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Innovation and Coworking

BIOVISION OF THE FUTURE
TECH TRENDS & SAPIENZA RESEARCH

Design challenge for a sustainable and desirable life

Human-Robot Collaboration
in industry and beyond

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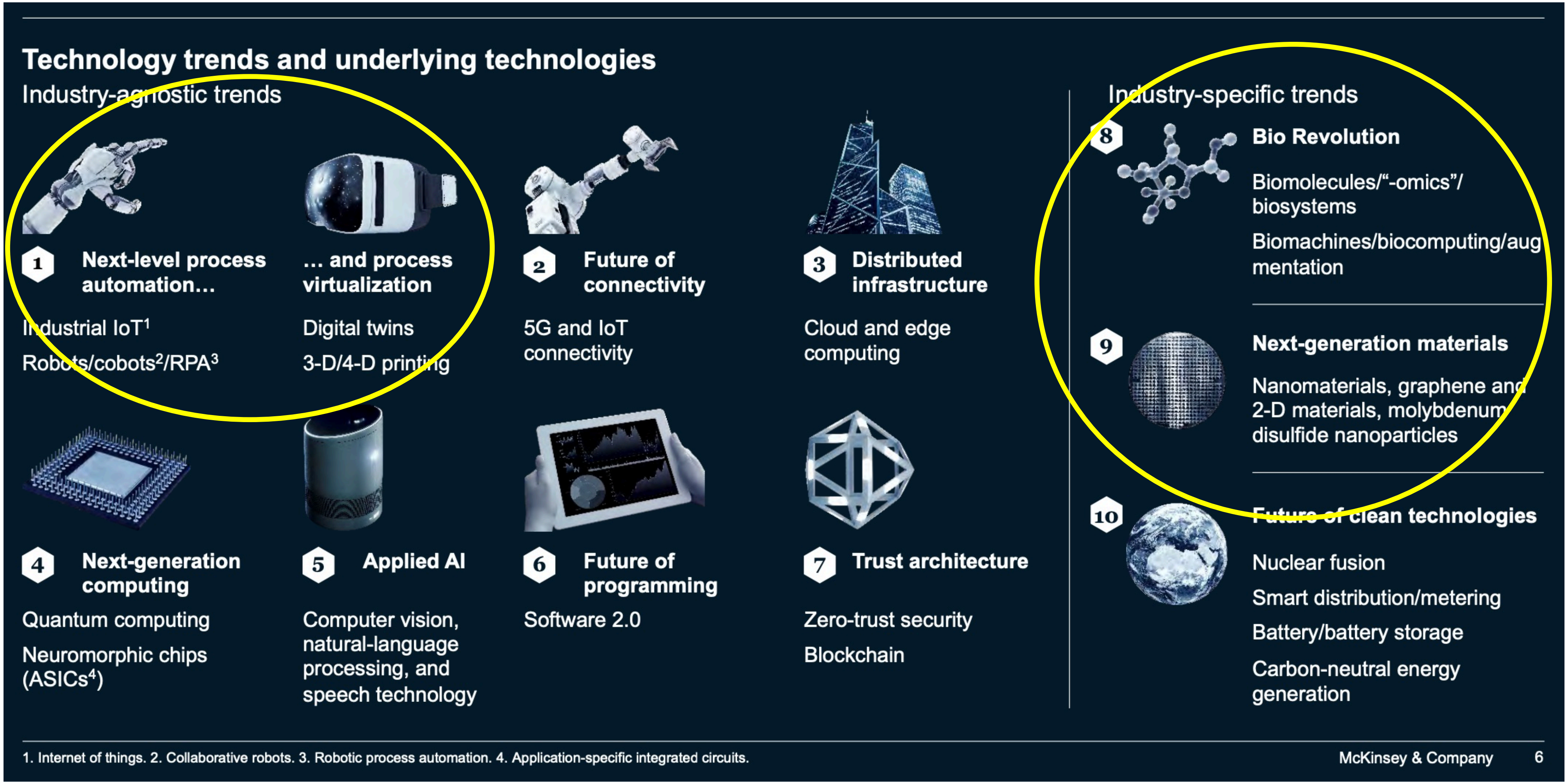
SAPIENZA Università di Roma

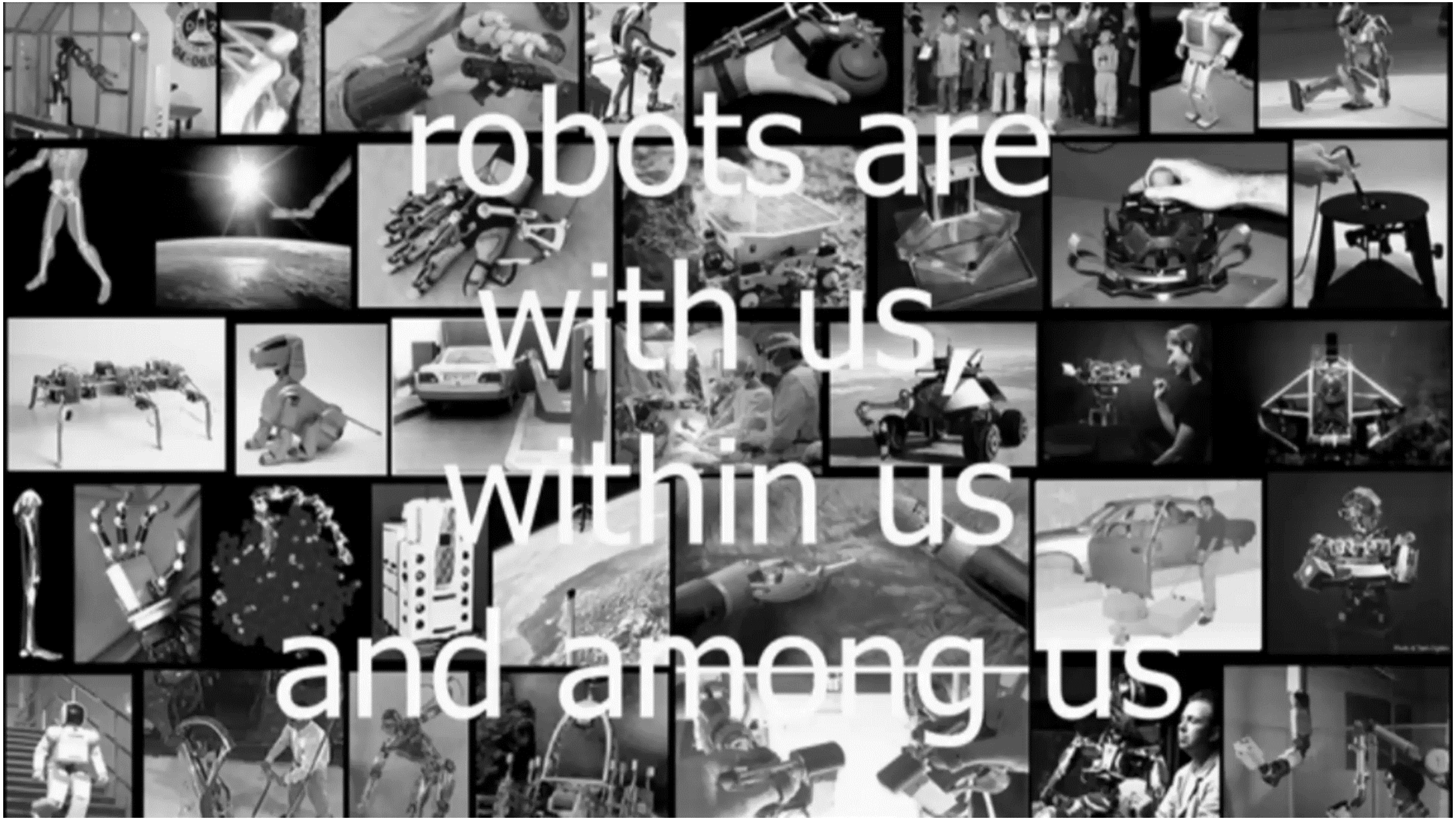
Roma, 9 Maggio 2022

Tech Trends McKinsey 2021



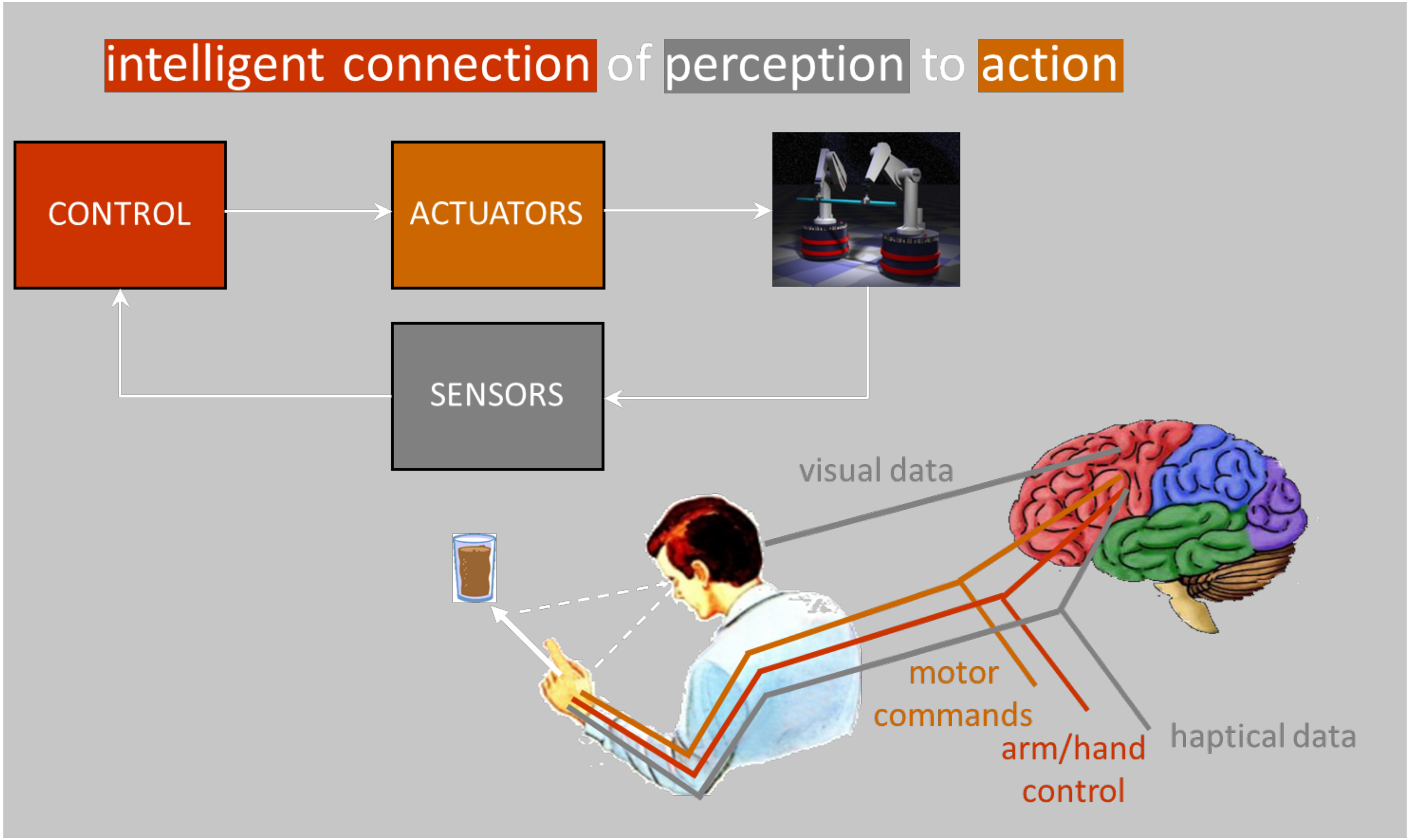
7 tech trends common to multiple industrial sectors and 3 more specific

Collaborative, Autonomous, Interactive …



Source: Springer Handbook of Robotics

Robotics

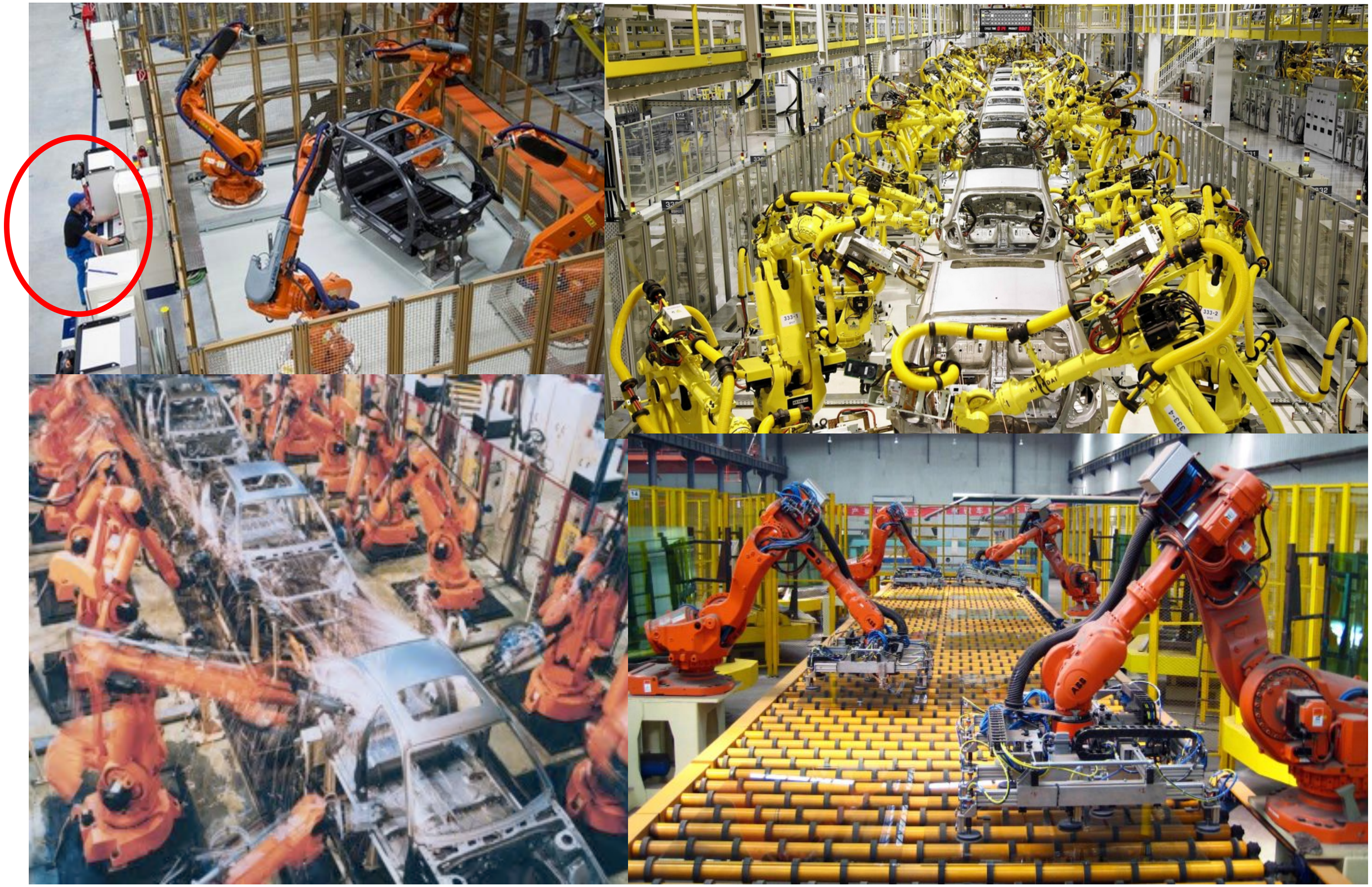

intelligent connection of perception to action
CONTROL
ACTUATORS
SENSORS
visual data
motor
commands
arm/hand
control
haptical data

Robots and humans

science fiction and popular notions of robotics have long foreseen humans and robots **existing side-by-side** and **collaborating to do work** together

factory floors …

… **no humans!?**



Crashes & collisions in industrial settings

unexpected effects of disturbances!

bad motion programming!!

… and related tragic news

Berliner Zeitung

Panorama - 01.07.2015

TRAGISCHER ARBEITSUNFALL IN BAUNATAL

Roboter tötet Arbeiter in VW-Werk

Tragischer Arbeitsunfall im VW-Werk in Baunatal: Beim Aufbau einer neuen Anlage wurde ein 22-jähriger Arbeiter von einem Roboter erfasst und getötet.

R.it | Esteri

July 1, 2015

Robot uccide operaio in fabbrica Volkswagen

E' successo a Baunatal a circa 100 km da Francoforte. La procura ha aperto inchiesta per stabilire se si sia trattato di errore umano o se l'automa sia stato programmato male

theguardian

Winner of the Pulitzer prize 2014

Robot kills worker at Volkswagen plant in Germany

Contractor was setting up the stationary robot when it grabbed and crushed him against a metal plate at the plant in Baunatal

Associated Press in Berlin

Thursday 2 July 2015 02.48 BST

A robot has killed a contractor at one of Volkswagen's production plants in Germany, the automaker has said.

The man died on Monday at the plant in Baunatal, about 100km (62 miles) north of Frankfurt, VW spokesman Heiko Hillwig said.

The 22-year-old was part of a team that was setting up the stationary robot when it grabbed and crushed him against a metal plate, Hillwig said.

He said initial conclusions indicate that human error was to blame, rather than a problem with the robot, which can be programmed to perform various tasks in the assembly process. He said it normally operates within a confined area at the plant, grabbing auto parts and manipulating them.

Another contractor was present when the incident occurred, but was not harmed, Hillwig said. He declined to give any more details about the case, citing an ongoing investigation.

German news agency DPA reported that prosecutors were considering whether to bring charges, and if so, against whom.

Ansa
Mondo

Dipendente Volkswagen ucciso da robot

Afferrato e schiacciato contro pannello di metallo

- Redazione ANSA
- BERLINO
02 luglio 2015 - 19:19
- NEWS

Suggerisci
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Altri

Robot 'uccide' operaio in Germania © ANSA/Ansa

CLICCA PER INGRANDIRE +

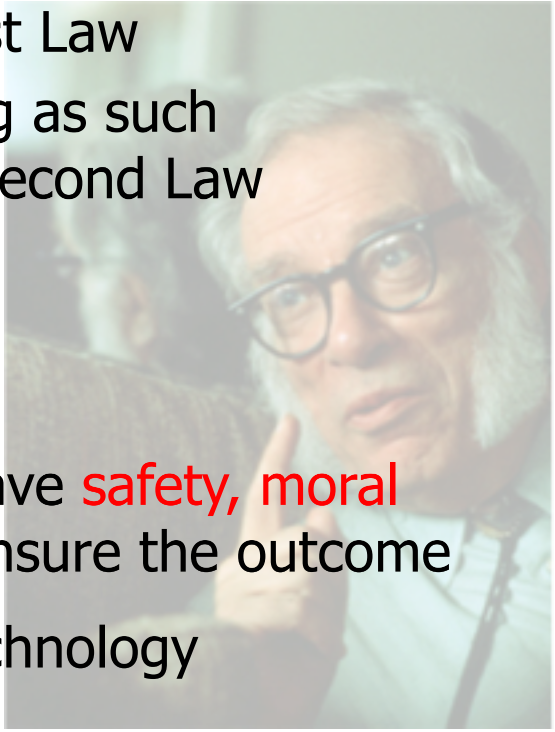
Stampa
Scrivi alla redazione

Un giovane dipendente della tedesca Volkswagen è stato ucciso da un robot della fabbrica. È accaduto a Baunatal, a

Laws of Robotics

- Laws of Robotics by Isaac Asimov in I, Robot (1950)
  1. A robot may not injure a human being or, through inaction, allow a human being to come to harm
  2. A robot must obey orders given to it by human beings, except where such orders would conflict with the First Law
  3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law

- More from Asimov (1920-1992) ...
  - We cannot leave to AI decisions which may have safety, moral and legal consequences because we cannot ensure the outcome
  - Yet we can have AI in robotics with proper technology



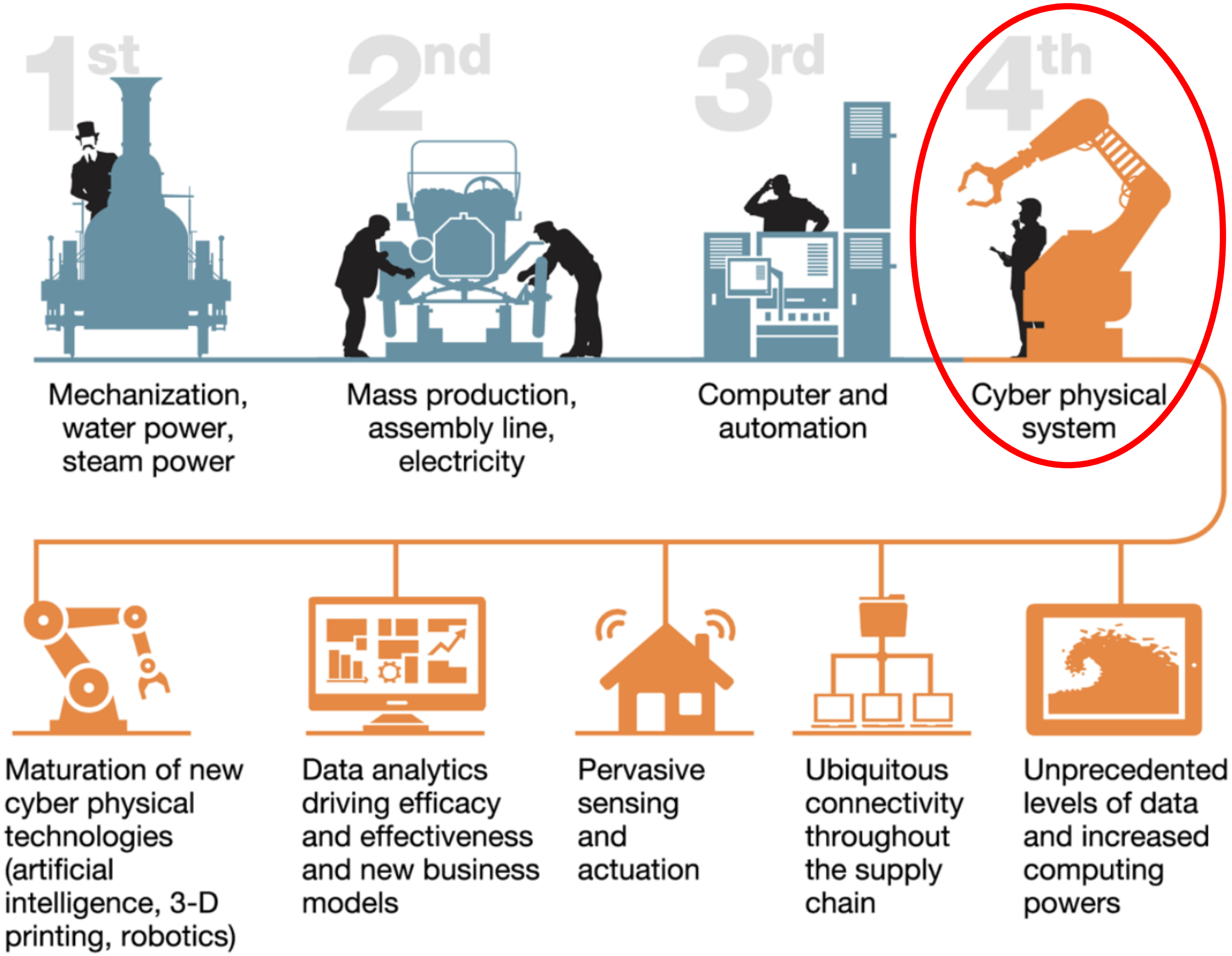
Traditional industrial perspective

- safeguarding/stopping the robot when a human is in the workspace
- monitoring workspace with sensors to slow down/stop robot motion

Innovative industrial perspective

- robot co-workers …

Industrial revolutions



"comprehensive transformation of the whole sphere of industrial production through the merging of digital technology and internet with conventional industry"

(Angela Merkel - *Organization for Economic Cooperation and Development, 2014*)

Industry 4.0

a list of key enabling technologies for the 4th industrial revolution

1	Advanced Manufact. Solutions	• **Collaborative robots** networked and easily programmable
2	Additive Manufacturing	• 3D additive printers with software for digital design
3	Augmented Reality	• Augmented reality to support production processes
4	Simulation	• Simulation tools of interconnected machines/cells for process optimization
5	Horizontal/ Vertical Integration	• Integration of information along the value chain from suppliers to customers
6	Industrial Internet	• Bidirectional communication between production processes and products
7	Cloud	• Big data storage and exchange in open network systems
8	Cyber-security	• Security in operation of networks and open systems
9	Big Data and Analytics	• Big data analysis to optimize products and production processes

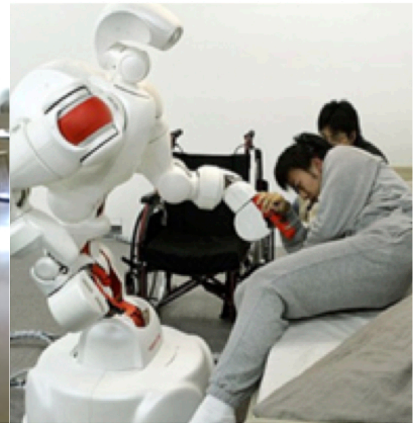
Collaborative robots

traditional robotics

replacing humans

human-friendly robotics

collaborating with humans

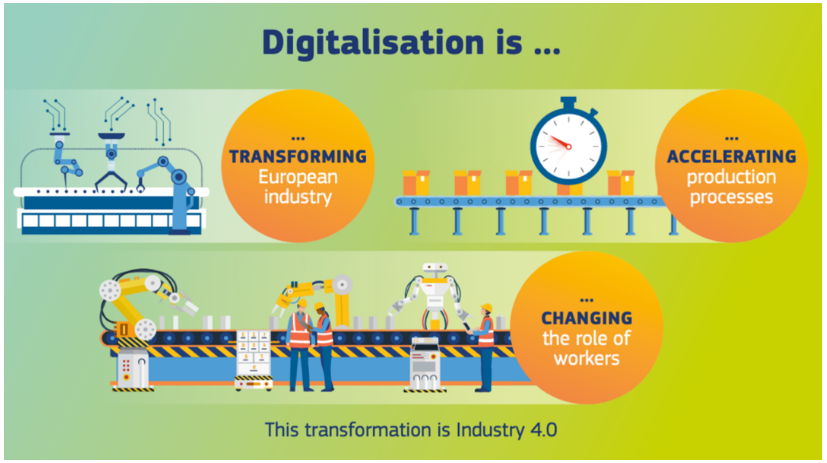


co-workers on **factory floor**

personal/service robots

Industry 5.0 !!


European Commission
Industry 5.0
Towards a sustainable, human-centric and resilient European industry
R&I PAPER SERIES
POLICY BRIEF
Research and Innovation


Digitalisation is ...
... TRANSFORMING European industry
... ACCELERATING production processes
... CHANGING the role of workers
This transformation is Industry 4.0


Industry 5.0 ...
HUMAN-CENTRIC
... promotes talents, diversity and empowerment
RESILIENT
... is agile and resilient with flexible and adaptable technologies
SUSTAINABLE
... leads action on sustainability and respects planetary boundaries

Human-Robot Interaction (HRI)

physical and cognitive interaction between a Sarcos robot and a human

intrinsic compliance and natural dynamic behavior of the robot
are here more important than fast and accurate motion execution

cognitive vs physical HRI

cognitive interaction (cHRI)
– Robot@CWE EU Project

physical interaction (pHRI)
– handshaking at @PAL Robotics

Other physical HR interactions

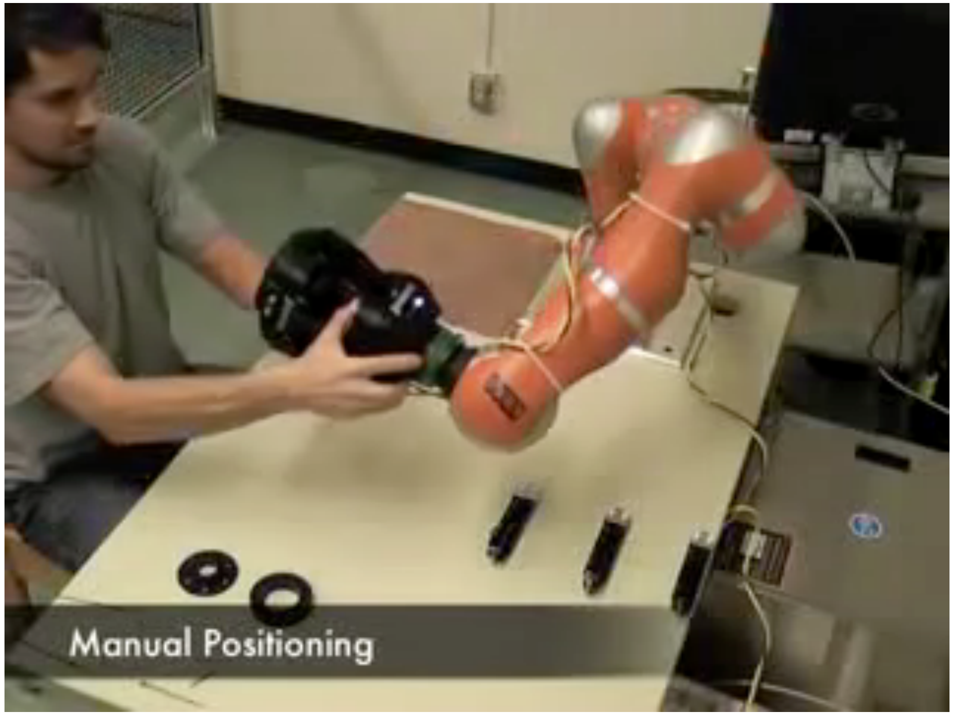
human augmentation

soft robotic system
for improving
worker ergonomics

upper-limb
and lower-limb

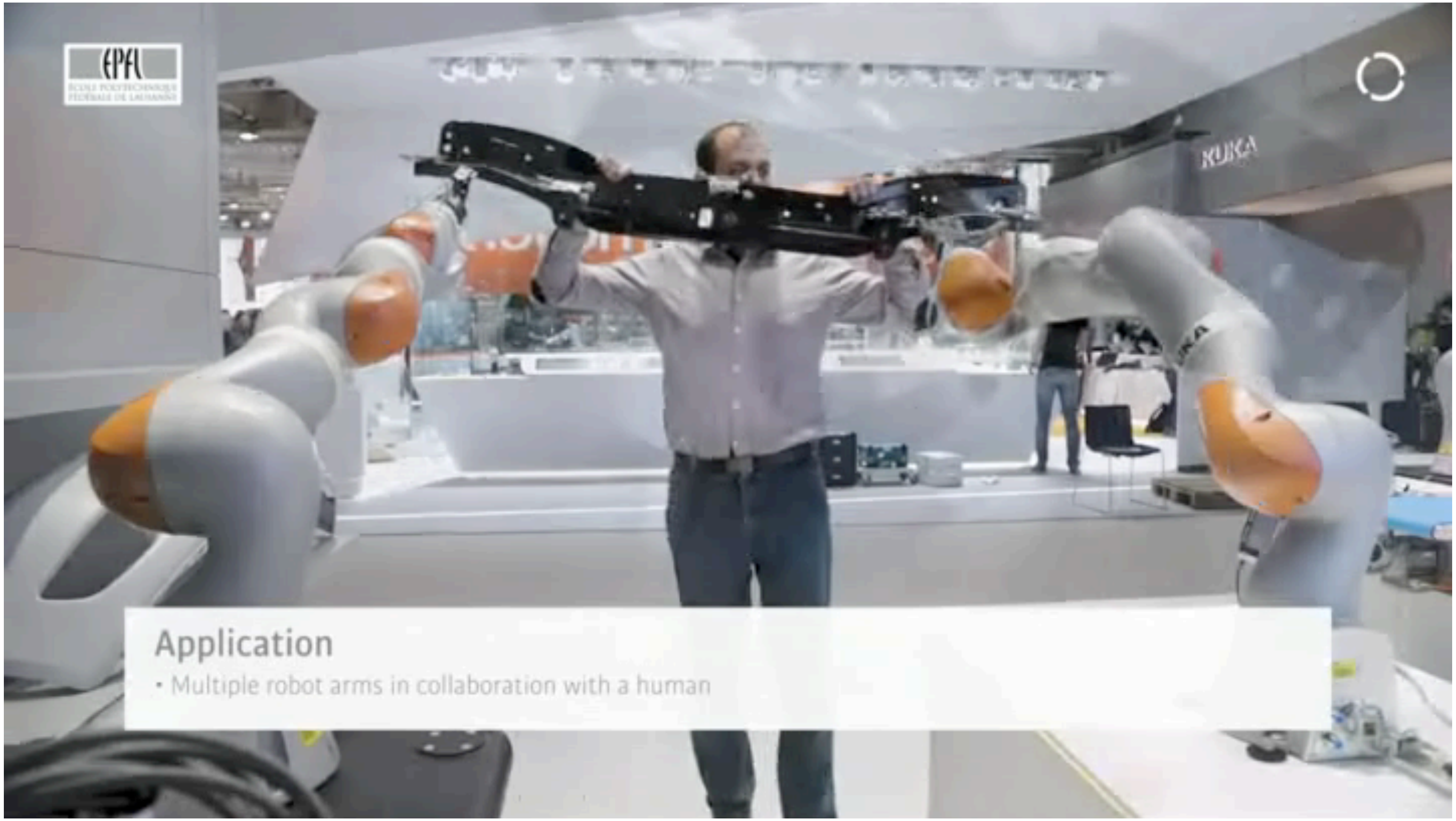
exoskeletons
for rehabilitation

Human-robot collaboration



- Mr. Helper humanoid collaborates in carrying large and/or heavy loads [Tohoku University, 2000]
- Kuka LWR4 with a Robotiq wrist force/torque sensor collaborates in an assembly task [2015]

Working with humans or for humans?



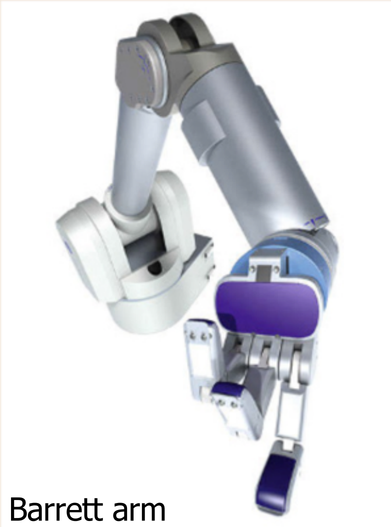
[in 2017]

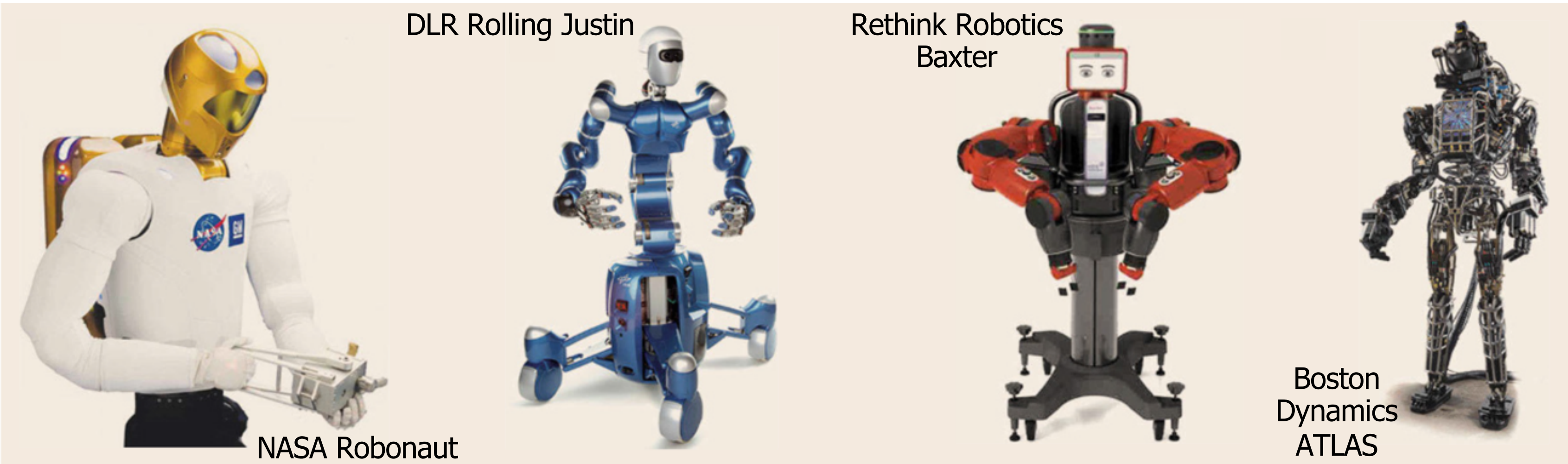
State of the art on pHRI

- technical developments of components and systems for successful physical human–robot interaction over the last two decades
  - mechatronics (actuation/sensing), planning, and control
  - design of lightweight and compliant robots (and bioinspired soft robots!)
  - safe interaction control schemes

  ⇒ beyond high-payload/high-precision position-controlled industrial robots
- rise of a new generation of dependable robots capable of
  - sensing (or estimating) human motion and physical contacts
  - rendering natural and compliant behavior for the whole robot structure
  - planning legible motions that respect human preferences
  - generating interaction plans for collaboration and coaction with humans
- advances in the field of human safety in industrial robotics
- novel and unforeseen application domains are now open

Human-friendly robot design





iF Design Award

DESIGN AWARD 2003

Product | Industry

DLR LBR III

Lightweight robot

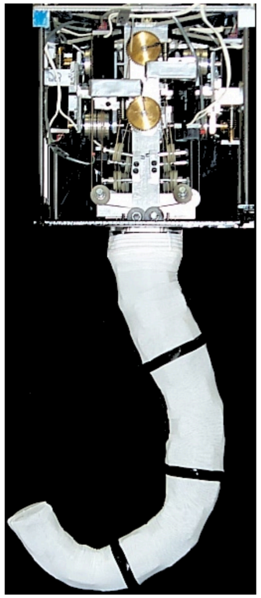
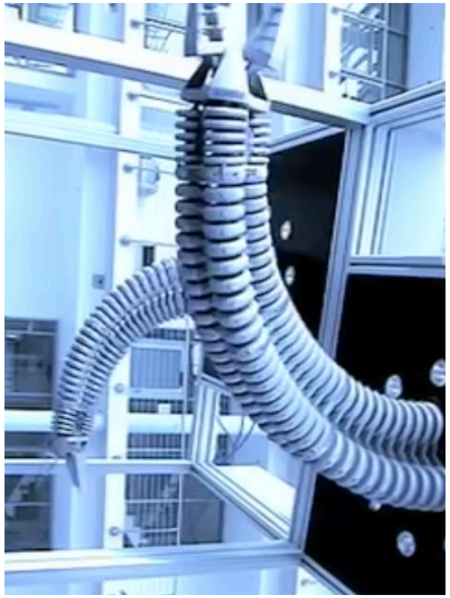
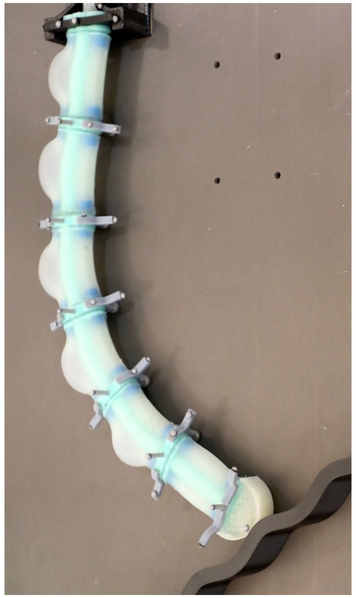
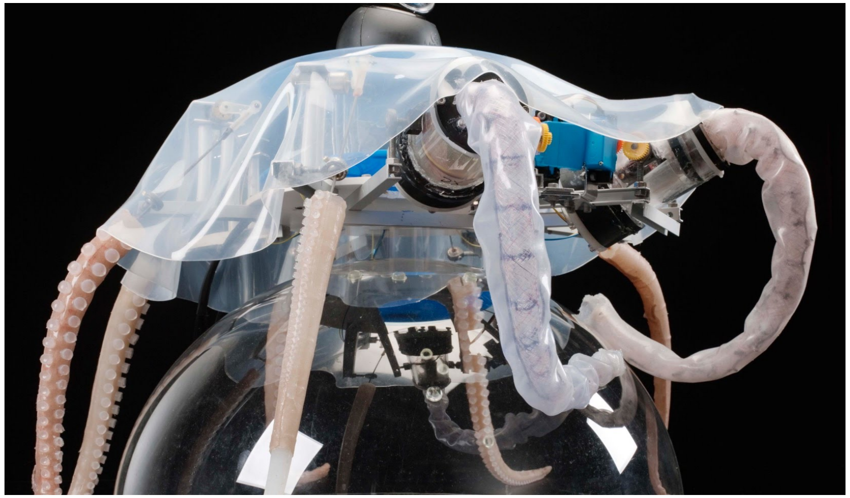
7-dof arm designed by the Italian engineer Antonio Pascucci

first robot that carries a payload equal to its own weight (13.5 kg)!

LBR = LeichtBauRoboter =
LWR= LightWeight Robot

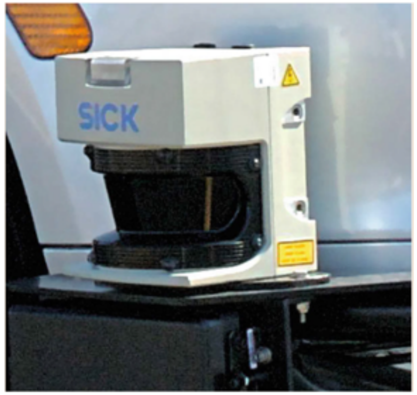
Soft robots

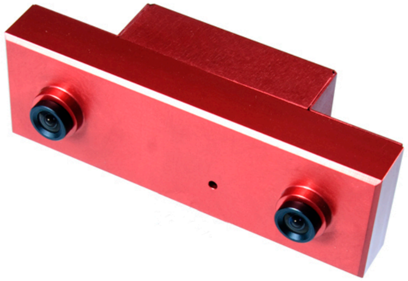
- continuum soft manipulators
  - long, flexible, lightweight, slender arms
  - tendon/cable-driven, segmented, distributed/embedded actuation
  - energy efficient, (intentional) bio-inspired design
- useful in many special robotic applications
  - surgical, underwater, human interaction, cluttered environments, …

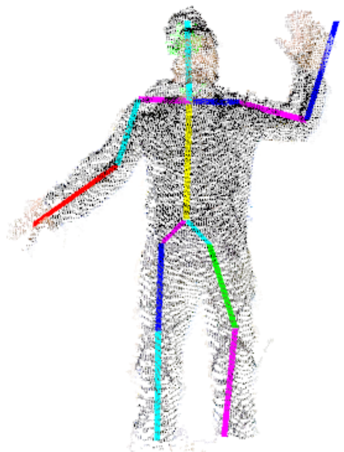





Perception for interaction

- exteroceptive sensing
  - laser scanners, proximity sensors (magnetic, ultrasound, …)
  - cameras (single, stereo, depth and RGB-D sensing, …), Vicon system

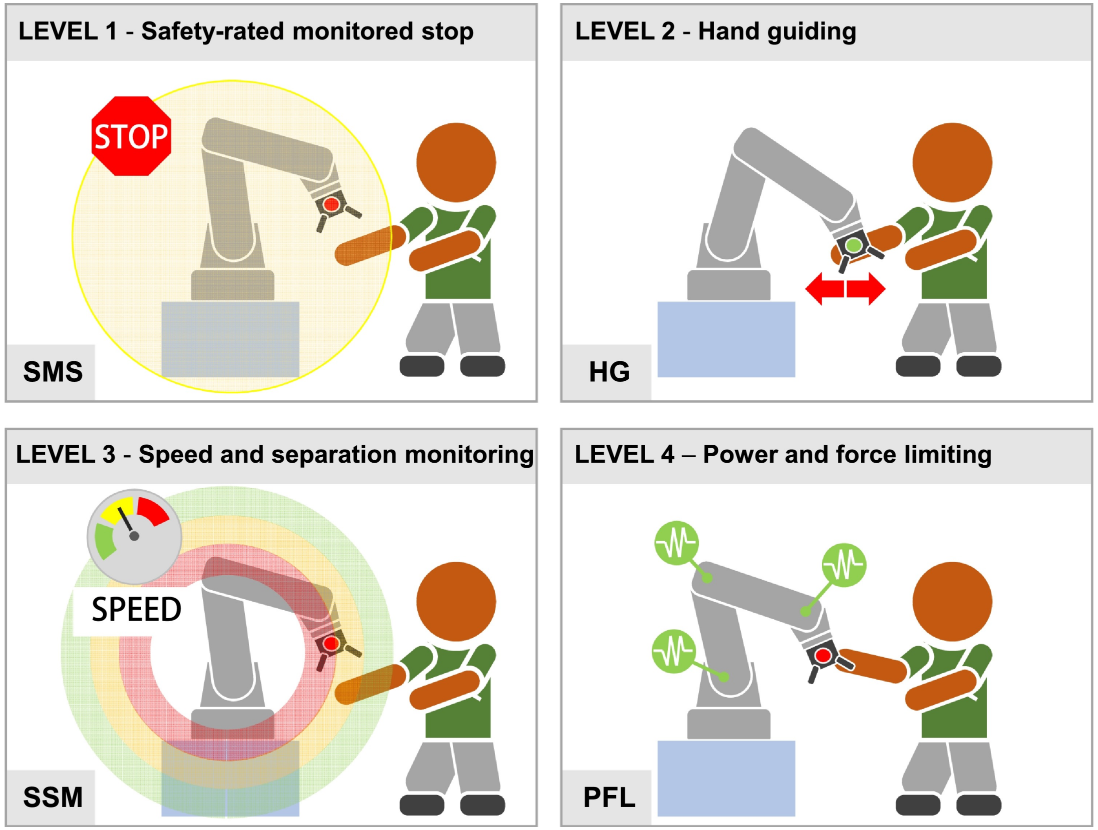


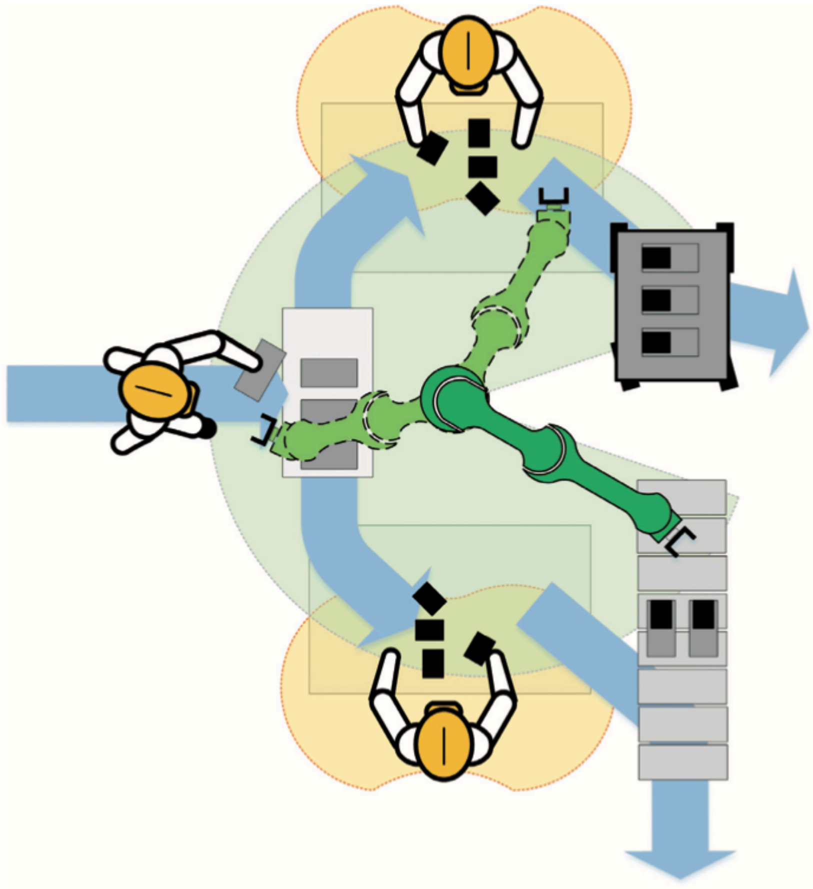




Levels of pHRI

- different possible levels of pHRI are defined also within the ISO 10218 safety standard for industrial robots (collaborative spaces)





ISO TS 15066:2016

Risk analysis and mitigation

risk estimation process

for each single hazard and combined

RISK related to the considered hazard — is a function of — SEVERITY OF HARM that can result from the considered hazard — and — PROBABILITY OF OCCURRENCE of that harm:

- Exposure of person(s) to the hazard
- the occurrence of a hazardous event
- the possibility to avoid or limit the harm

risk mitigation measures

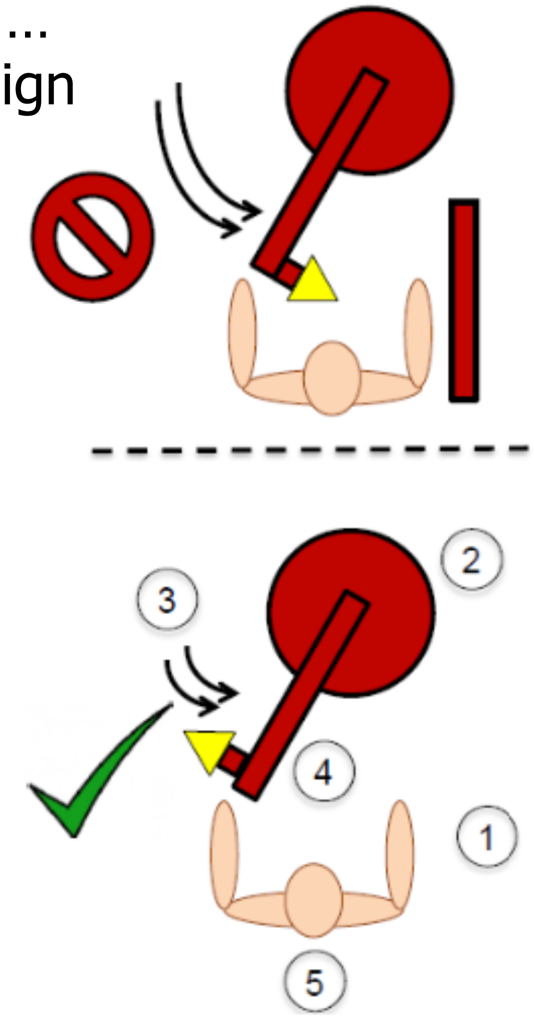
exemplified

Most preferred → *Least preferred*

Inherently Safe Design Measures			Safeguarding & Complementary Protective Measures		Information for Use		
Elimination	**Substitution**	**Limit Interaction**	**Safeguard**	**Comp Protective Measures**	**Warnings & Awareness Means**	**Administrative** (organizational) **Controls**	**PPE**
Process or layout design, redesign or modification	• Less hazardous materials • Intrinsically safe • Reduce energy • …	• Eliminate or reduce human interaction • Automate tasks • Modify layout or process flow • …	• Guards • Interlocks • Protective Devices • Safety controls, logic & functions • Safety parameters & configurations • …	• Fall prevention • Escape & rescue • Safe access • Safe handling • Energy isolation • Enabling devices • Estops …	• Lights, beacons and strobes • Audible alarms • Signs, labels or markings	• Training and SOPs • Inspections • Rotation of workers • Changing schedules • Control of Haz Energy • HazCom • Confined Space • Management	Clothing, footwear, glasses, respirators gloves & more for specific safety purposes

Modification of power and force limits

an example of risk critical task …
mitigated by application re-design

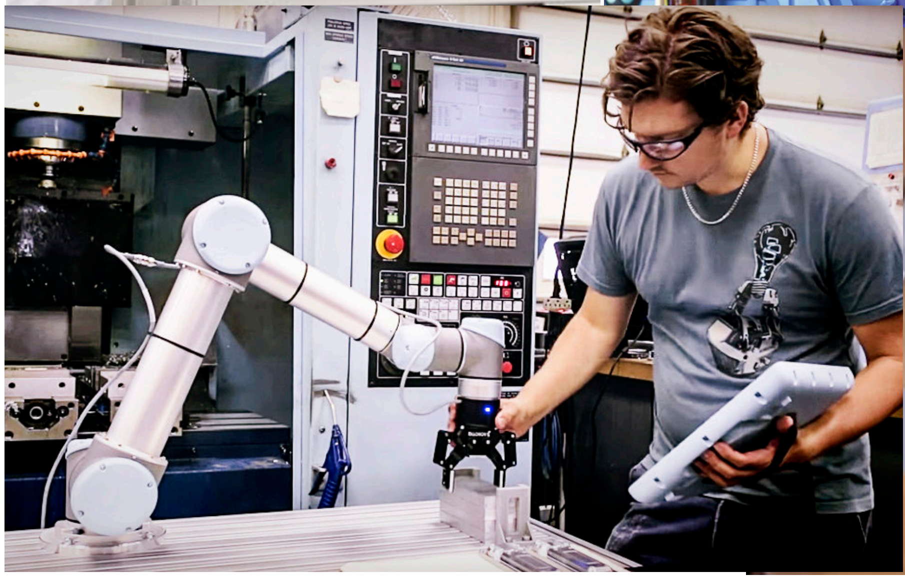


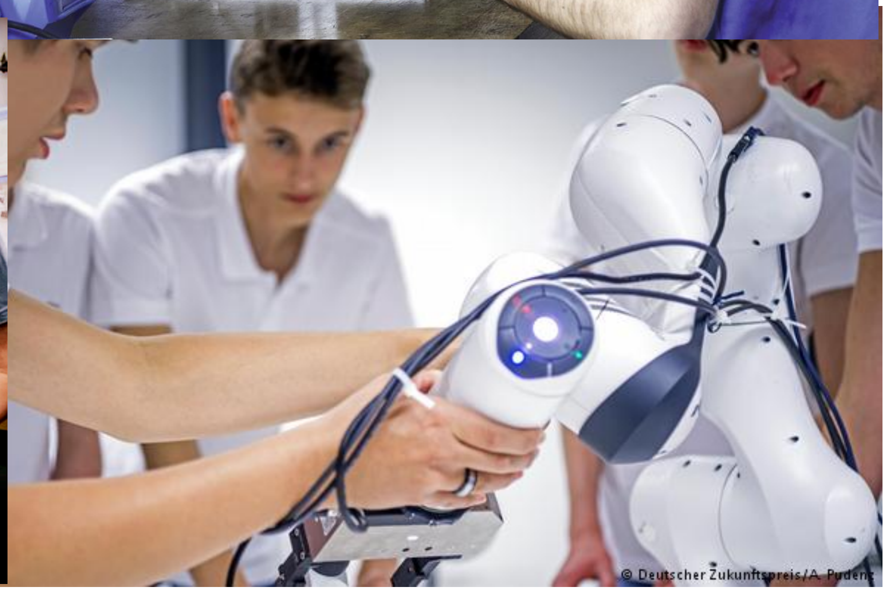
1. Eliminate pinch and crush points
2. Reduce robot system inertia or mass
3. Reduce robot system velocity

   2. & 3. will reduce energy transfer in a collision
4. Modify robot posture such that contact surface area is increased
5. Avoid sensitive body areas (head & neck)

\+ Safe control: collision detection & reaction

Human-friendly factory floor





From factories to our homes

industry

automobile
chemical
electronic
food

field

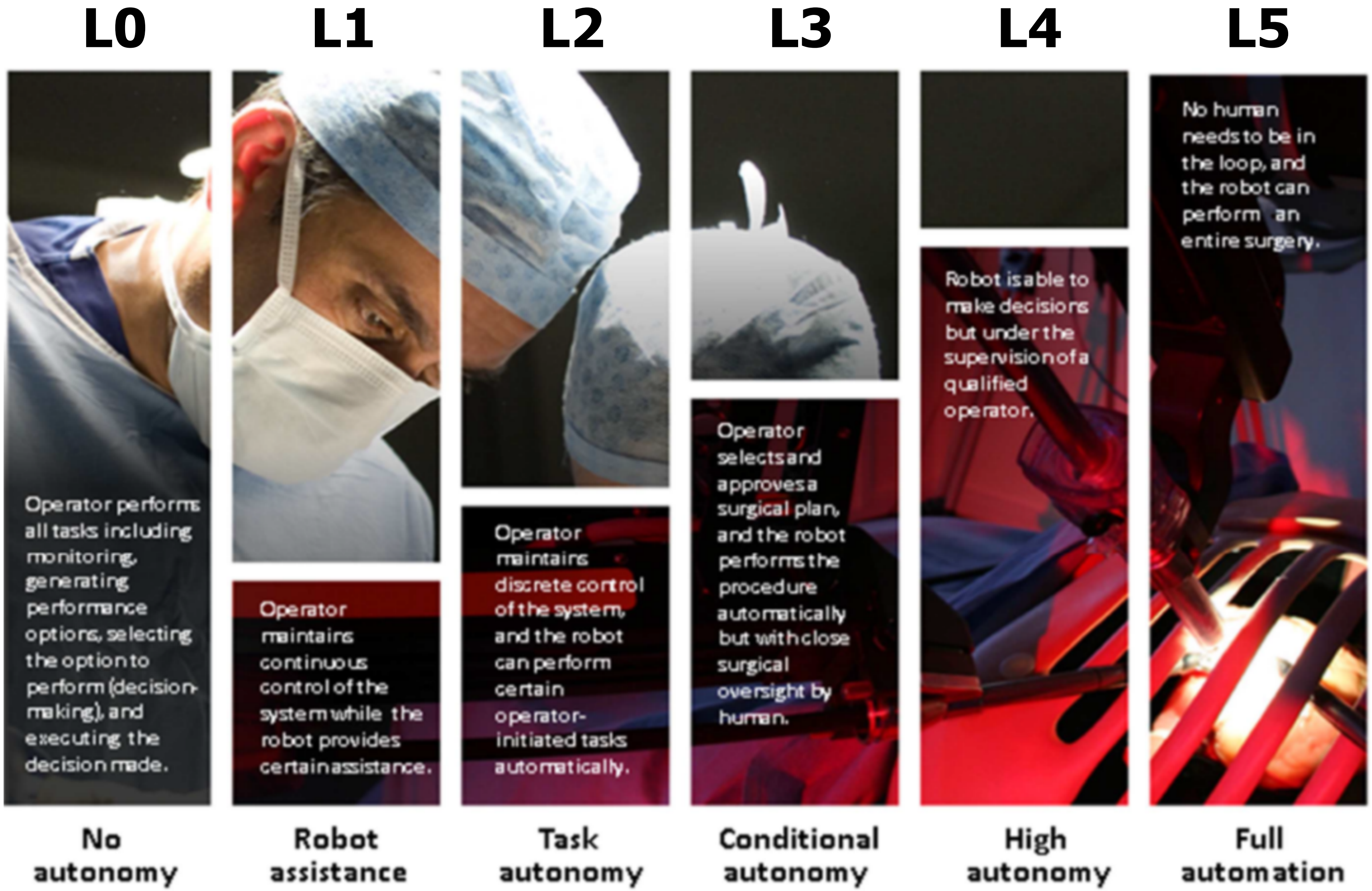
aeronautics
aerospace
subsea
rescue

service

domestic
edutainment
rehabilitation
medicine

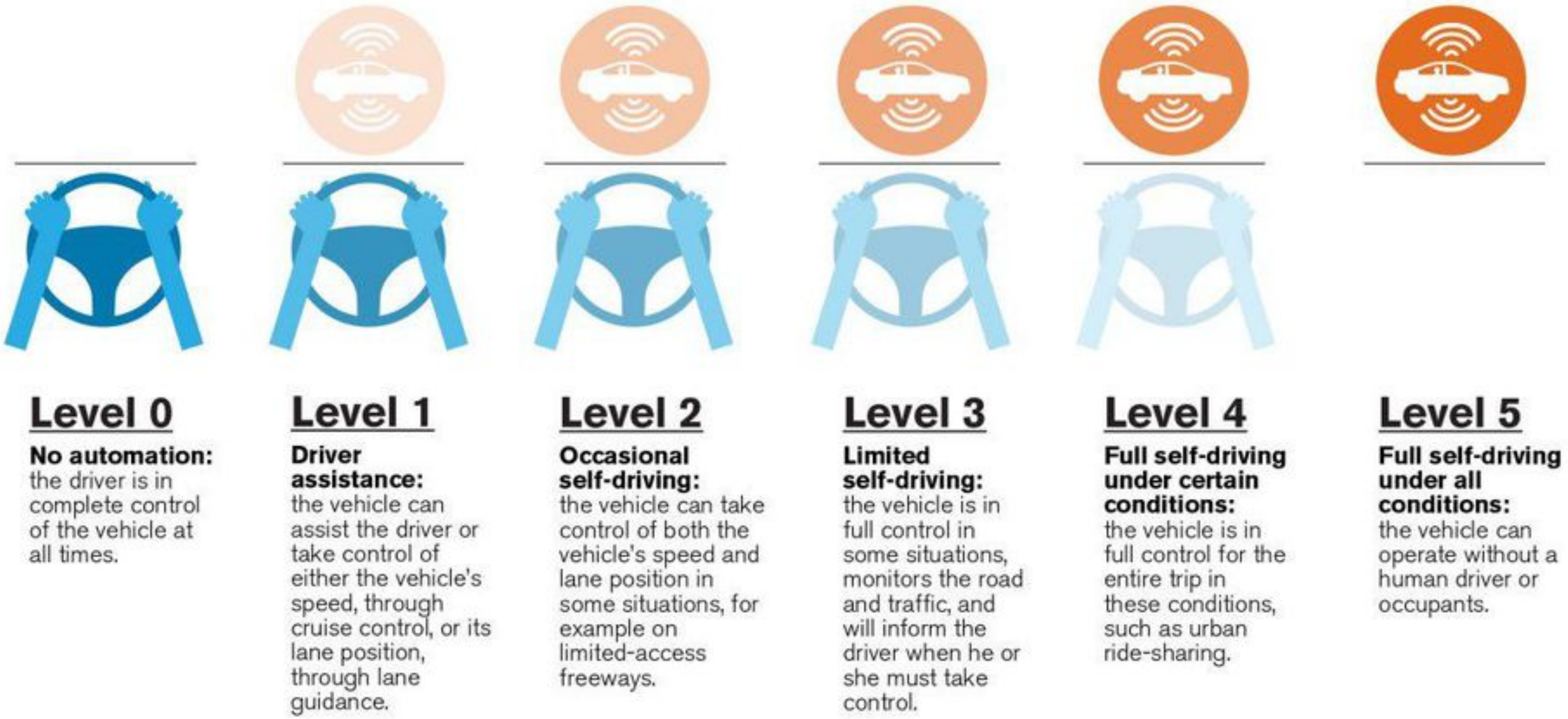
level of autonomy

Levels of autonomy
surgical robotics



Levels of autonomy
automotive

L0 **L1** **L2** **L3** **L4** **L5**



Source: SAE & NHTSA

A control architecture for safe pHRI

- planned and controlled robot behaviors in a 3-layer architecture

Safety

lightweight mechanical design
compliance at robot joints

collision detection and reaction

Coexistence

robot and human sharing the same workspace

collision avoidance
no need of physical contact

Collaboration

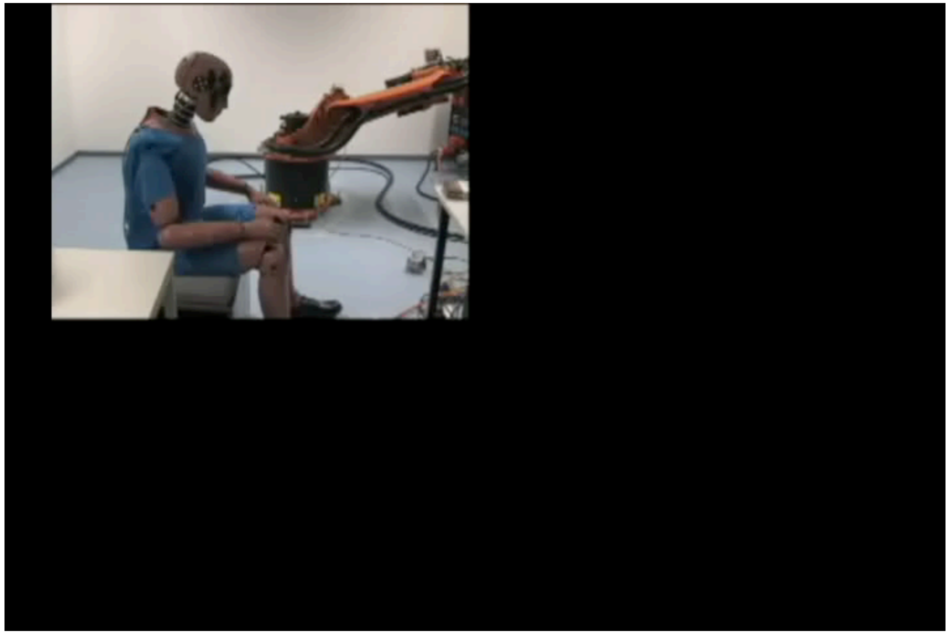
contactless, e.g., gestures or voice commands

with intentional contact and
coordinated exchange of forces

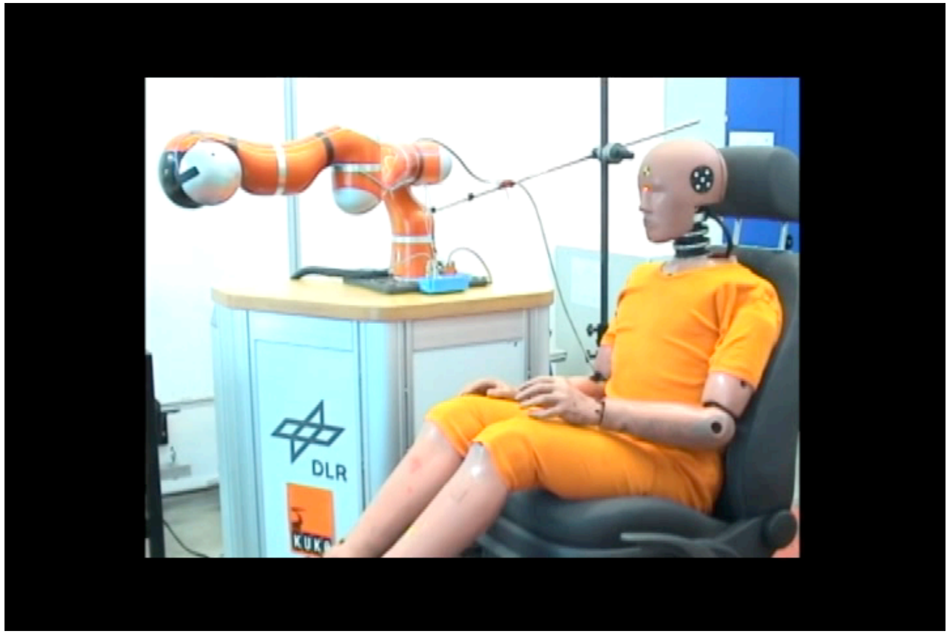
A. De Luca, F. Flacco: *IEEE BioRob Conference*, 2012

Robotic crash tests

industrial robots-dummy
without control



KUKA LWR-dummy
with collision detection/reaction



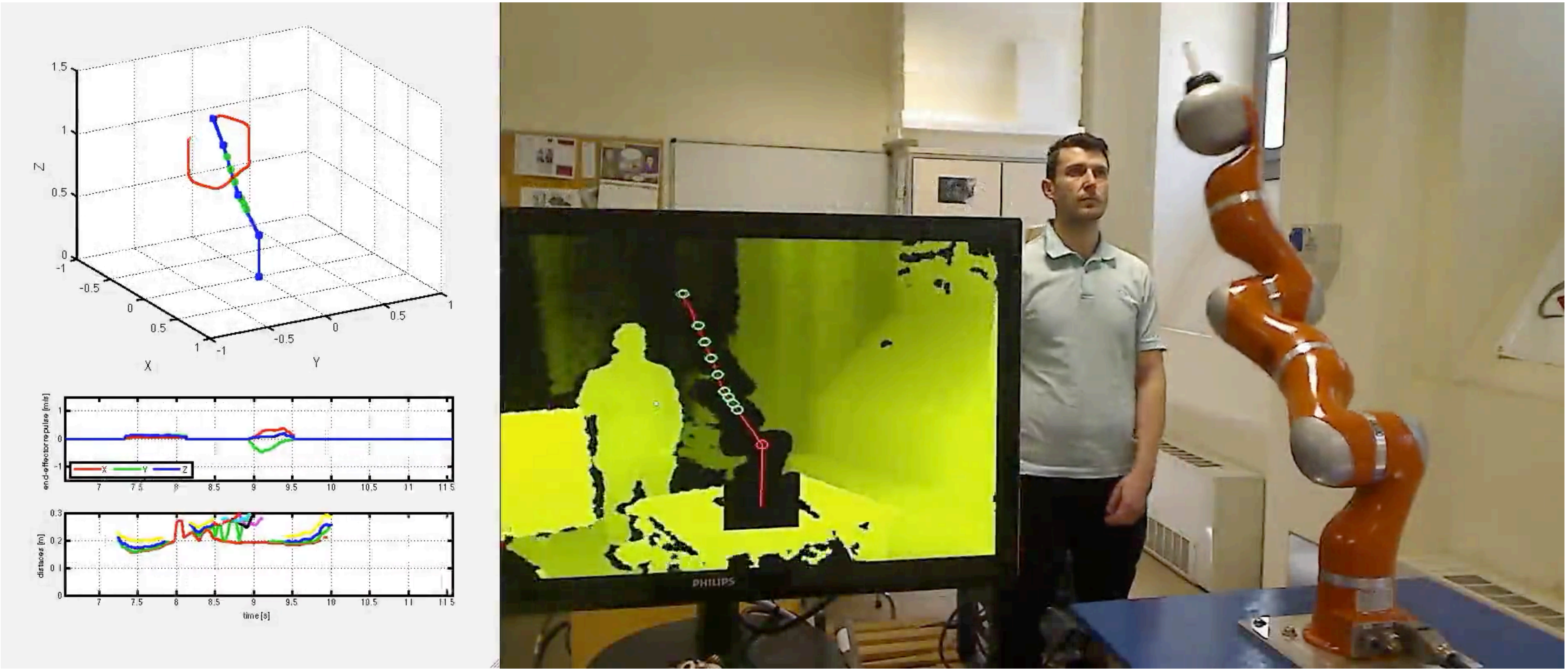
DLR KUKA SAPIENZA UNIVERSITÀ DI ROMA

Collision detection and reaction

- first impact @60-90^o/sec: robot detects, reacts, and floats

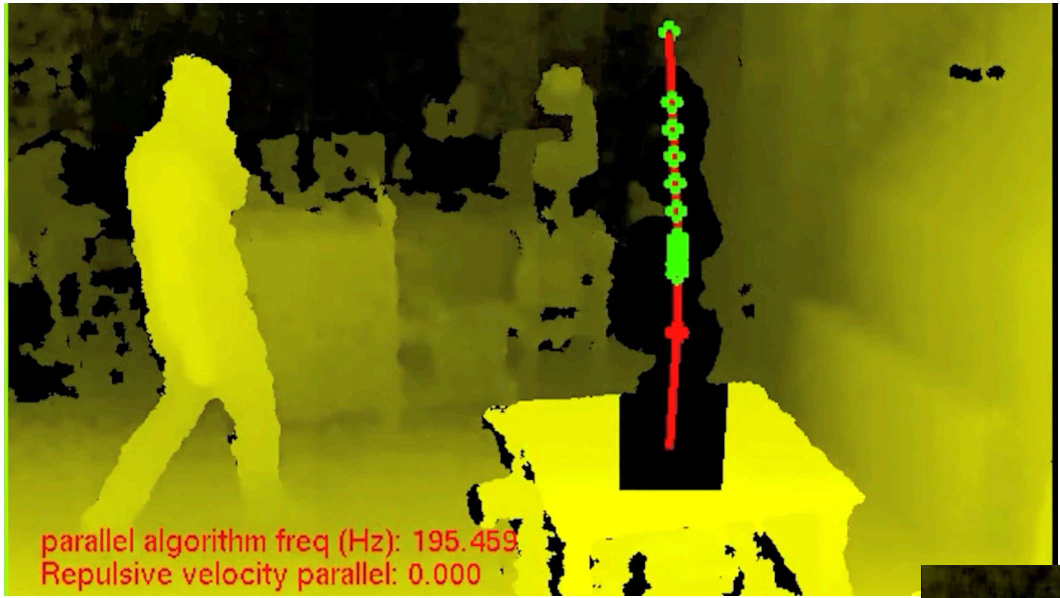
sensor-less!

Human-robot coexistence



robot resumes its cyclic Cartesian task as soon as possible …

From coexistence to collaboration



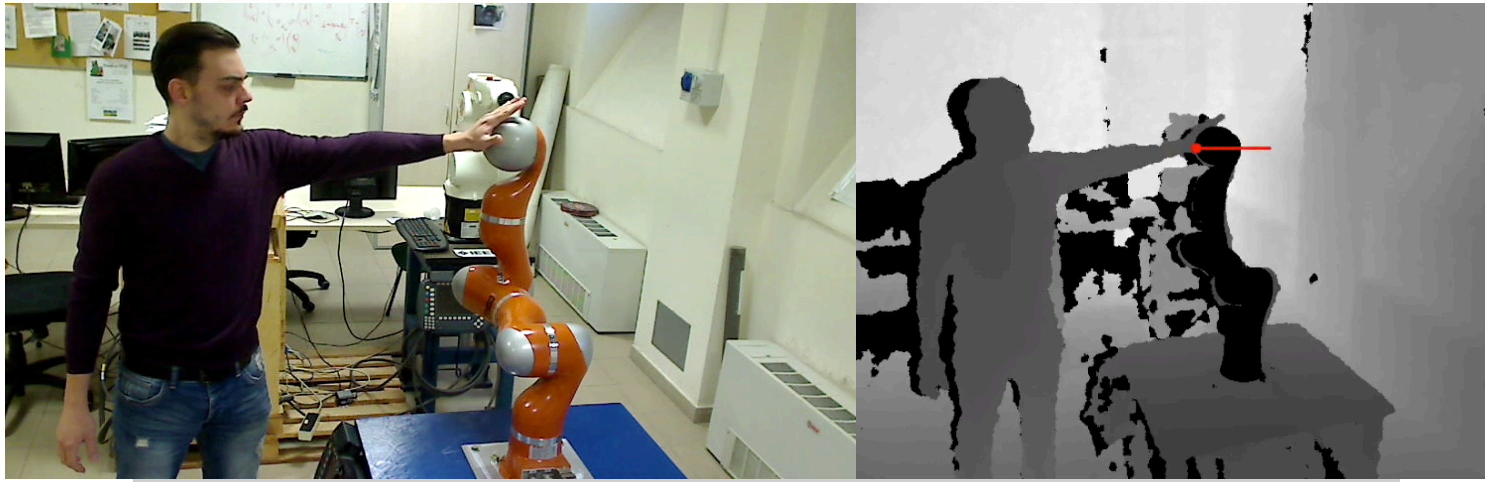
coexistence through collision avoidance

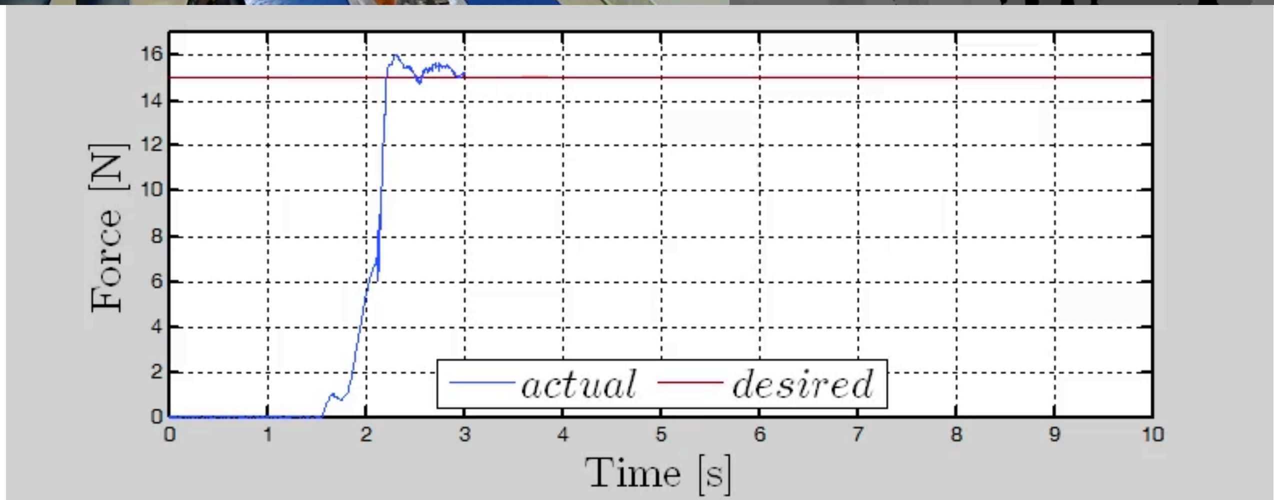
physical collaboration through contact identification (here, end-effector only)

On-line estimation of contact forces

Contact force regulation with a "virtual" force sensor

- contact force estimation & control (anywhere/anytime)

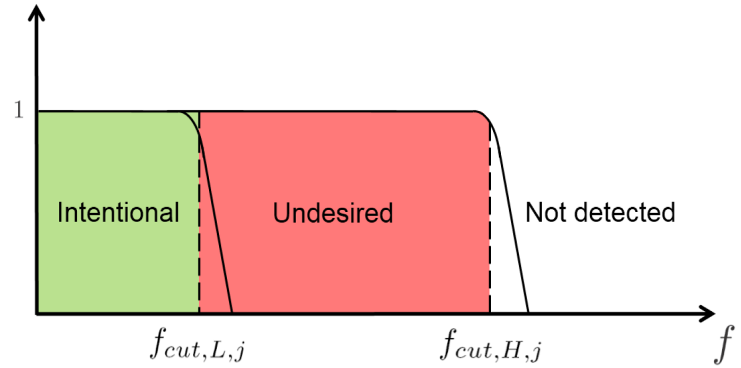


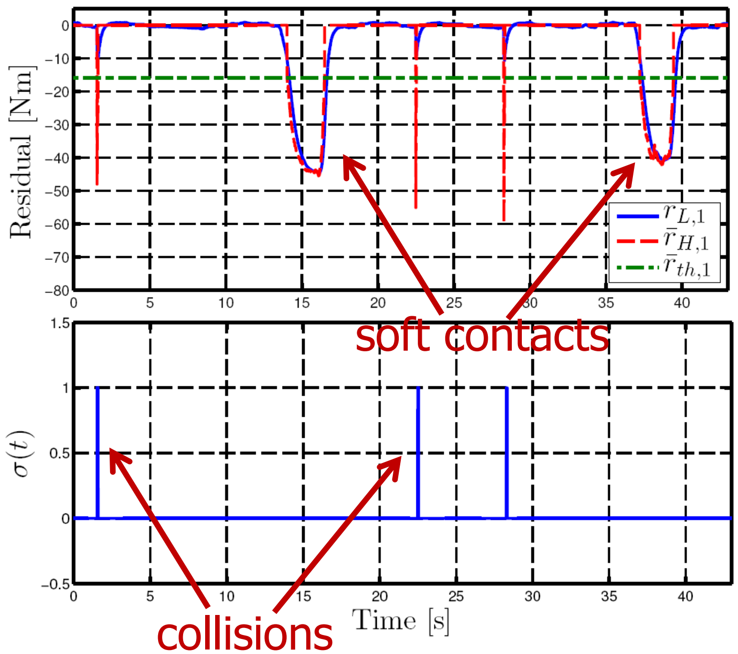


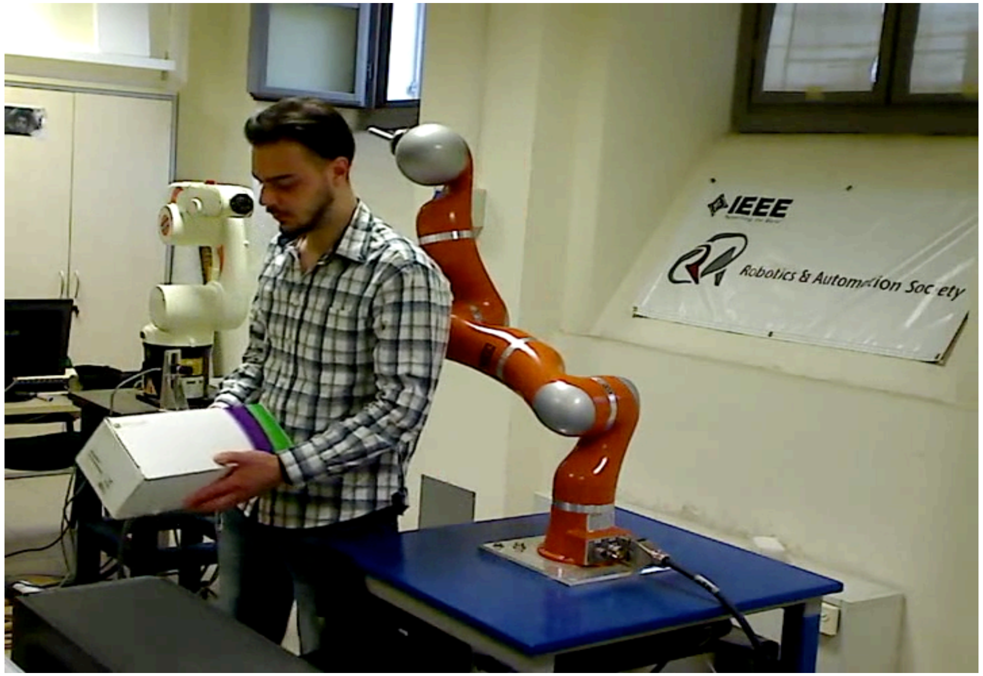
Collision or collaboration?

- hard/accidental collisions
- soft/intentional contacts

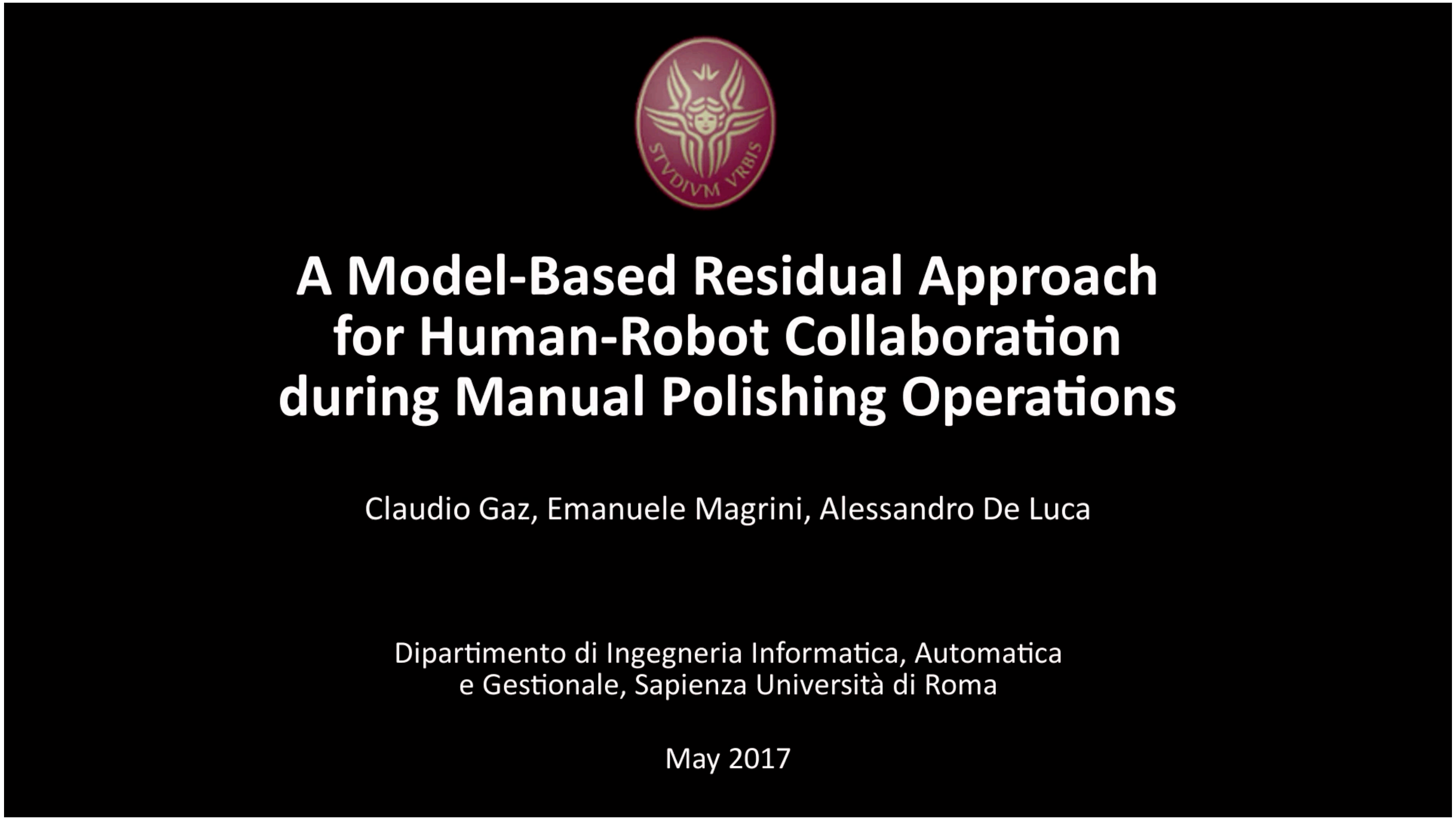
distinguished with a frequency analysis of a model-based signal ("residual")







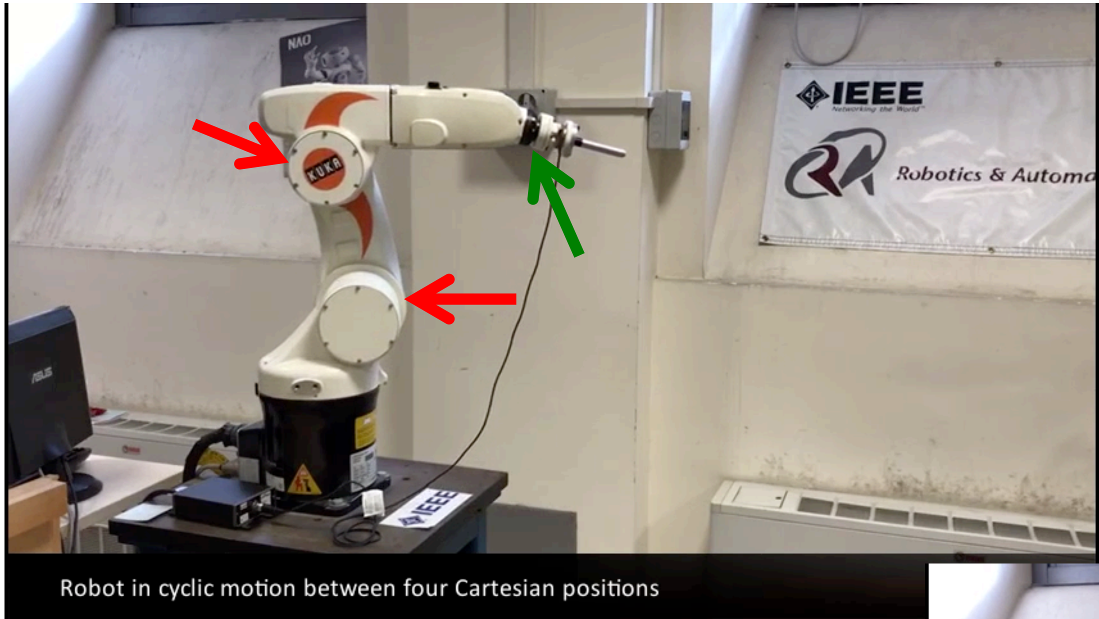
Selected reactions to contact forces

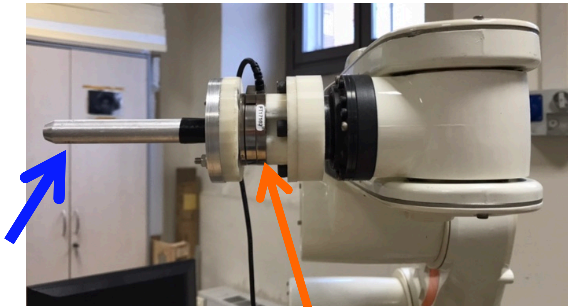


6-dof **Universal Robots UR10**
collaborative robot with F/T sensor

SYMPLEXITY

… also on conventional industrial robots

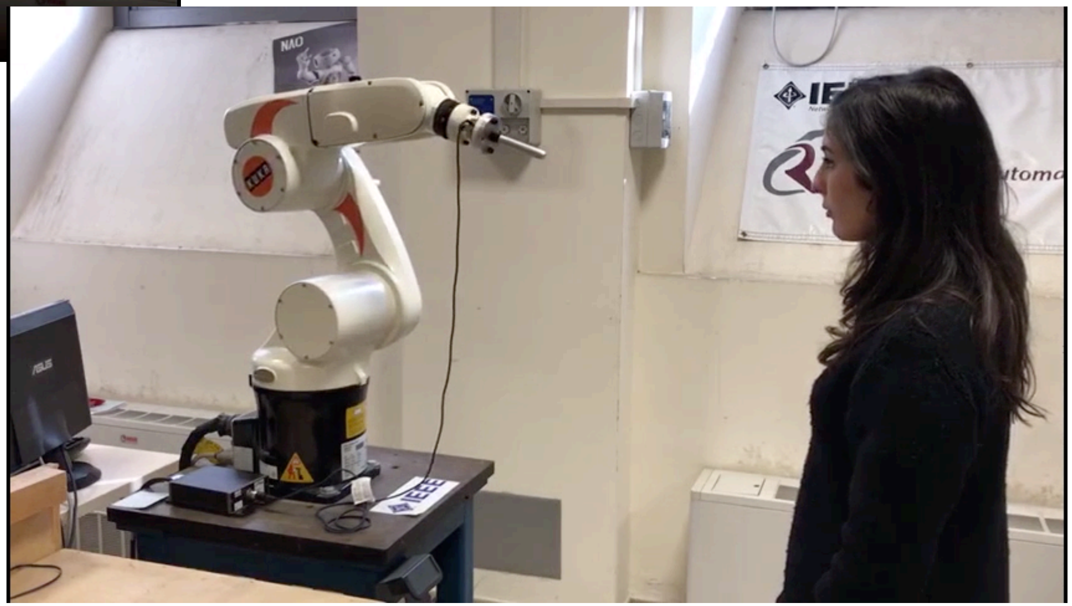




intentional forces at end-effector

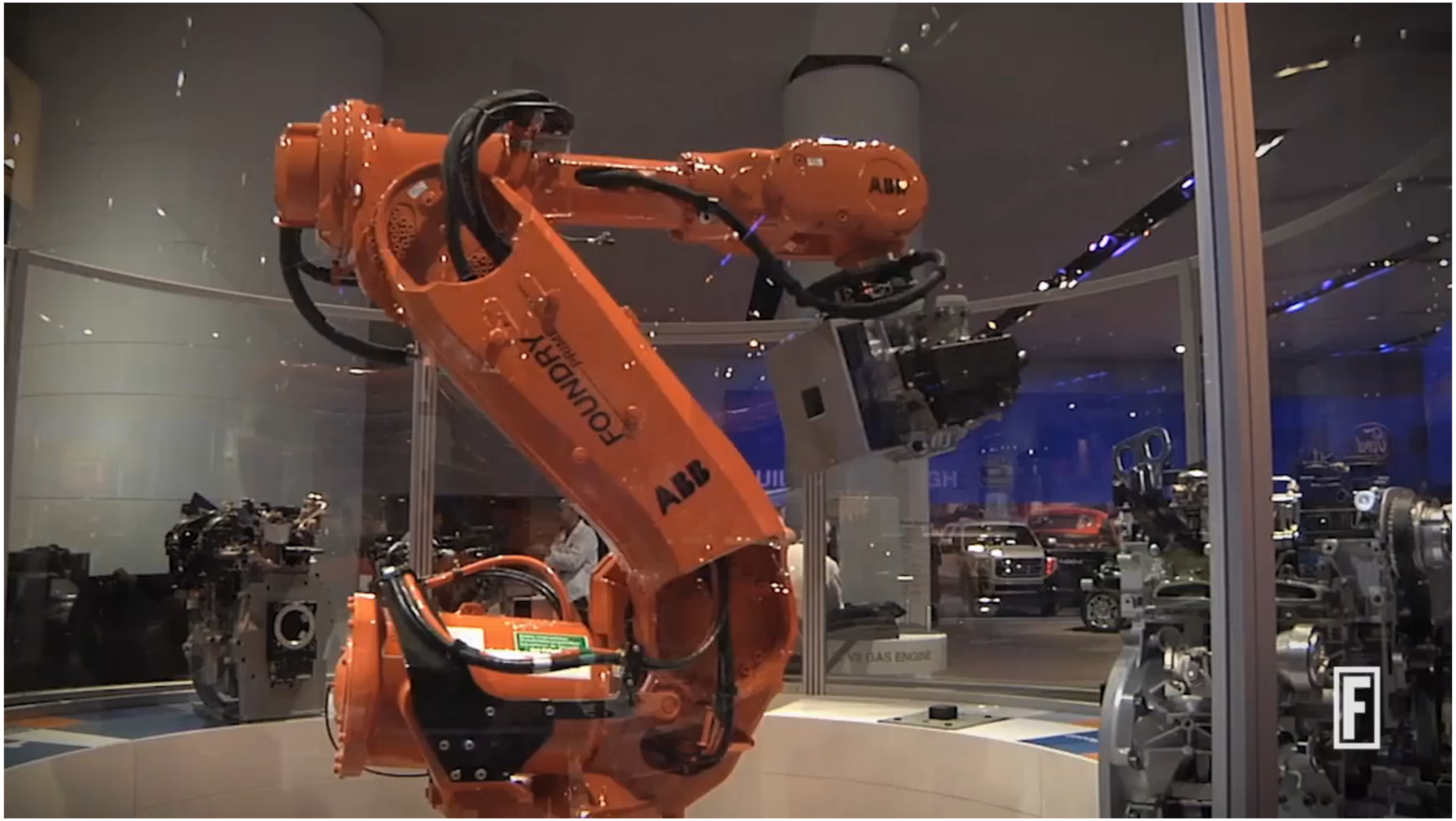
ATI Mini45 F/T sensor

intentional contacts
and/or collisions
may occur **anywhere**



6-dof **KUKA KR5 Sixx** with
a closed control architecture
and RSI interface at $T_c = 12$ ms

Robots as job killers?



Source: Fortune

Jobs lost… Jobs gained

McKinsey Report 2017

Poche occupazioni sono interamente automatizzabili, anche se il 60% di tutte le occupazioni hanno almeno il 30% delle loro attività che sono automatizzabili (già con le attuali tecnologie)

Esempi di occupazione

addetto macchine tessili, selezionatore di prodotti agricoli

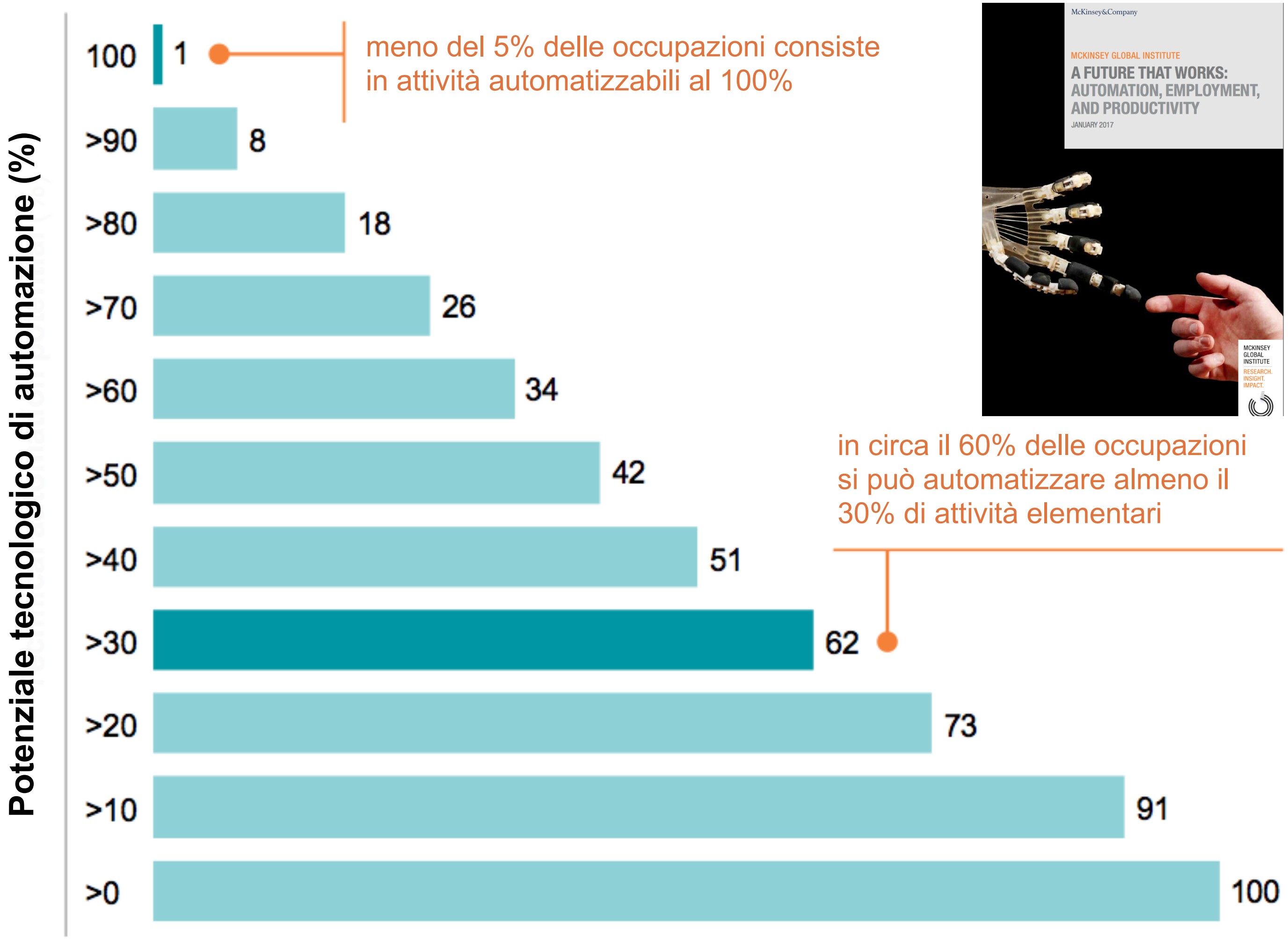
magazziniere, agente di viaggi, riparatore di orologi

tecnico chimico, aiuto infermiere, sviluppatore web

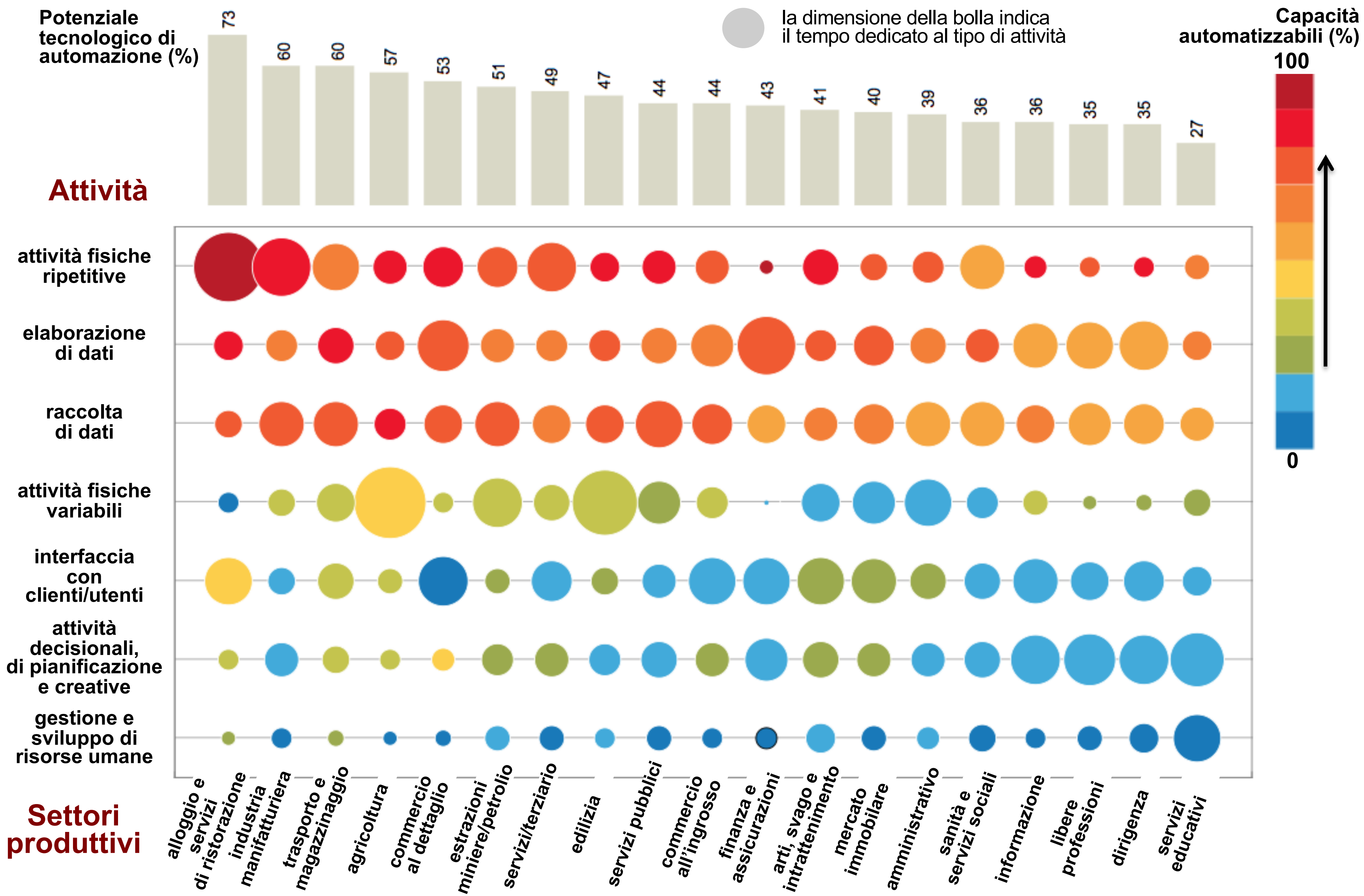
disegnatore di moda, amministratore delegato, statistico

psichiatra, legislatore

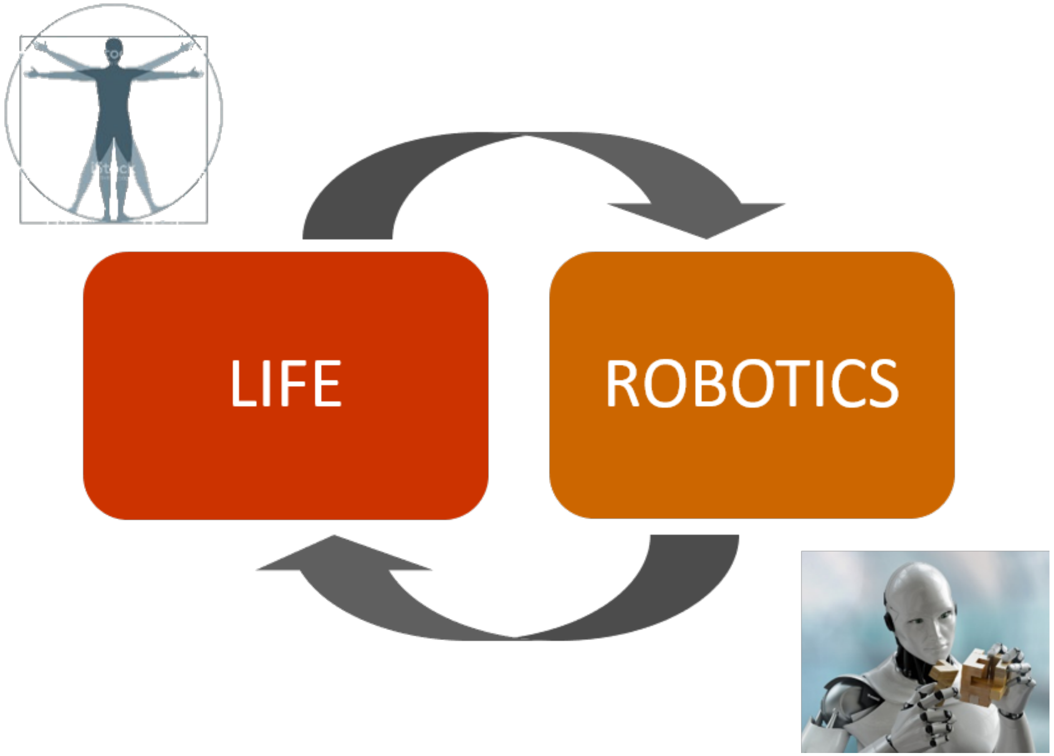
Accumulo percentuale (%)
100% = 820 tipi di occupazione considerati, con oltre 2000 attività elementari



Diversi settori, diversi mix di attività, diversa automazione ...



Robots and humans

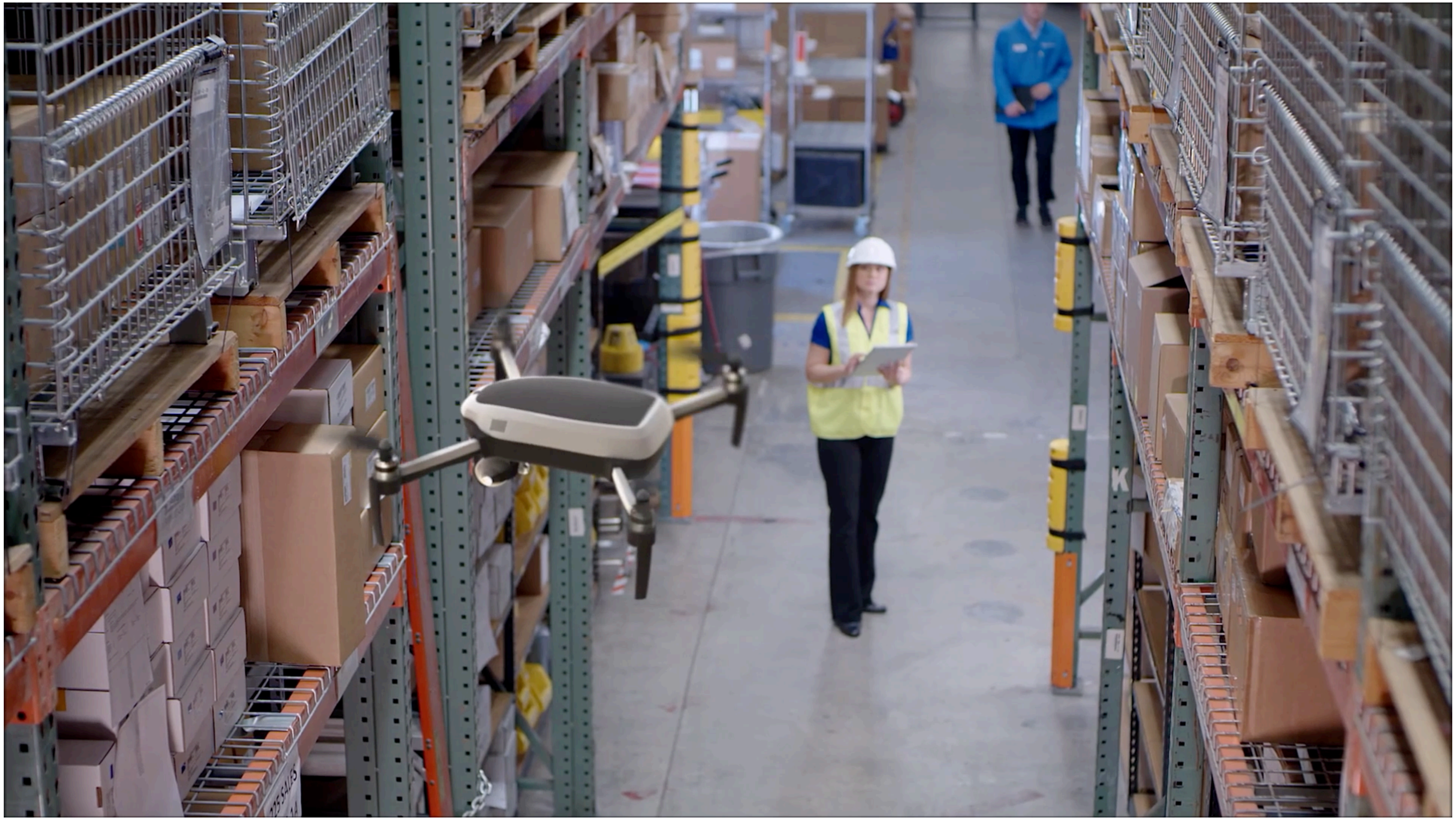


A future where robots are more social than solitary

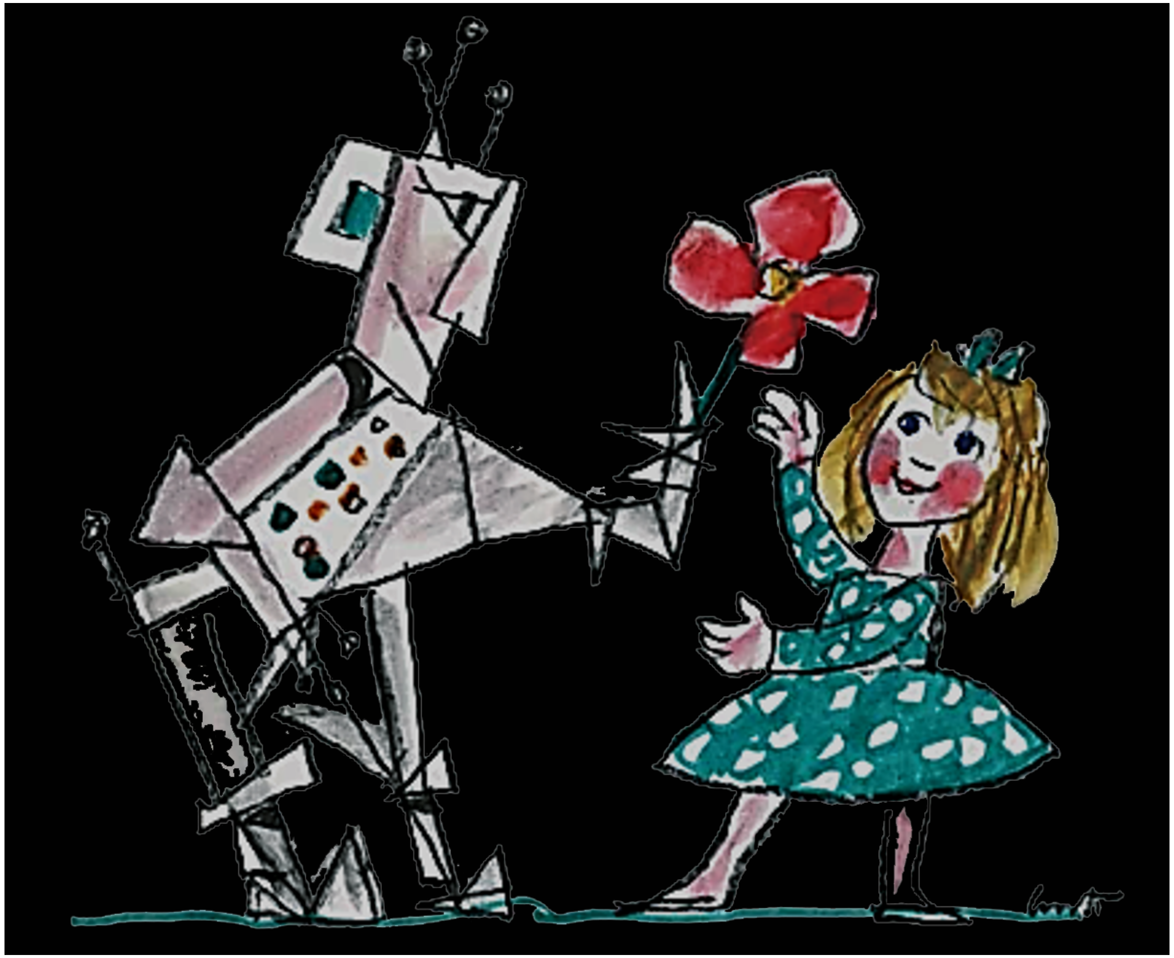
Robots will enhance human work and life rather than replace us in our homes, hospitals, factories, farms and freeways

From Information & Communication Technology (ICT) to InterAction Technology (**IAT**)

From Internet of Things (IoT) to Internet of Skills (IoS)



Roboethics



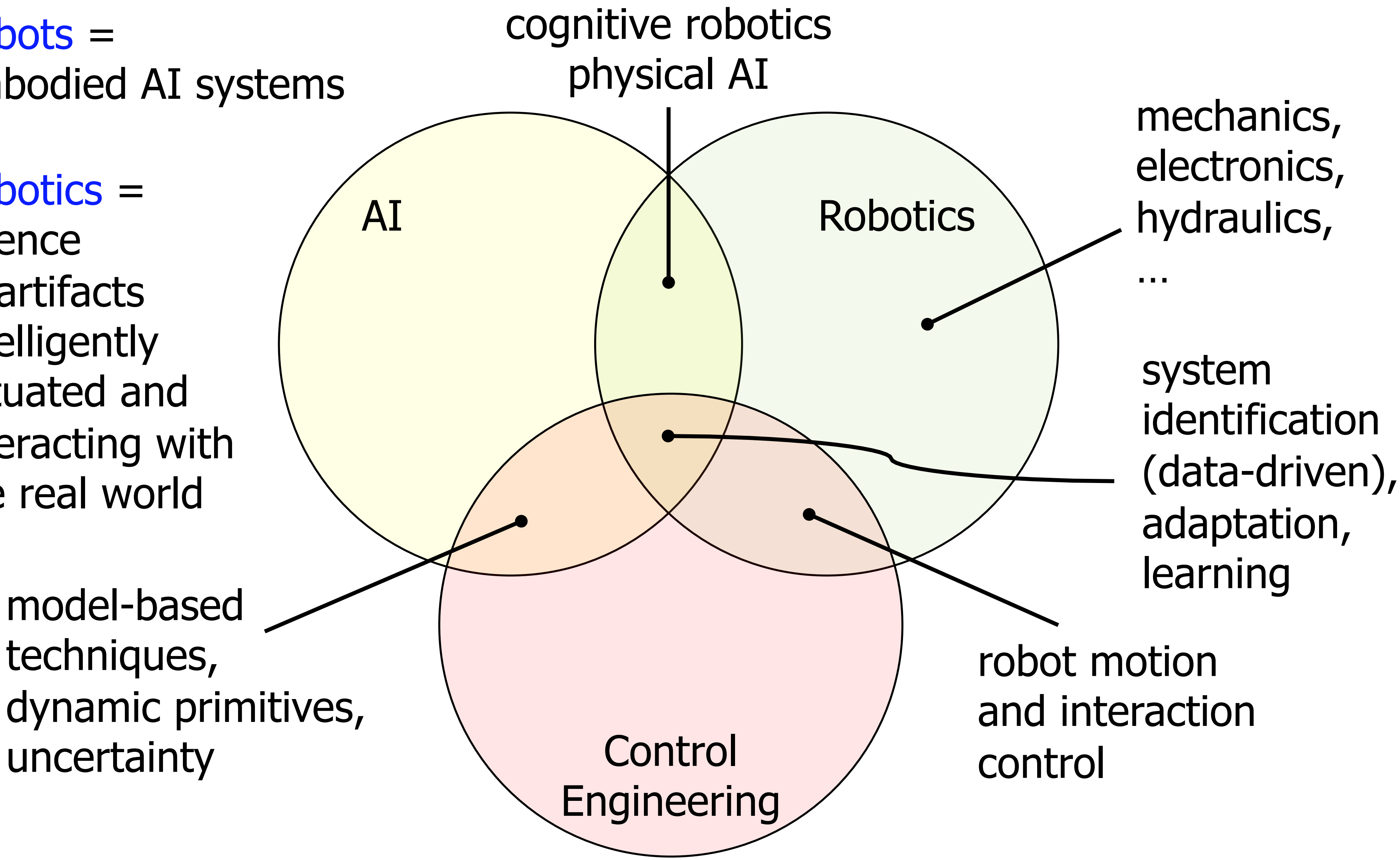
Ethical, legal and societal issues for design, construction and use of robots

Cohabitation of humans with robots

Next generation of intelligent robots?

Robots =
embodied AI systems

Robotics =
science
of artifacts
intelligently
actuated and
interacting with
the real world



References

- research papers (open in IRIS)
  - http://www.diag.uniroma1.it/deluca/Publications.php
- YouTube channel DIAG Robotics Lab with our research videos
  - www.youtube.com/user/RoboticsLabSapienza
  - see in particular the playlist: Physical Human-Robot Interaction
- web sites of courses
  - Robotics 1 www.diag.uniroma1.it/deluca/rob1_en
  - Robotics 2 www.diag.uniroma1.it/deluca/rob2_en
- YouTube channel Video DIAG - Sapienza
  - www.youtube.com/channel/UCbaID7wz_ATPrddPkYlVK1w
  - playlist Robotics 1: video-lectures 2014-15
  - playlist Robotics 2: video-lectures 2019-20
- email deluca@diag.uniroma1.it