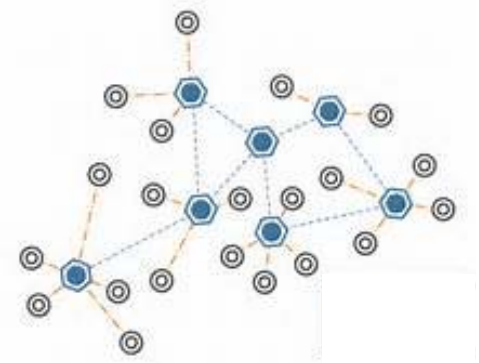


from open-loop to closed-loop

from single control to automation

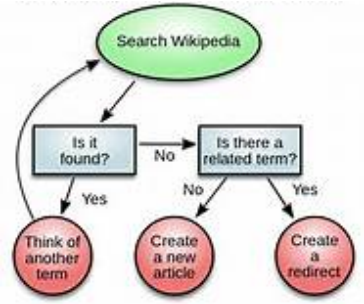
next step?

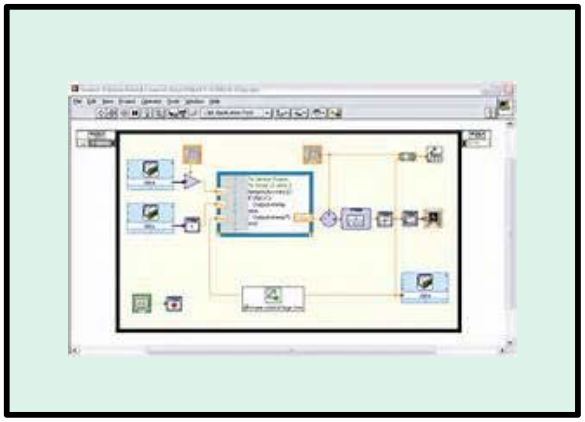
From physics-based to data-based modeling



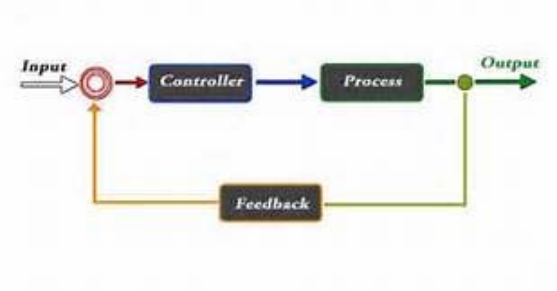
$$\dot{x} = f(x,u)$$
$$y = h(x,u)$$

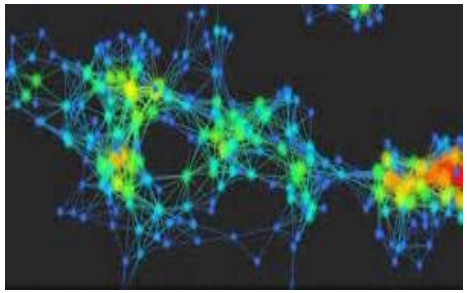
From fixed design to adaptive learning and reasoning



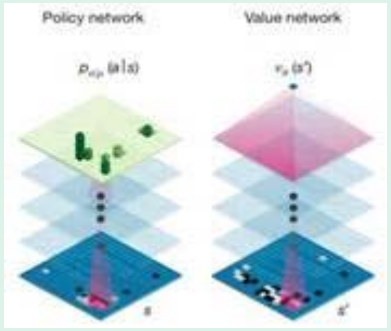


From one-dimensional architecture to multi-layer decision structure





$$\ddot{\phi} = \dot{\theta}\dot{\psi}\left(\frac{I_y - I_z}{I_x}\right) - \frac{J_r}{I_x}\dot{\theta}\Omega + \frac{l}{I_x}U_2,$$
$$\ddot{\theta} = \dot{\phi}\dot{\psi}\left(\frac{I_z - I_x}{I_y}\right) - \frac{J_r}{I_y}\dot{\phi}\Omega + \frac{l}{I_y}U_3,$$
$$\ddot{\psi} = \dot{\phi}\dot{\theta}\left(\frac{I_x - I_y}{I_z}\right) + \frac{1}{I_z}U_4,$$
$$\ddot{z} = -g + (\cos\phi\cos\theta)U_1/m,$$
$$\ddot{x} = (\cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi)U_1/m,$$
$$\ddot{y} = (\cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi)U_1/m.$$



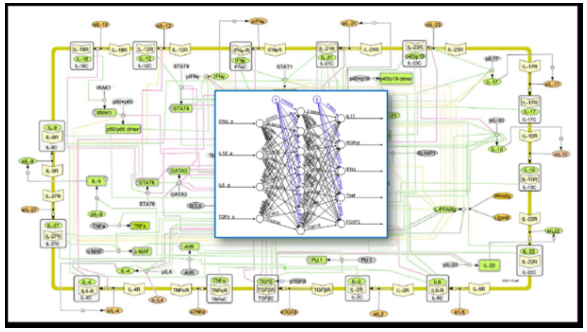
Paradigm shift for controlling human-robot teams!

Integrate AI and control methodologically!

activity recognition

model checking

deep learning



behavioral reasoning

machine learning

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There is much to do!

From qualitative approach to quantitative design

Robustness
Correctness

Architecture
Hierarchy

Modeling
Prediction

Security
Attack
protection

Stability
Performance

...

Thank you!