Collaborative Robots in Manufacturing

2020-10-23, Mikael Hedelind

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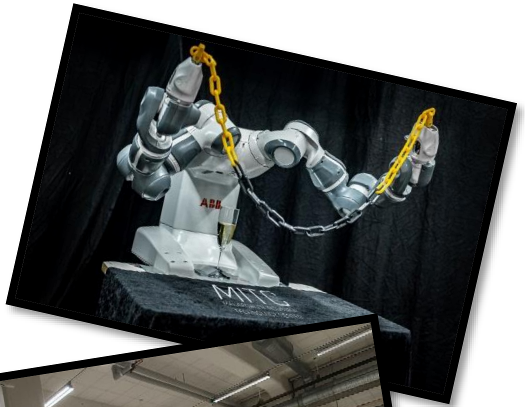
Mikael Hedelind

- MSc in computer science, focused on artificial intelligence
- Licentiate engineer in Innovation and design, focused on applied industrial robotics
- Worked as project manager in industry for over 10 years
  - R&D industrial robotics
  - Coordinator of EU projects in robotics and human-robot collaboration
- Worked as a programme manager at Vinnova for two years
- Now working mostly as part of Mälardalen Industrial Technology Center



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MÄLARDALEN INDUSTRIAL TECHNOLOGY CENTER

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Overview

- What is industrial robotics?
- .. and why?

- New “collaborative” type of robots
  - What’s new?

- How can they be used?
  - And where?

- What’s ongoing in the field?

World Robotics
Industrial Robots
2 0 2 0
one market

World Robotics 2020 – Industrial Robots

Produced by VDMA Services GmbH, Lyoner Str. 18, 60528 Frankfurt, Germany.

The robot statistics are based on consolidated world data reported by robot suppliers as well as on the statistics of the national robot associations of United Kingdom (BARA), Peoples Republic of China (CRIA), Denmark, (DIRA), Japan (JARA), Republic of Korea (KAR), Russian Federation (RAR), North America (RIA), Italy (SIRI) and Chinese Taipei (TAIROA).

The cover is sponsored by Stäubli AG.

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We express our most sincere gratitude to all partners!

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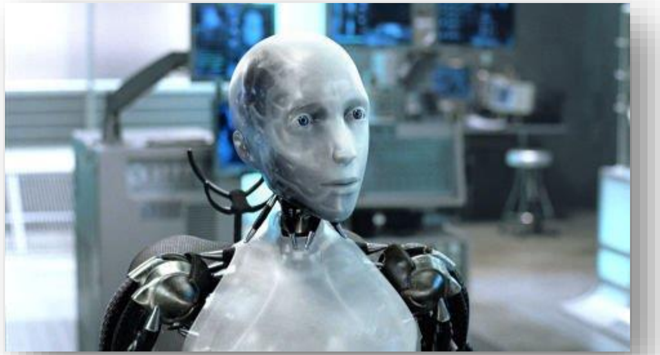
·ria
Robotic Industries Association


Vägledning för tillämpning av maskindirektivet 2006/42/EG
Andra utgåvan
Juni 2010
Huvudredaktör
Ian Fraser
INTERNATIONAL STANDARD
ISO 10218-1
Robots and robotic devices — Safety requirements for industrial robots —
Part 1:
Robots
INTERNATIONAL STANDARD
ISO 10218-2
Robots and robotic devices — Safety requirements for industrial robots —
Part 2:
Robot systems and integration
ISO/TS 15066:2016
Robots and Robotic Devices - Collaborative Robots

Robotics

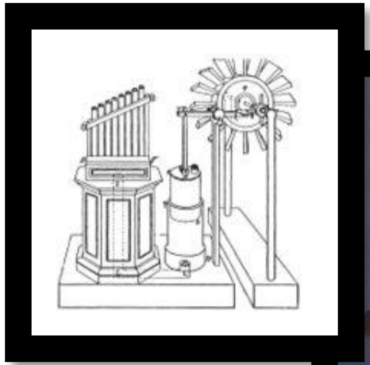


1921 - Karel Čapek - Rossum's Universal Robots

1942 – Isaac Asimov - Runaround, first to use the word robotics

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 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.

Zeroth Law: "A robot may not harm humanity, or, by inaction, allow humanity to come to harm;"



Hero (or Heron) of Alexandria – ”aeolipile” – First documented steam engine and a wind organ

Jaquet Droz “The Writer” Automata

10-70

1774

Robot

Characteristics

A robot is a *mechanical* or *virtual, artificial agent*.

Characteristics of a robot:

- Is not 'natural' - it has been **artificially created**
- Can **sense** its environment
- Has some degree of intelligence, or **ability to make choices** based on the environment, or automatic control / pre-programmed sequence
- Is **re-programmable**
- Can **manipulate** things in its environment
- Appears to have intent or **agency**

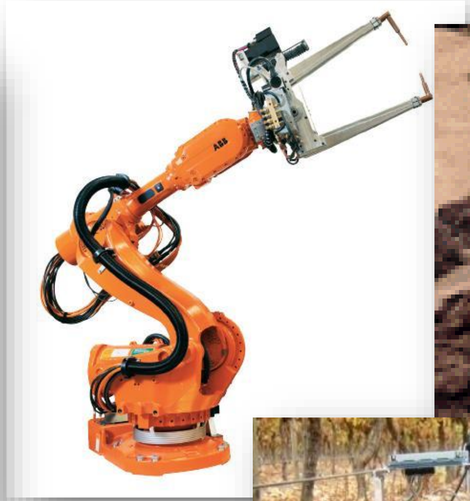
A robot is simply a machine that seems to exhibit "*intelligent behaviour*" by performing an action cued by an external stimulus or cued by an internally programmed instruction.[1]

[1]http://www.asc-csa.gc.ca/eng/educators/resources/robot_type/background_info.asp

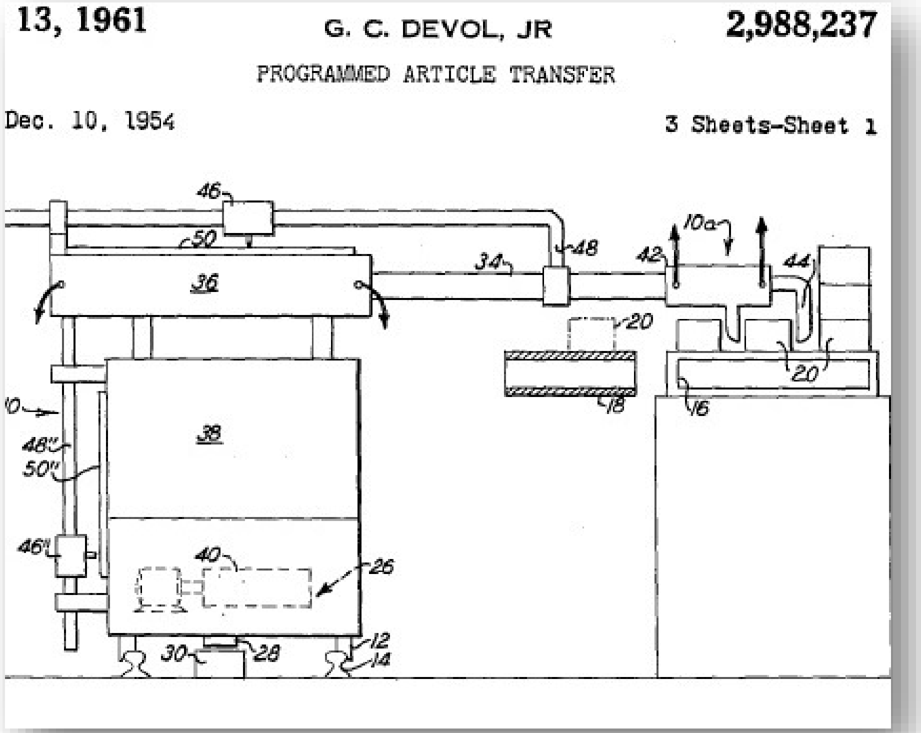
Types of robots

Sample of what is out there

- **Industrial robots**
- Field robots
- Space robots
- Health robots
- Toy robots
- Domestic robots
- Virtual robots
- Humanoid robots
- …



Industrial Robots

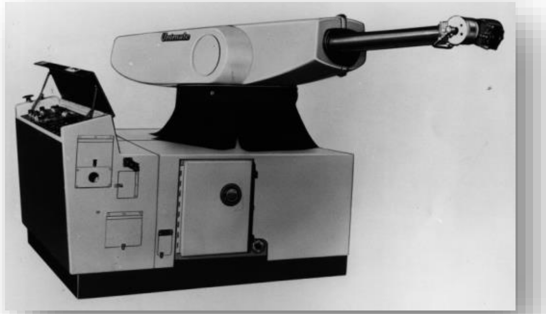


1954 - George Charles Devol Jr. – Unimate
"You know, there aren't many people who get a chance to start a whole new industry"

1960 – Joseph F. Engelberger - ***Unimation*** **sells the first robot to General Motors used for lifting hot metal sheets after die-casting**

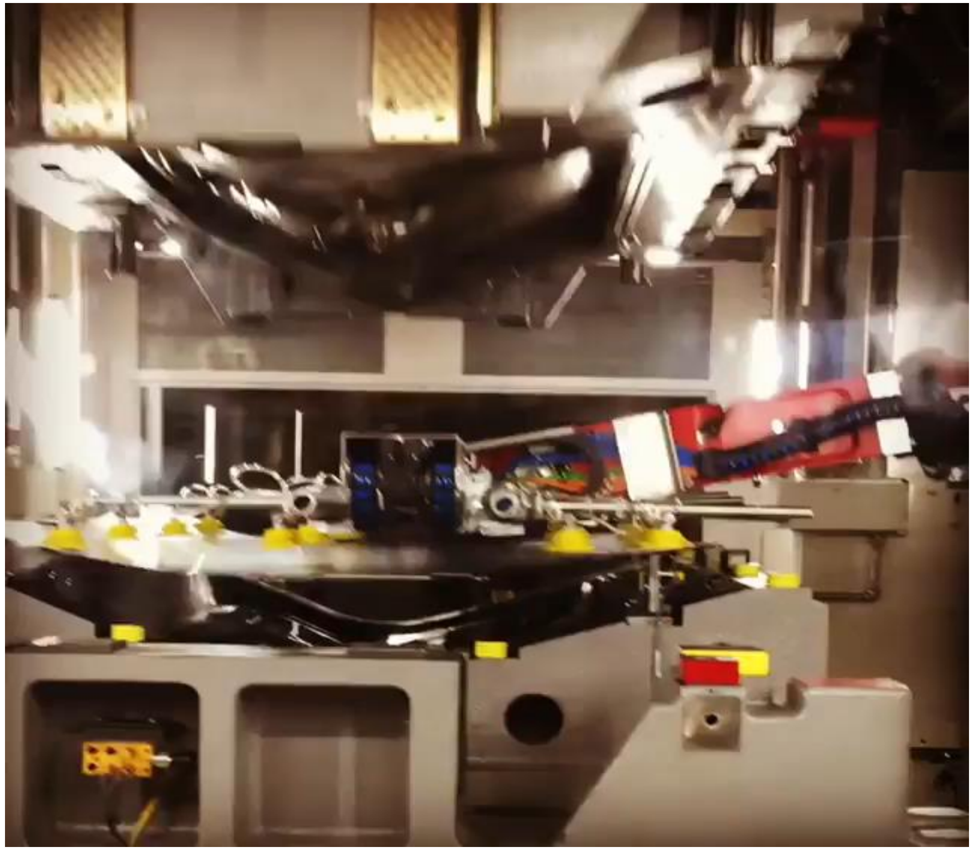
1973 – ASEA – **The first** ***microprocessor controlled electrical robot***

1979 – ***Robert Williams*** **– First human to die by a robot, Ford Motor CO. The robot was supplied by Unit Handling Systems, a division of Litton Industries, had a weight of 1 ton and had no safety systems.**



Why industrial automation?

Dull, Dirty, Dangerous



Industrial Robots

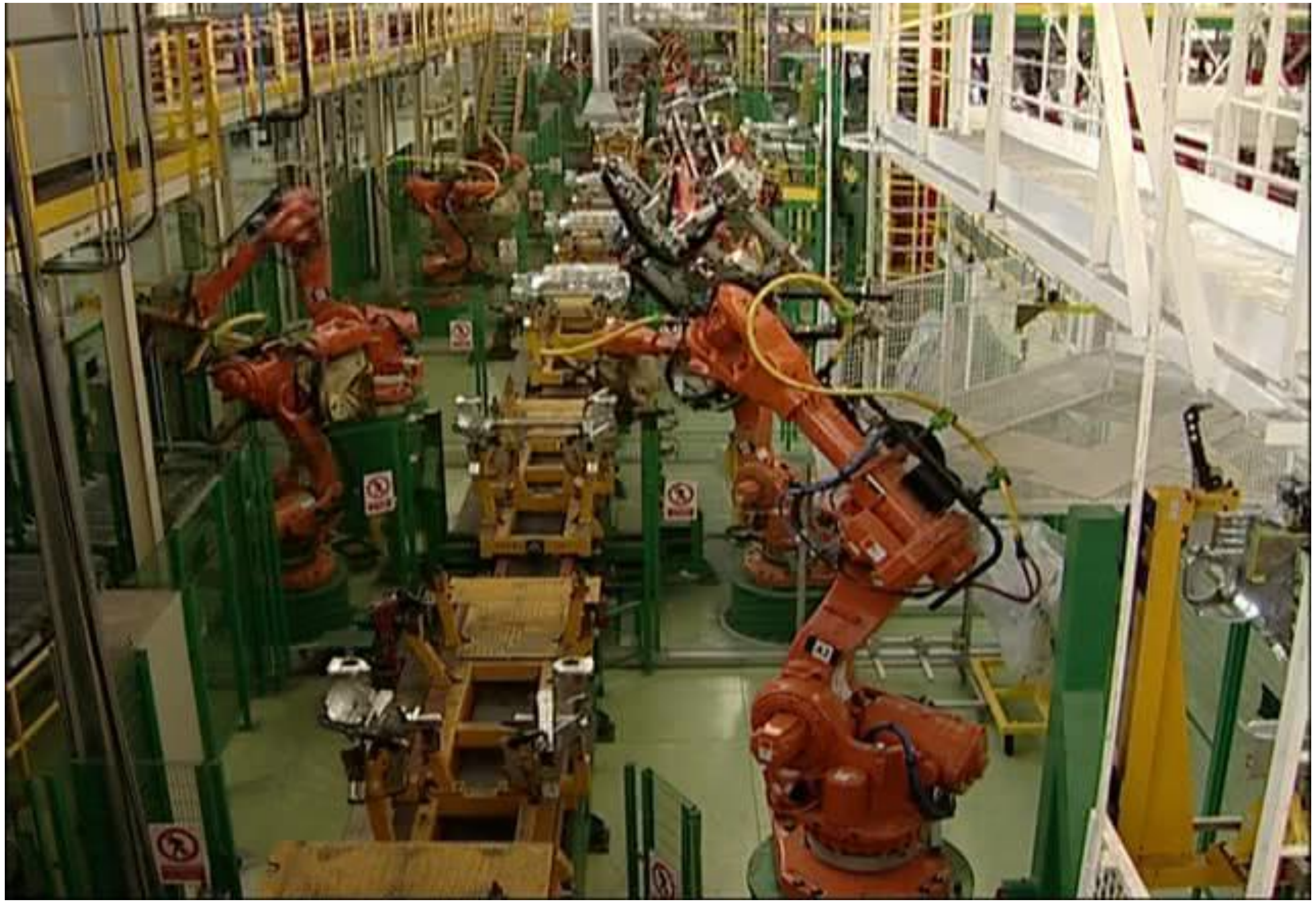
Development has mainly been driven by the needs of the **automotive industry**

First robots were made for **machine tending**, but the one main application has been **welding** and other **body in white operations**

General industries and consumer industries becomes more important

The robot systems get **more and more sophisticated**

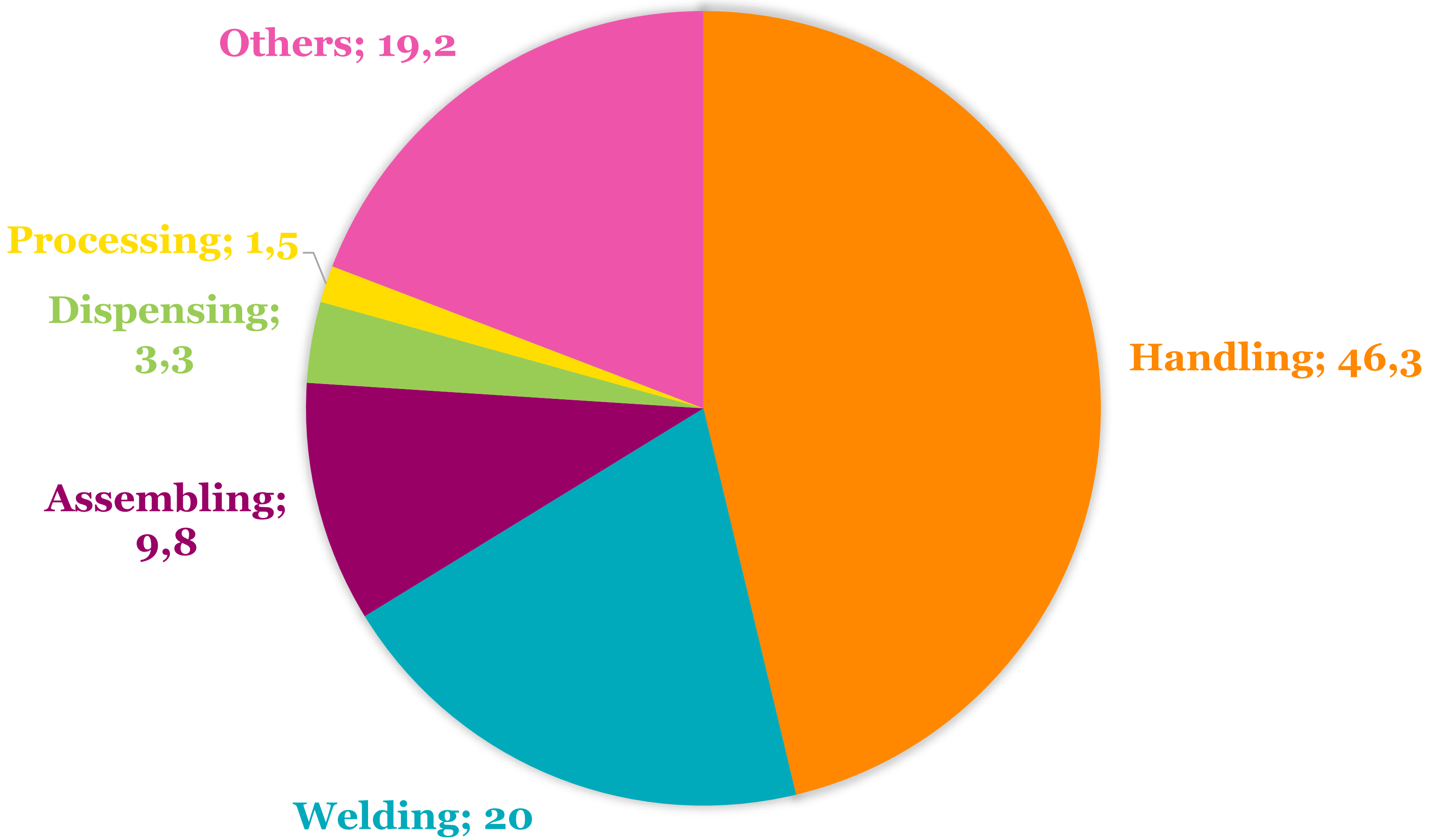
Increasing amount of software involved



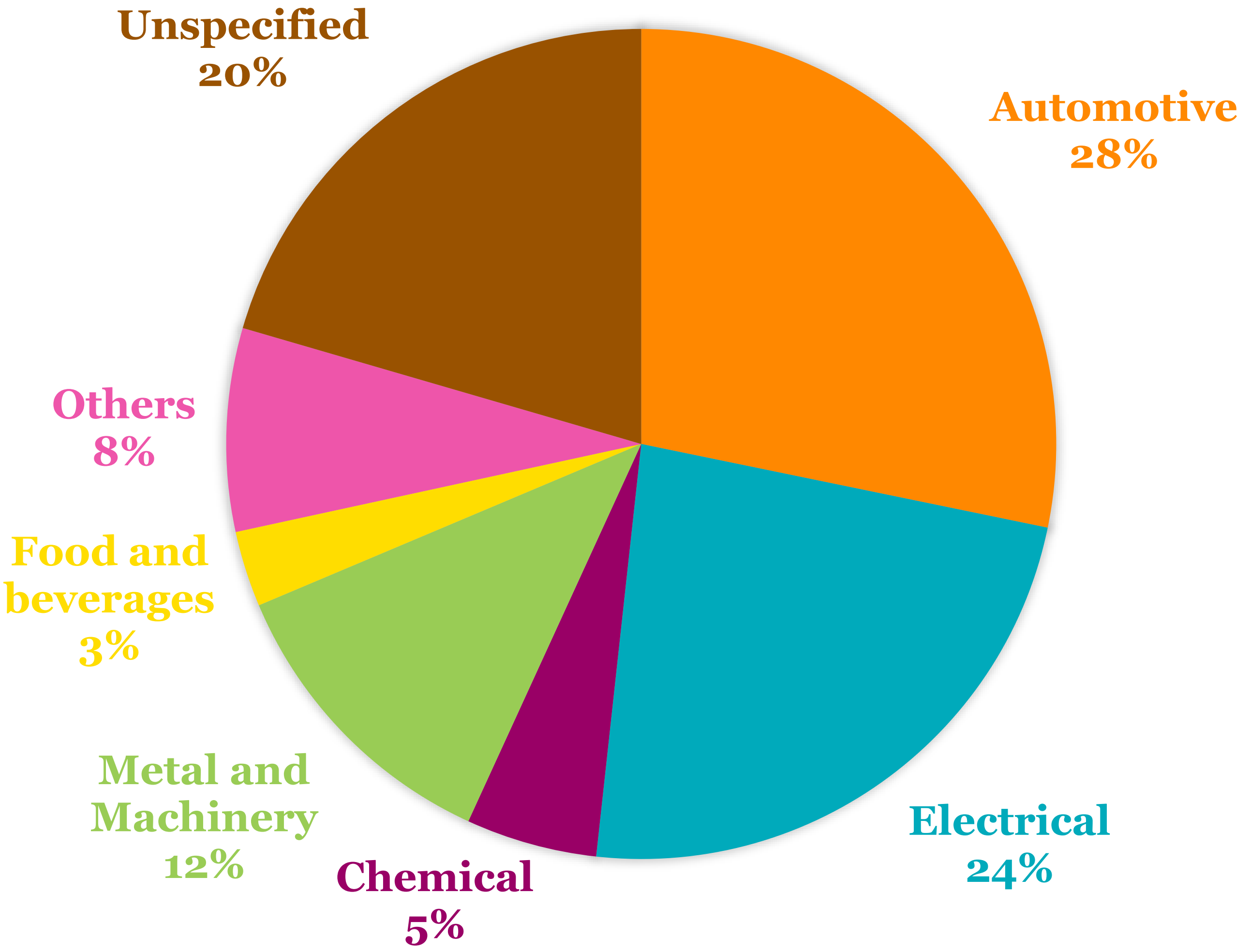
Some data for 2019

- 2019 saw the first decline after six consecutive years of growth, with approximately 373,000 units sold in 2019 (-12% compared to 2018).
- The decline was broad -based across all regions- with Asia and the Americas both down -13% followed by Europe -5%, reflected in almost all industries, led by declines in Electrical & Electronics -17% and Automotive -16%.
- China remained the largest market accounting for 38% of total worldwide installations, despite fewer units sold (-9%), followed by Japan with 13% and United States with 9% of total installations.
- By the end of 2019, approximately 2.7 million units (+12% compared to 2018) of industrial robots have been in operation worldwide.

ROBOTS PER APPLICATION (%), 2019



ROBOTS PER INDUSTRY, 2019



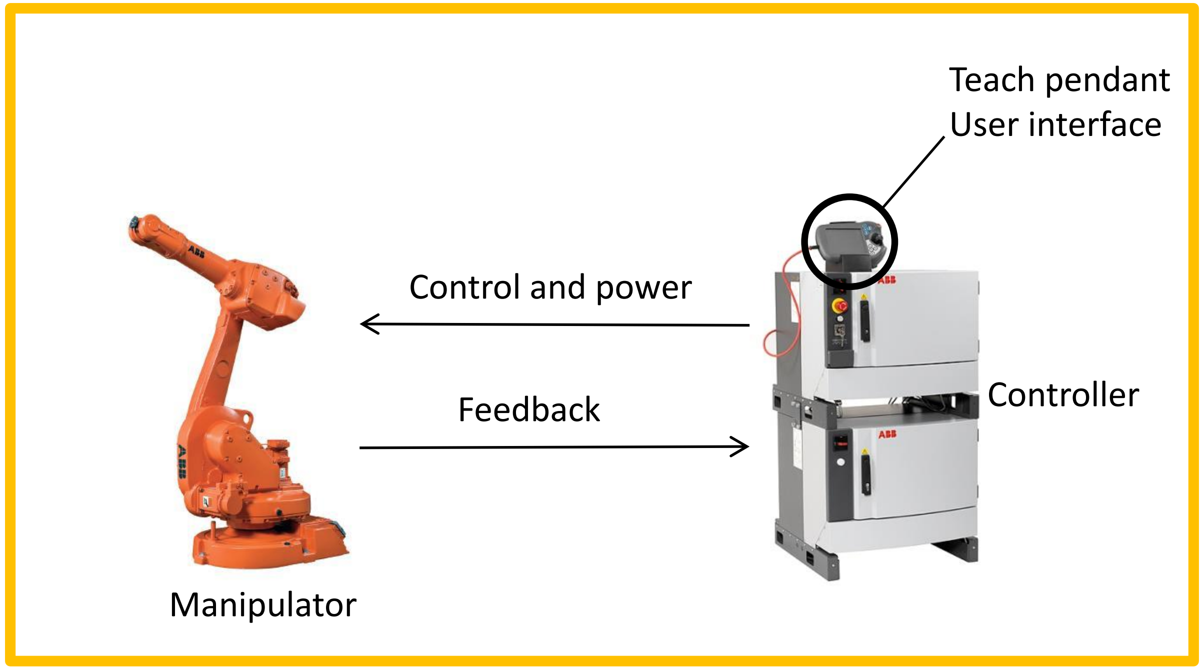
2020 and forward

- While COVID- 19 is the greatest single catalyst for change in industry in a generation, it hasn't started any new trends. Instead, it has **accelerated four mega-trends** that are fundamentally changing the face of manufacturing in the long-term: the **individualized consumer**, **labor shortages**, **uncertainty** and **digitalization**.

- Technology, in the shape of **robotics and automation**, and enabled by **artificial intelligence**, offers many solutions to the challenges presented by these four mega-trends – and by major events such as the pandemic. The pace of change and adoption of robotics driven by AI is accelerating -- from the largest global blue-chip companies to the smallest workshops and SMEs.

Robot System

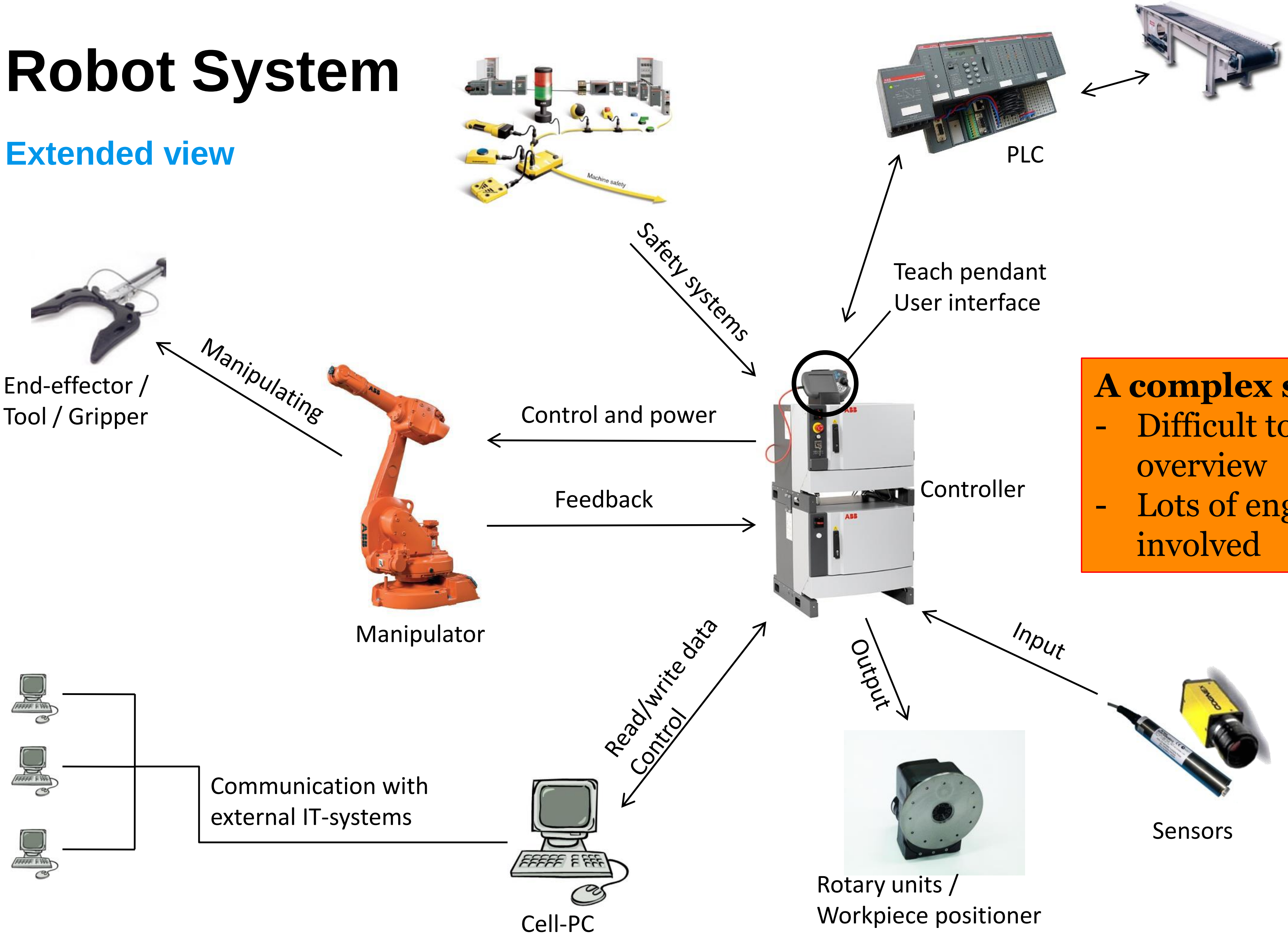
What is included?



Robot System

Robot System

Extended view



A complex system;
- Difficult to get an overview
- Lots of engineering involved

How to buy a robot?

- **Most robots are sold through a tier business model**
  - Robot manufacturer
  - System integrator
  - End user

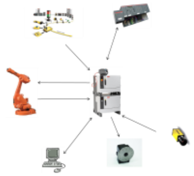
- **System integrator**
  - Buys the robot from the manufacturer
  - Builds a system that contains the robot
  - Installs the robot system at the end user

"Naked robot"

Engineering of tools and peripheral equipment

Programming (Robot/PLC)

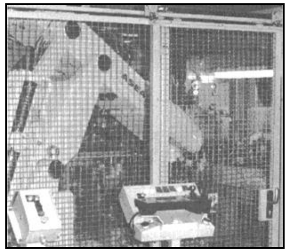
System integration and test (FAT/SAT)



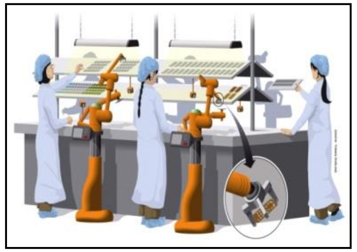
Productive operation

Maintenance & Service

Evolution of safety concepts







absolute separation
of robot and human
workspaces

complete union
of robot and human
workspaces

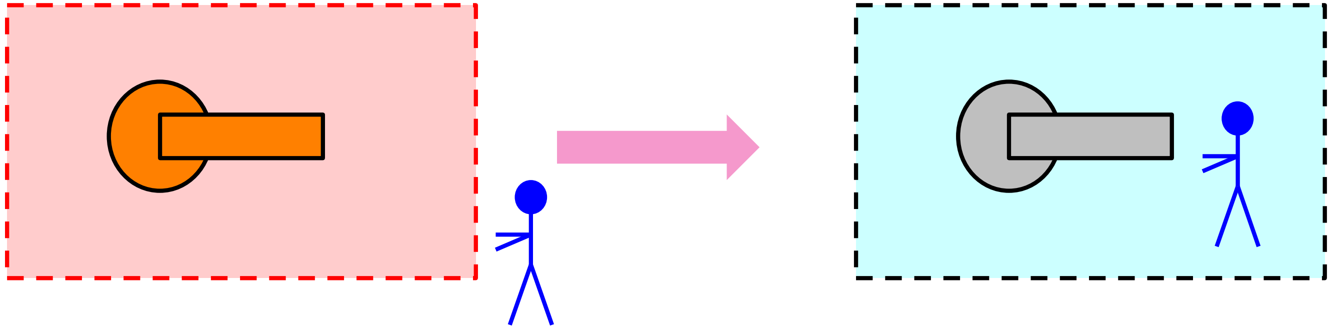
Discrete safety
→ No HRC

Safety controllers
→ Limited HRC

Harmless manipulators
→ Full HRC

Conventional industrial robots

Collaborative industrial robots



First HRC applications

Human strengths

- Cognition
- Reaction
- Adaptation
- Improvisation

Robot strengths

- Force
- Repeatability
- Quality

Safety

Purpose
The directive, which is about product safety, means that safety must be integrated in the product in all phases, from design to usage.

In short the following three step principle should be applied:

1, Design to ensure safety
2, Protect the user from all dangerous parts/components
3, Warn the user of all remaining risks

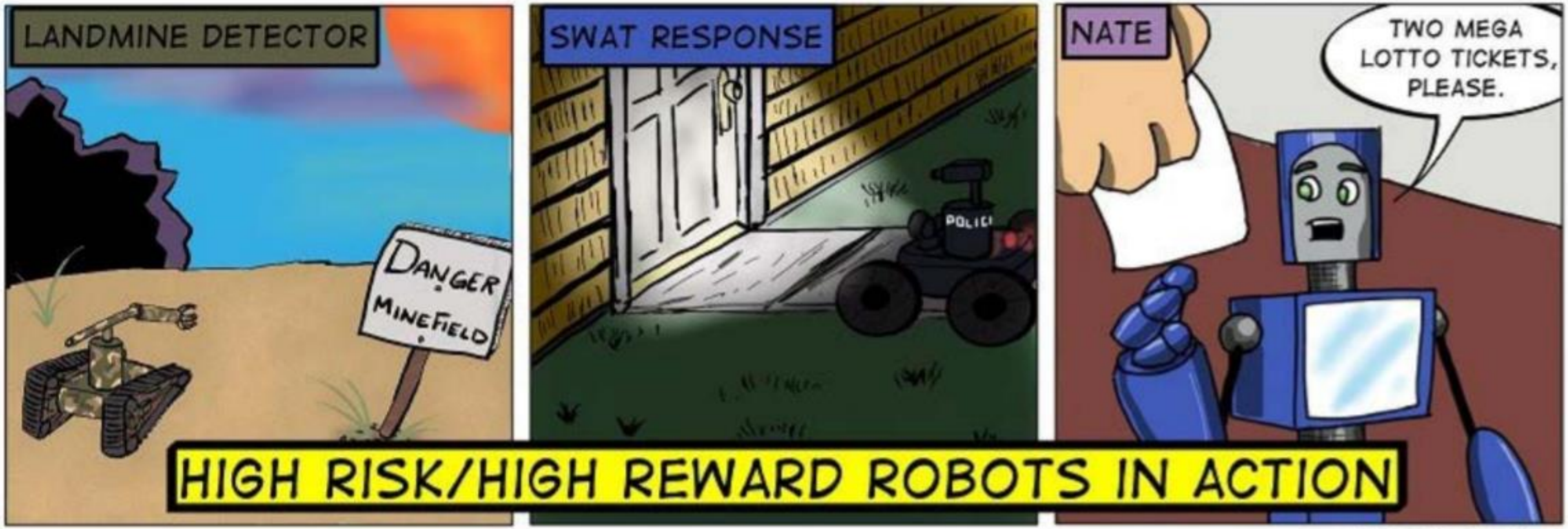
Risk assessment

One way of ensuring safety in a product is to map all possible (foreseeable) risks, their root-cause, effects, and the measures taken to avoid the risks.

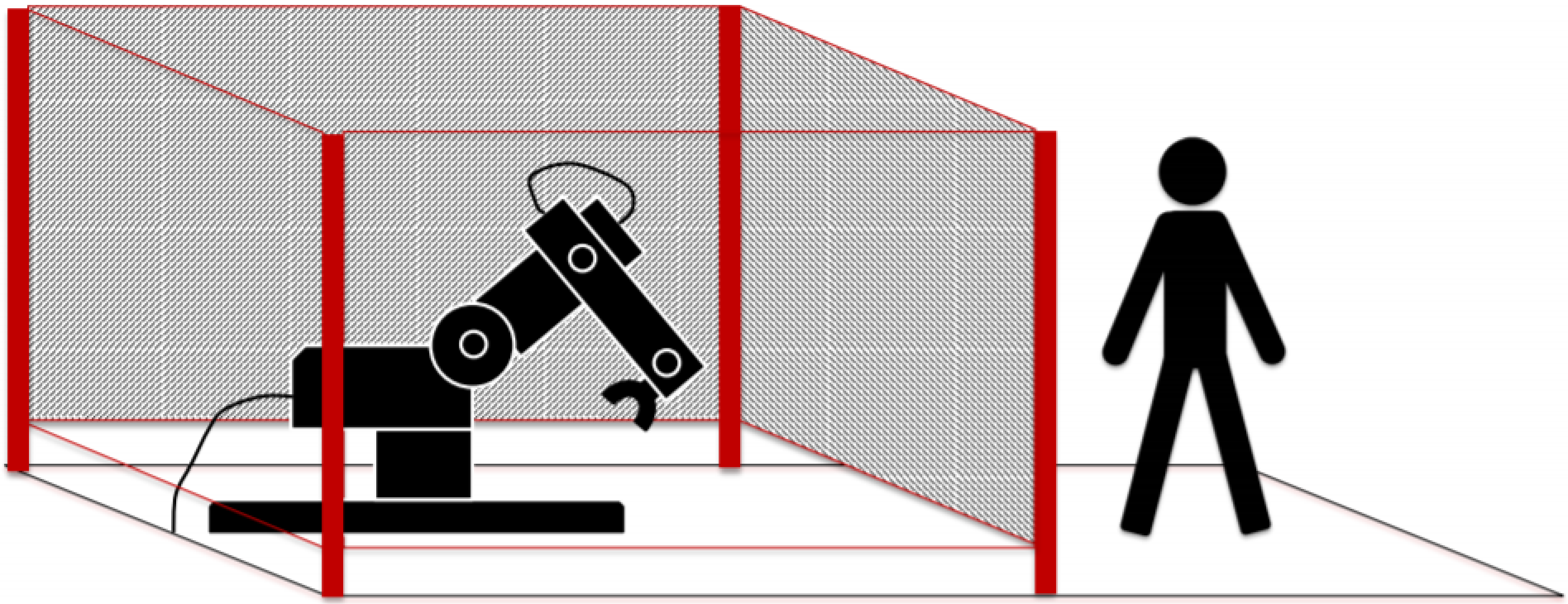
“European machine directive”
Maskindirektivet is included in Swedish law through AFS 1994:48

What is risk?

RISK = Likelihood * Consequence

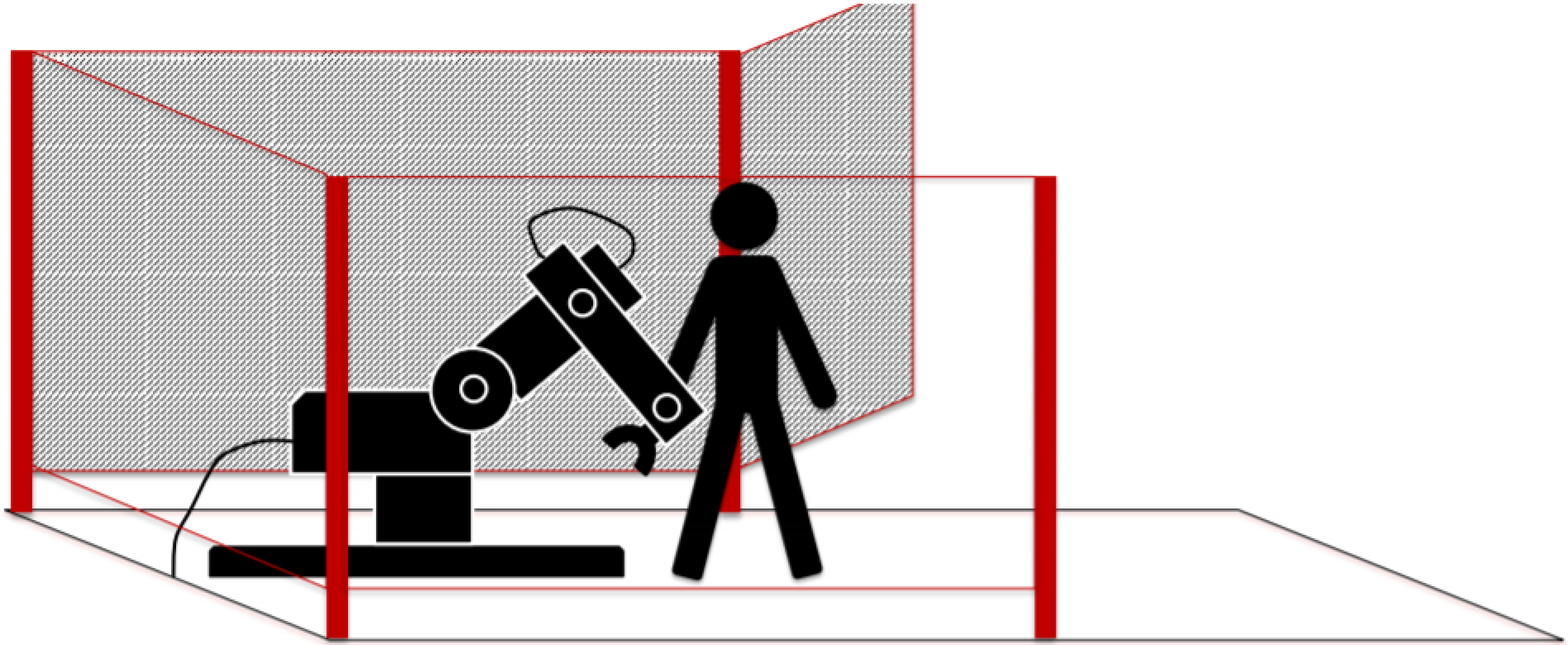


Traditional Industrial Robot Risk Reduction



In production operation or automatic mode, operators are prevented from accessing the machine with safeguarding devices.

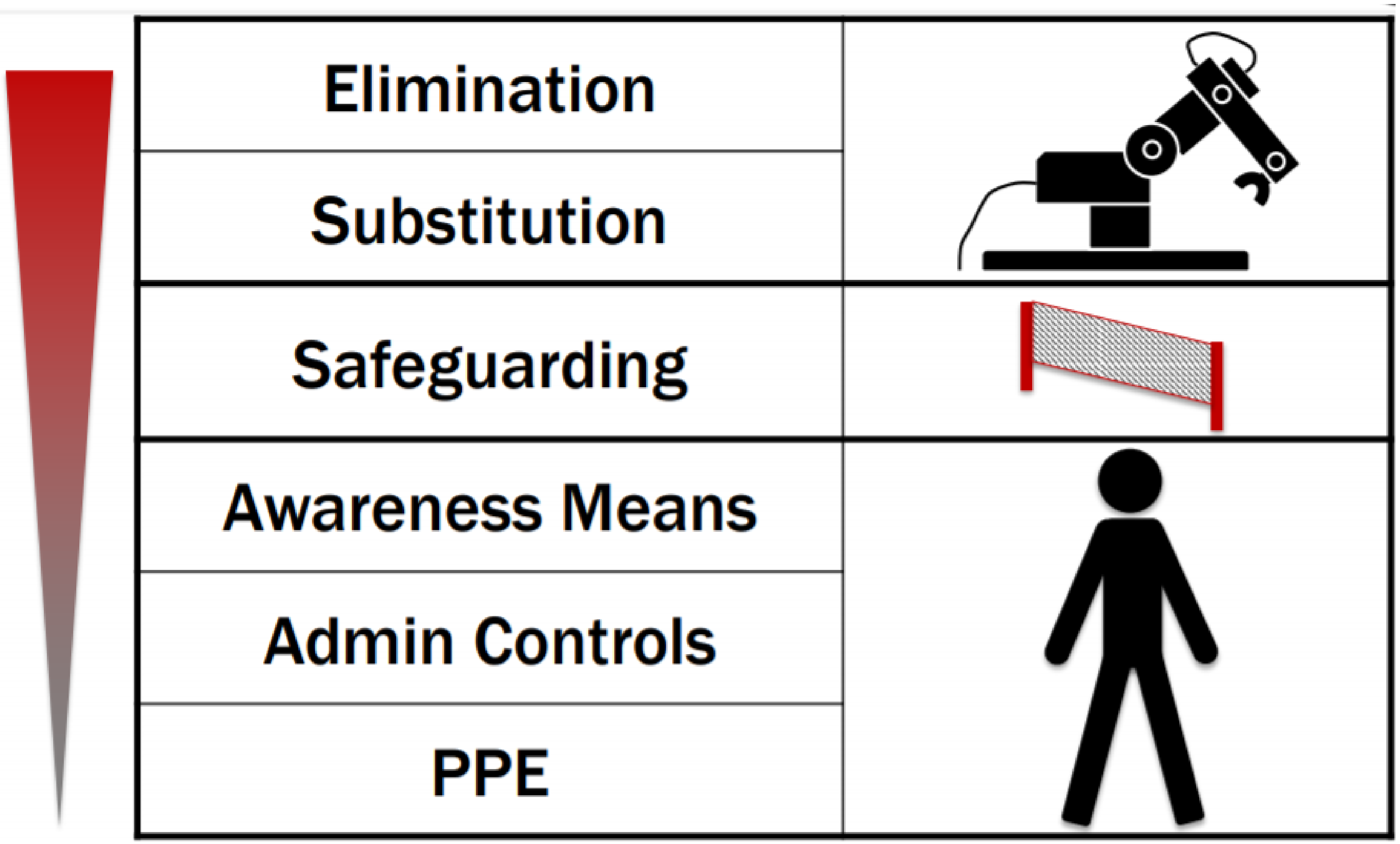
Traditional Industrial Robot Risk Reduction



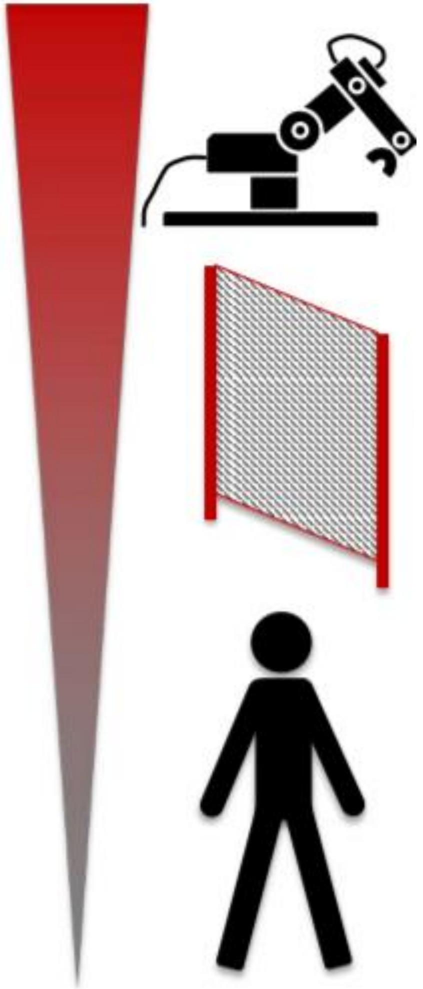
Accessing the machine requires:

- removing the safeguards, and
- limiting, controlling or eliminating the machine's energy

Hierarchy of risk reduction



Hierarchy of risk reduction



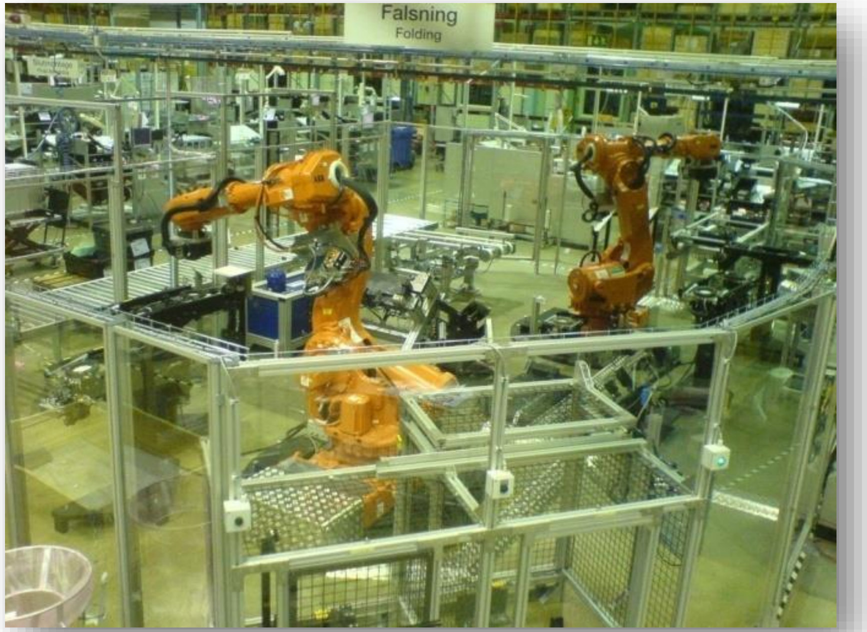
The EU machine directive and other regulations require machine manufacturers to provide guarding to protect operators and employees from hazards.

Consensus standards (ISO, ANSI, CSA) provide guidance for the safe integration and application of machinery, but presume safeguarding is necessary to reduce risk.

Awareness means, administrative controls and PPE are an effective means of reducing residual risk AFTER hazards are reduced through engineered means.

Safety

Inner and outer safety



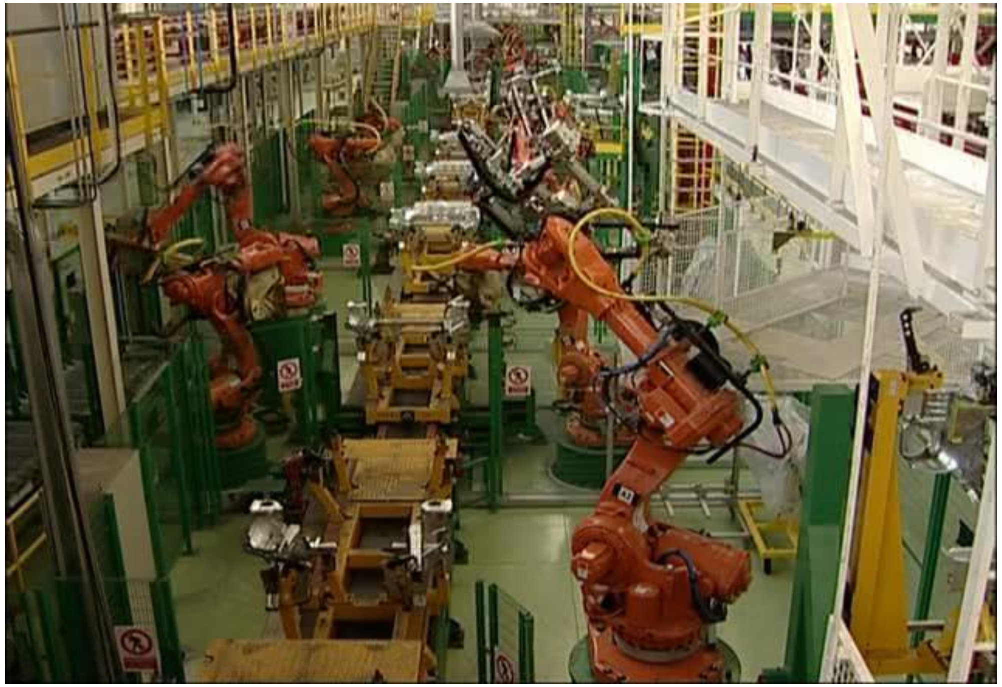
Outer Safety

- Safety relays / sensors
- Light beams / light curtains
- Physical fences/walls

Inner safety

- Three position “hold-to-run” device
- Reduced speed
- Training!!!

Traditional industrial robots vs. Collaborative industrial robots



What is a Collaborative Robot?

- IFR definition:

A collaborative industrial robot is an industrial robot that is designed in compliance with ISO 10218- 1 and intended for collaborative use.

Notes on ISO 10218-1:2011

- ISO 10218-1:2011 specifies **requirements and guidelines for the inherent safe design, protective measures and information for use of industrial robots**. It describes basic hazards associated with robots and provides requirements to eliminate, or adequately reduce, the risks associated with these hazards.

- ISO 10218-1:2011 **does not address the robot as a complete machine**. Noise emission is generally not considered a significant hazard of the robot alone, and consequently noise is excluded from the scope of ISO 10218-1:2011.

- ISO 10218-1:2011 **does not apply to non-industrial robots**, although the safety principles established in ISO 10218 can be utilized for these other robots.

What is ISO/TS 15066?

ISO/TS Technical Specification

- A voluntary document with normative language representing technical consensus of the committee
- "More" than a technical report, expected to become a standard but not quite ready to be a standard now

Provides guidance not in ISO 10218-1 & -2

- Collaborative operation consist of approximately 8 pages out of 152 total pages in ISO 10218-1 & -2
- ISO 10218-1 first introduced the concept of collaborative applications in 2006, which was revised in 2011

Important notes on the IFR definition

A collaborative industrial robot is an industrial robot that is designed in compliance with ISO 10218- 1 and intended for collaborative use.

- Robots that are **designed for collaborative use but not used collaboratively** are included in the statistics.
- **Traditional robots that are used in a collaborative application** (e.g. by upgrading the unit with the relevant sensors and software) are not included.

Year	Cobot installations	Total industrial robot installations	Cobot share	Growth year-over-year
	units	units	%	%
2017	11,107	399,640	2.78%	
2018*	16,217	422,271	3.84%	+46%
2019	18,049	373,240	4.84%	+11%

Important notes on the IFR definition

A collaborative industrial robot is an industrial robot that is designed in compliance with ISO 10218- 1 and intended for collaborative use.

- The definition implies that a cobot is **necessarily an industrial robot** as defined in ISO 8373:2012 (cf. chapter 1.7.1). This excludes all kinds of service robots that also usually operate in the same workspace as humans. Cobot statistics is a proper subset of industrial robot statistics.
- Compliance with ISO 10218-1 is **by self-declaration of the robot supplier**.
- **Standard only refers to the robot and not to the final application**. For statistical relevance, it is not decisive whether the end user puts the unit into a collaborative application.

ISO 10218-1:2011

Robots and robotic devices - Safety requirements for industrial robots - Part 1: Robots (ISO 10218-1:2011)

There are four important functions a Robot needs to have in order to be suitable for Collaborative Applications:

1- Safety rated monitored stop

2- Hand guiding

3- Speed and separation monitoring (SSM)

4- Power and force limiting (PFL)

Safety Rated Monitored Stop

What the collaborative robot does in the presence of an operator or obstruction

- Stop-motion condition ensured
- Drive power remains on
- Motion resumes after obstruction clears
- Robot motion resumes without additional action
- Protective stop delivered if stop condition is violated

Applications

- Direct part loading or unloading
- Work-in-process inspections
- When 1 moves (not both) in collaborative workspace
- Standstill function in other collaborative operations

Robot motion or stop function		Operator's proximity to collaborative workspace	
		Outside	Inside
Robot's proximity to collaborative workspace	Outside	Continue	Continue
	Inside and moving	Continue	Protective stop
	Inside, at Safety-Rated Monitored Stop	Continue	Continue

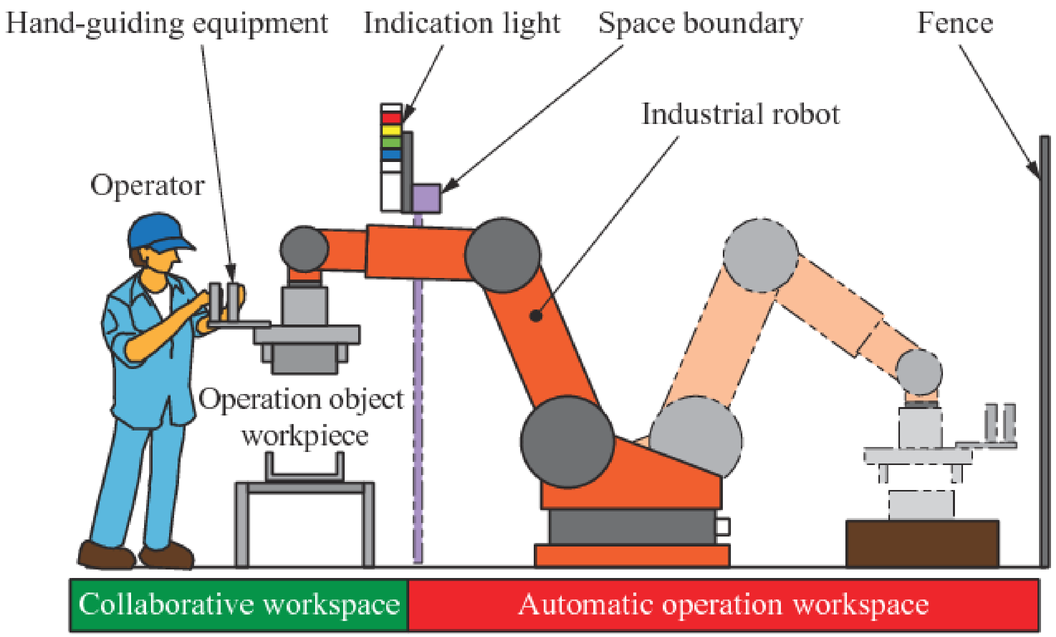
Truth table for safety-rated monitored stop operations.

Figure: Risks management and cobots. Identifying critical variables, doi:10.3850/978-981-11-2724-3 0791-cd

Hand guiding*

Where an operator leads robot movement through direct interface

- Robot stops when operator arrives (Safety-rated monitored stop)
- Operator grasps enabling device, activating motion
- Robot motion responds to operator commands
- Non-collaborative operation resumes when operator leaves collaborative workspace



Applications

- Robotic lift assist
- Highly variable applications
- Limited or small-batch productions

*In Automatic mode, not teaching

Figure: “Study on Application of a Human-Robot Collaborative System Using Hand-Guiding in a Production Line.” (2016).

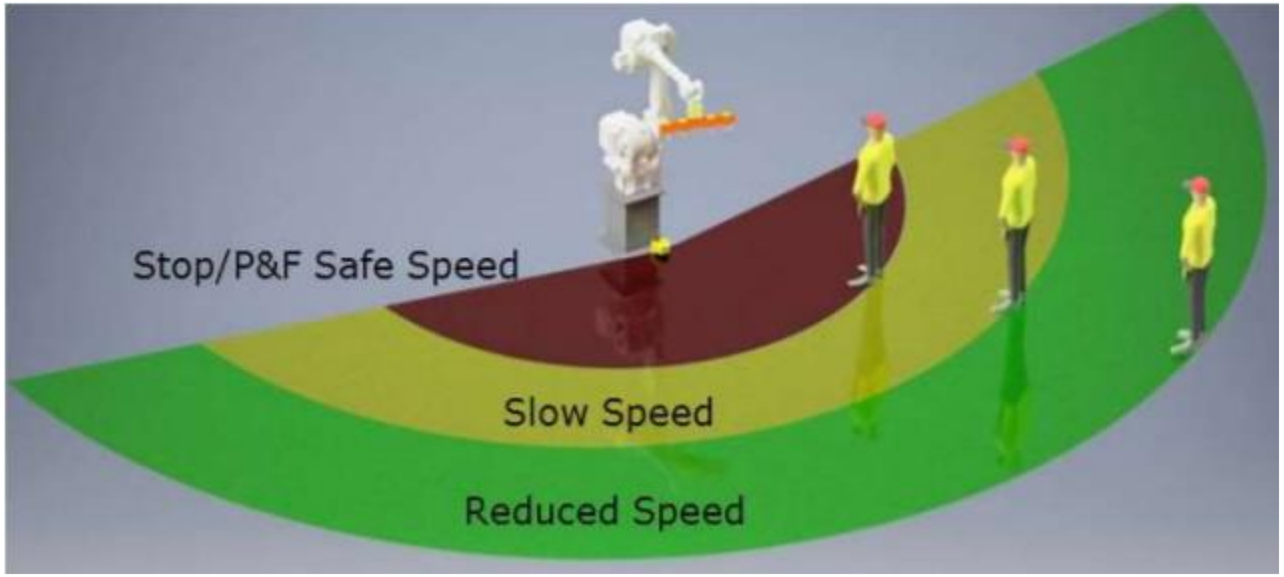
Speed & Separation Monitoring

Where the robot speed reduces when an obstruction is detected, separation distances are monitored (scanners, vision systems, proximity sensors)

- Robot speed directly correlates to separation distance—zones dictate allowable speed
- Stop condition given if direct contact proximity is attained (Safety-rated monitored stop)

Applications

- Simultaneous tasks
- Direct operator interface



Power And Force Limiting

Where incidental contact initiated by robot are limited in energy to not cause operator harm

- Forces robot can exert are limited
- Robot system design eliminates pinch points, sharp edges, etc.
- Robot complies and reacts when contact is made

Applications

- Small or highly variable applications
- Conditions requiring frequent operator presence
- Machine tending
- Loading/unloading

ISO 10218-2:2011

Robots and robotic devices - Safety requirements for industrial robots - Part 2: Robot systems and integration (ISO 10218-2:2011)

- This part of ISO 10218 specifies safety requirements for the integration of industrial robots and industrial robot systems as defined in ISO 10218-1, and industrial robot cell(s). The integration includes the following:
  - a) the design, manufacturing, installation, operation, maintenance and decommissioning of the industrial robot system or cell;
  - b) necessary information for the design, manufacturing, installation, operation, maintenance and decommissioning of the industrial robot system or cell;
  - c) component devices of the industrial robot system or cell.

Risk Assessment

Part 2 requires a risk assessment for collaborative applications to evaluate task/hazard combinations and set appropriate limits

- Means of anticipating tasks and hazards with the goal of applying suitable risk reduction measures
- Uses an iterative process as a means to determine that risk reduction measures applied can achieve their desired effect
- Avoids “one size fits all” prescriptive measures, which can either be too restrictive or can require defeating safeguards in order to accomplish certain tasks

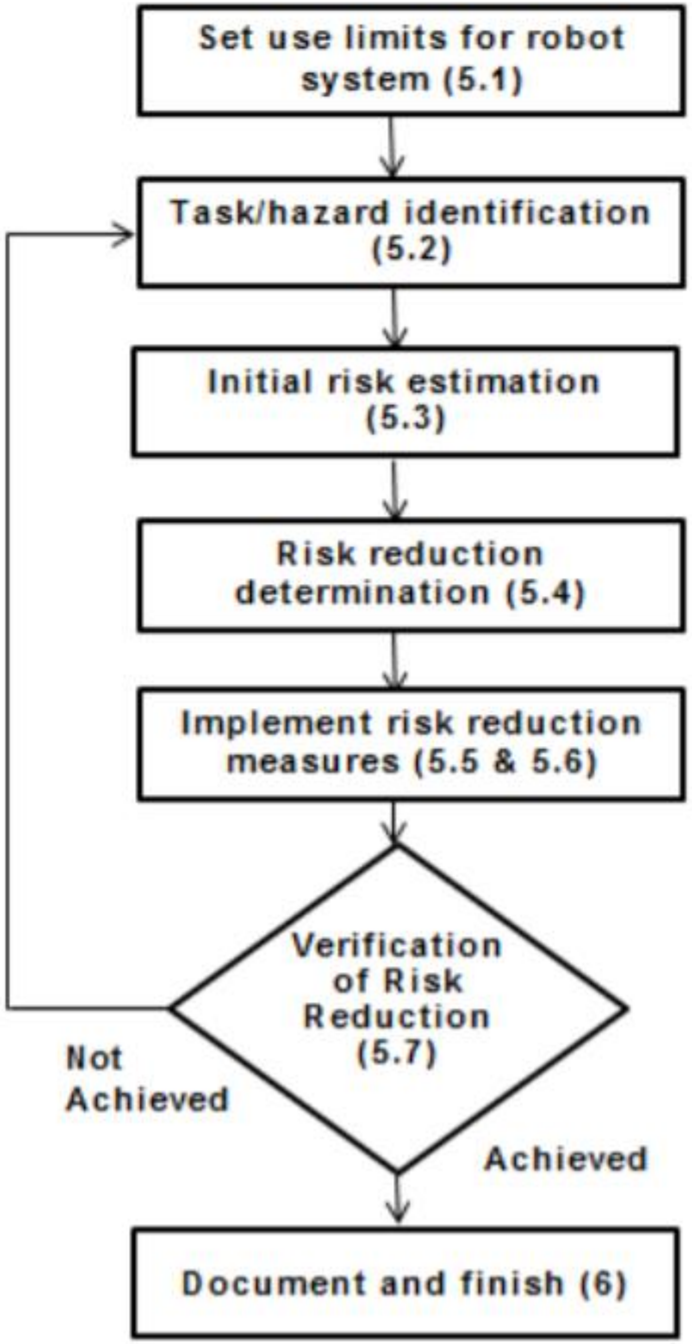
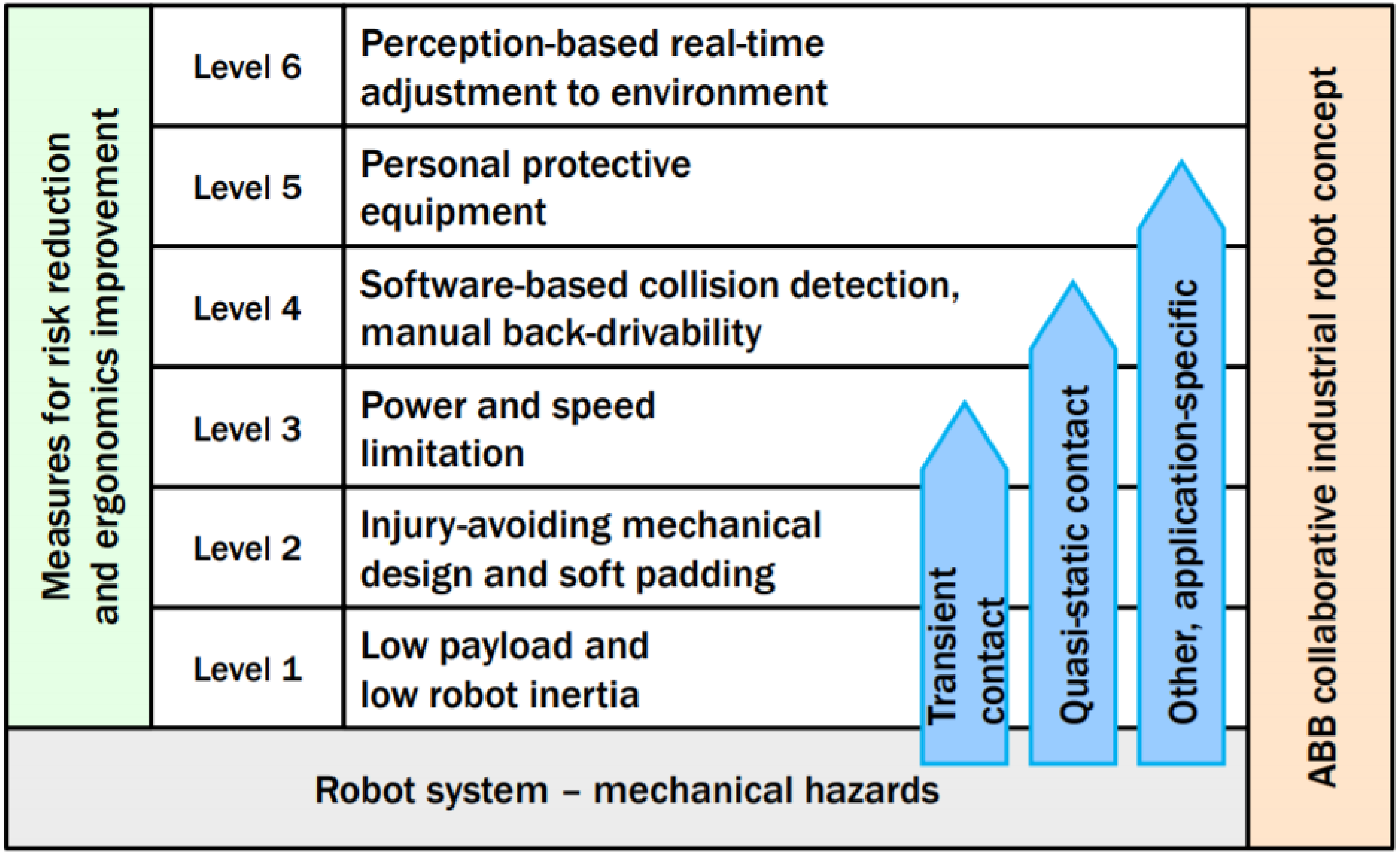


ABB Yumi Safety Concept



Levels of collaboration

Requirement for intrinsic safety features vs. external sensors

Level of collaboration

Green area: robot's workspace; yellow area: worker's workspace
Source: IFR (classification), adapted and modified from Bauer et al. (2016).

New Challenges

Robot automation

YuMi target

Manual assembly

New challenges

Open world	→	Perception and adopting to changes
New users	→	Ease of use
Short product life-cycle	→	High flexibility requirements
Difficult application	→	New ways to teach the robot the task

Challenges in HRC

- Safe interaction
  - Safety standards
  - Collaborative operating modes
- Intuitive Interfaces
  - Programming approaches
  - Input modes
  - Reality enhancement
- Design methods
  - Task planning and task allocation
  - Control laws
  - Sensors

Villani, V., Mechatronics (2018), https://doi.org/10.1016/j.mechatronics.2018.02.009

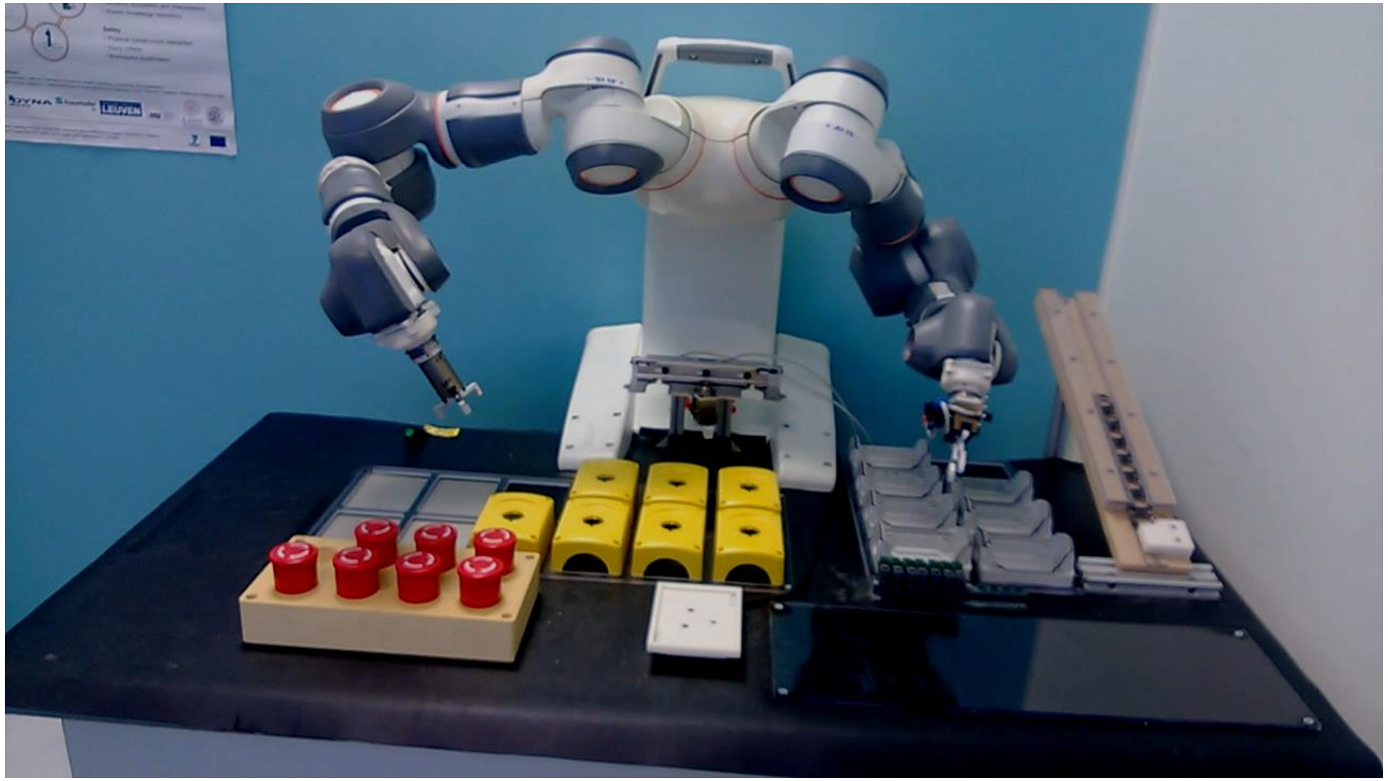
Research project on cognitive robots

Intuitive ways of instructing the robot
- Task-level instruction
- Skill and knowledge representation

Robot control
- Sensor integration
- Dual-arm assembly

Learning
- Skill-based architectures
- Semantic acquisition and interpretation

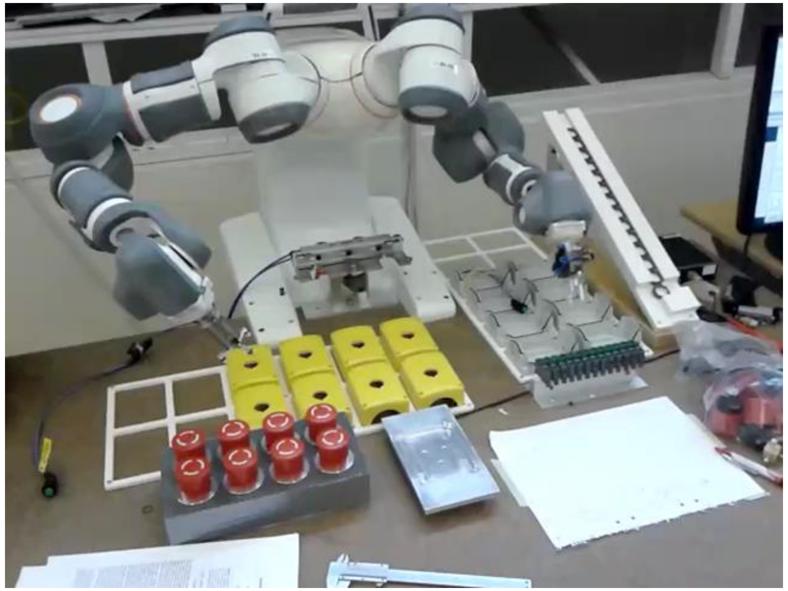
Safety
- Physical human-robot interaction
- Workspace supervision



Research project on cognitive robots

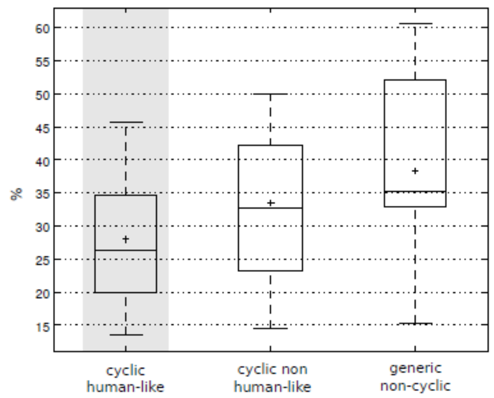
- •Evaluate HDT-IE
  - •Human is out of workspace (vision)
    - no severity index lookup
    - no safety actions
  - •Human is present (vision)
    - no severity index lookup
    - use human-like motions (change redundancy resolution at RAPID-level)
    - predict the area the human is heading to prefetch some information for lookup table
  - •Evaluate Proximity Sensor
  - •Human is close •(proximity sensor)
    - Look up severity index
      - If green:
        - do nothing
      - if yellow:
        - slow down speed at RAPID-level
      - if orange:
        - evasive action in null space motion of task
        - if danger field exceeds a threshold, the main task is suspended
      - if red: protective stop

Human-centric robot motion

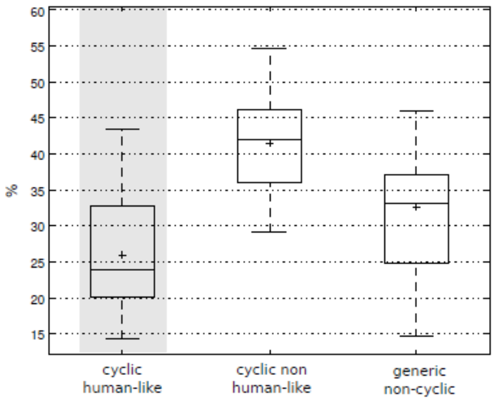


- All stress indicators show lowest levels for human-like motion
  - ECG – Electrocardiography
  - SCR – Skin conductivity, resistivity
  - EMG – Electromyography

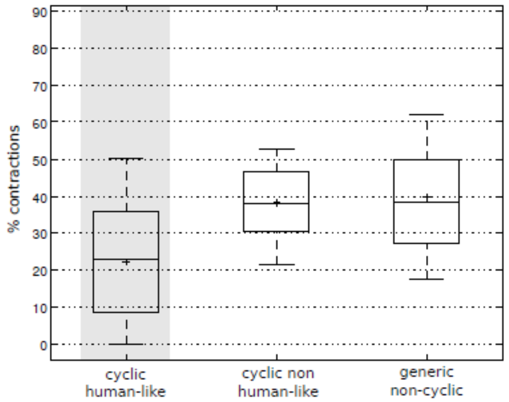
ECG – relative signal



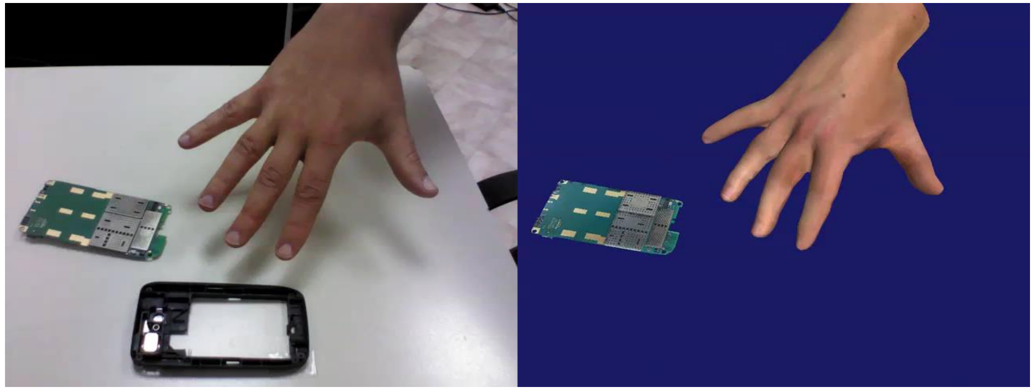
SCR – relative signal



EMG – relative signal



H2020 SARAFun



Approach

- Physical setup
- Learning from observation
- Reasoning and virtual environment
- Learning by doing
- Production

Research Areas

- Observe human assembly
- 3D Vision
- Tactile sensors in hand
- Physical human robot interaction
- Shared knowledge repository
- Intelligent grasp and manipulation control

Video from: Information Technologies Institute,
Centre for Research and Technology Hellas

Approach

- *Physical setup*
- *Learning from observation*
- *Reasoning and virtual environment*
- *Learning by doing*
- *Production*

Research Areas

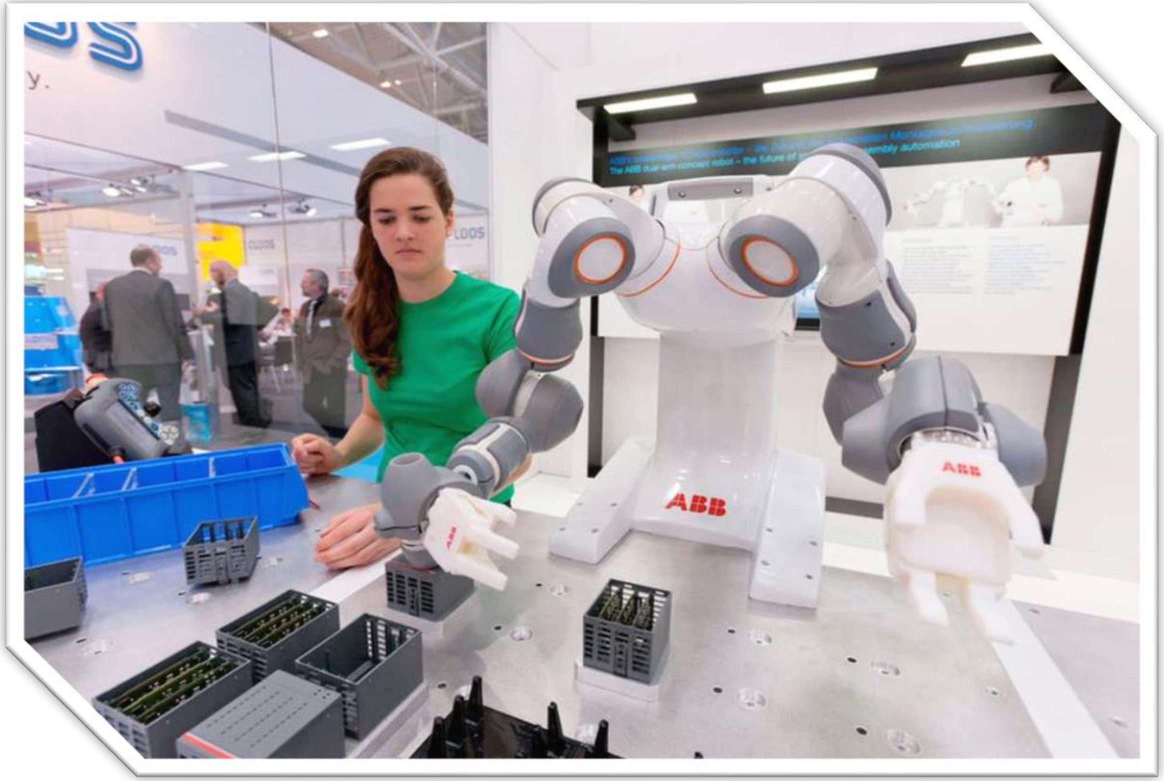
- *Observe human assembly*
- *3D Vision*
- *Tactile sensors in hand*
- *Physical human robot interaction*
- *Shared knowledge repository*
- *Intelligent grasp and manipulation control*

The absence of holistic, digitally networked solutions [..] hindered the speedier application of collaborative robotic solutions. Human-robot collaboration (HRC), – the prospects for which have been considerably hyped in recent years –has only made relatively slow progress in industry.

The number of HRC systems sold has remained well below expectations until very recently. It is only now, with the integration of HRC workstations into the smart factory, that cobot sales are starting to pick up momentum.

Gerald Vogt, Group Division Manager, Stäubli Robotics, 2020

Robotics and AI



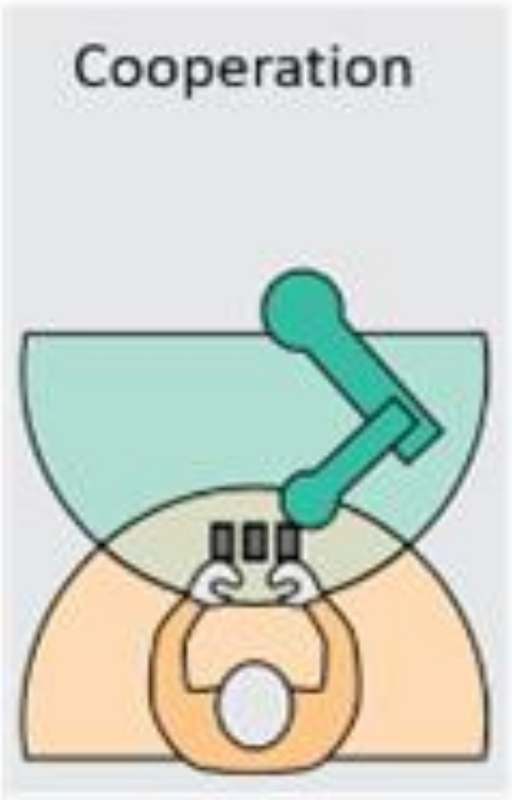
https://www.robotics.org/blog-article.cfm/AI-Robotics-3-Trends-to-Keep-an-Eye-On/89

So, what is a collaborative robot?

So really, a collaborative robot is defined by…

- The complete robot system,
- The task the robot is performing,
- The space in which the task is being performed, and
- The timing at which a task is being performed

…and not just the robot itself!



Thank you for your kind attention!

2020-10-23, Mikael Hedelind

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