Robotics and its anchoring

Václav Hlaváč

Czech Technical University in Prague

Czech Institute of Informatics, Robotics and Cybernetics

166 36 Prague 6, Jugoslávských partyzánů 3, Czech Republic

http://people.ciirc.cvut.cz/hlavac, vaclav.hlavac@cvut.cz

also Center for Machine Perception, http://cmp.felk.cvut.cz

Outline of the talk:

- Robot, robotics, what is?
- Robotics and production.
- Fairy tales, toys and prototypes.
- Path towards cognitive robotics.
- Cognitive robotics.
- Perception – action cycle.

What is robotics?

In this lecture, robotics is understood as the discipline aiming at creating intelligent machines, i.e., integrating several scientific and technological areas.

Two historical milestones:

Golem a clay statue that was made alive by a special formula. The idea originates in a cabalistic legend from 12th century. It became known in conjunction with Prague rabbi Yehudah Löwe ben Bezela from the edge between 16th and 17th century.

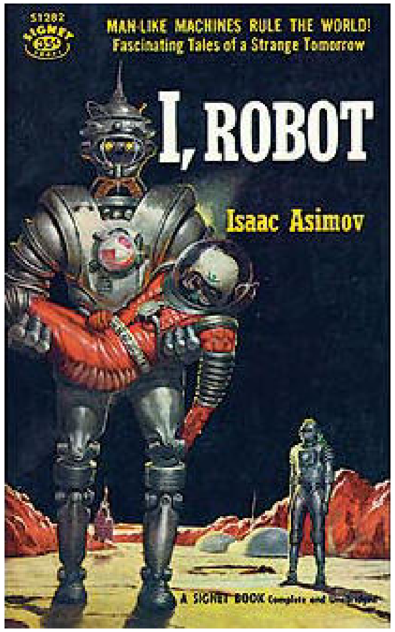
Robot Just young Rossum got an idea to make from it live and intelligent machines (Karel Čapek, R.U.R., prelude).

Staging R.U.R. in Paris 1924.

Three laws of robotics

(Isaac Asimov, I Robot, 1950.)

- A robot may not injure a human being or, through inaction, allow a human being to come to harm.
- A robot must obey the orders given to it by human beings, except where such orders would conflict with the First Law.
- A robot must protect its own existence, except where such protection would conflict with the First or Second Law.



Several definitions of the robot

Robot (McKerrow, 1986) The robot is a machine that can be programmed to perform different different tasks.

Robotics (Brady, 1985) is an intelligent connection between perception and action.

Robotics (McKerrow, 1986) comprises:

1. Design, production, control, and programming of robots.
2. Application of robots to tasks solving.
3. Analysis of control tasks, sensors, actuators, and algorithms in humans, animals and machines.
4. Application of the above to design and applications of robots.

Our definition of a robot

A physically-embodied, artificially intelligent autonomous device, which can sense its environment and can act in it to achieve some goals.

- Physically-embodiment requires the physical instantiation and existence in a single body.
- Autonomous means that it can make decisions on its own, i.e. it is not controlled by a human (teleoperated).
- It must think (or process information) to connect sensing and acting.
- Is an automatic washing machine a robot? Yes, even most people would not say so, but it does have goals, sensing, actuation and processing.
- Is a chess program a robot? No, even it has goals, intelligence. There is no sensing, acting and embodiment.
- Another view, distinguishing between the appliance and robot (David Bisset): whether the workspace is physically inside or outside the device. Fuzzy border, e.g. a recent car, a smartphone.

Courtesy: Andrew Davison, Imperial College London; C.A. Berry, Rose-Hulman Inst. of Technology.

Why are people interested in robots?

- We like to compare our abilities with the nature (symbolically). We intend to check how far do our creative abilities span and by means of repetition to penetrate into Laws of Nature.
- We intend to produce a perfect helper with abilities comparable to ours and who might be even more reliable than humans.

Quiz: Is the exoskeleton a robot?

- Exoskeleton serves to enhance human's abilities, e.g. in lifting and carrying heavy objects. Disadvantage: a quite high own weight.
- French exoskeleton prototype Hercule shown for the first time in 2012.
- Hercule: battery operated; allows lifting 100 kg payload and a 20 km long hike at a speed 4 km/hour.
- A similar prototype HULC from U.S. company Lokheed Martin, payload 90 kg.

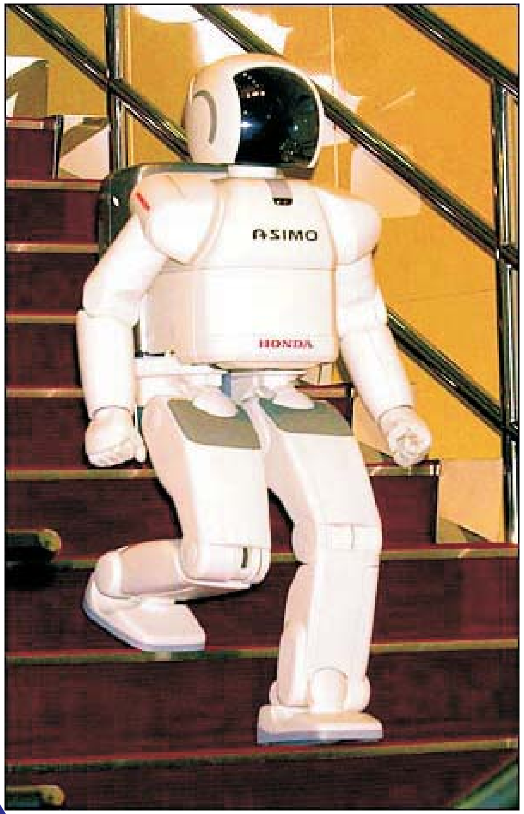
Robots and its subsystems

Subsystems:

- Mechanical.
- Electrical.
- Control.
- Power sources.

Towards cognitive robots:

- Sensors.
- Effectors/Actuators.
- Cognitive (model of the world, perception, planning, . . .).



Effectors and actuators

Effector is any device that has a physical effect on the (robot) environment.

- Equivalent to biological legs, arms, fingers.
- Body parts that perform physical work, which influences the robot environment.
- E.g., wheels, tracks, arms, grippers, surgical tools of a surgical robot.

Actuator is the mechanism that enables an action or movement (e.g., by an energy conversion).

- Equivalent to biological muscles and tendons.
- E.g. electric motors, hydraulic or pneumatic cylinders/drives.

Actions, behaviors

- Action is an elementary operation, by which the robot physically influences its environment using its effectors.
- Behavior:
  - Behavior is a concatenation of several robot actions (or consisting of a single action in a special case).
  - Behavior is what and external observer sees a robot doing.

Two taxonomies often used in robotics

Principal behaviors and needed effectors

- Locomotion

  moving around, going to places.

  - Still base (e.g. an industrial manipulator), wheeled, tracked (e.g. a tank) – are the most common.
  - Legs. Statically stable – can pause at any stage. Dynamically stable – stable as long as it keeps moving.
  - Other: fish-like, snake-like, etc.

- Manipulation:

  handling objects.

Application areas examples

- Manipulator robotics.
- Mobile robotics.
- Communication robotics,

  e.g. museum guide, toys.

Various approaches to robotics

Theoretical robotics: searches for principles, potentials and constraints (biology, psychology, etology, mathematics, physics).

Experimental robotics: checks principles, builds toy devices (cybernetics, artificial intelligence, combination of engineering disciplines).

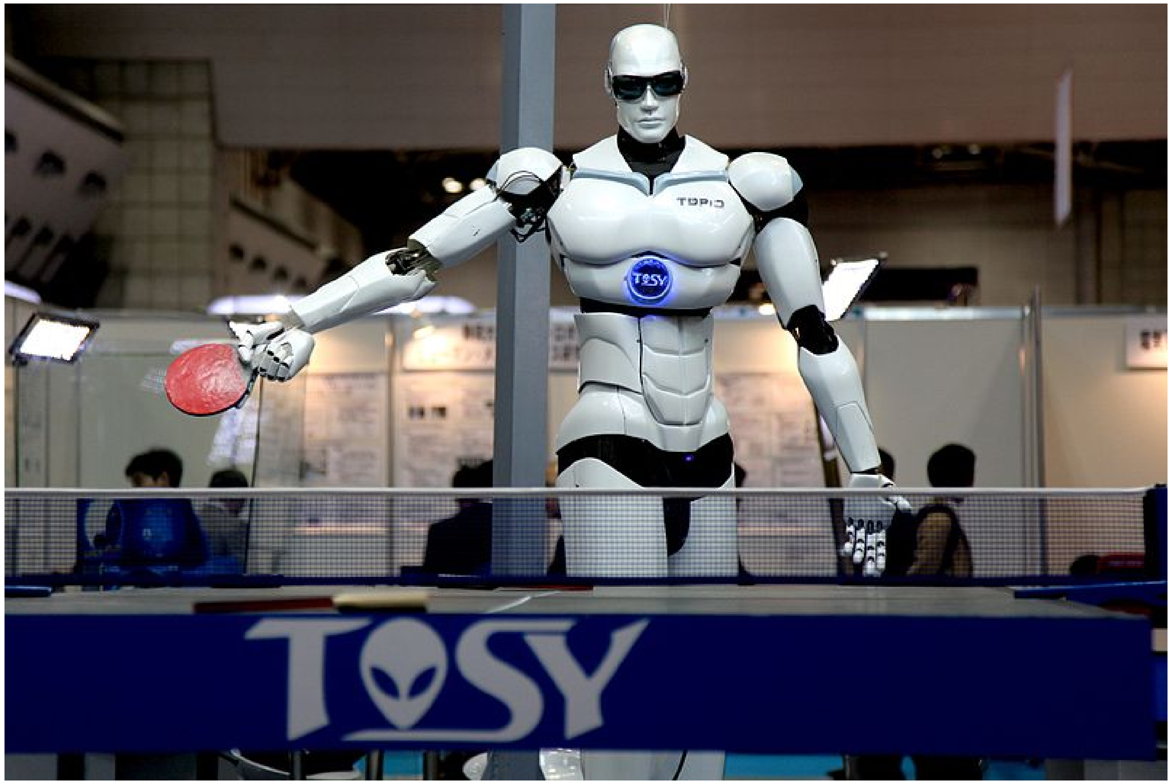
Experimental (industrial) robotics: Designs, builds and uses robots (control engineering theory and instrumentation, electronics, machine engineering, production automation).

Miscellaneous applied robotics: Designs various intelligent machines for industry and elsewhere. For instance, machines for quality check in production are often endowed by the ability to see, mobile robots are able to navigate autonomously, etc.

Robots in industry today

Automotive plant KIA Žilina, Hyundai industrial robots.

Robots under development

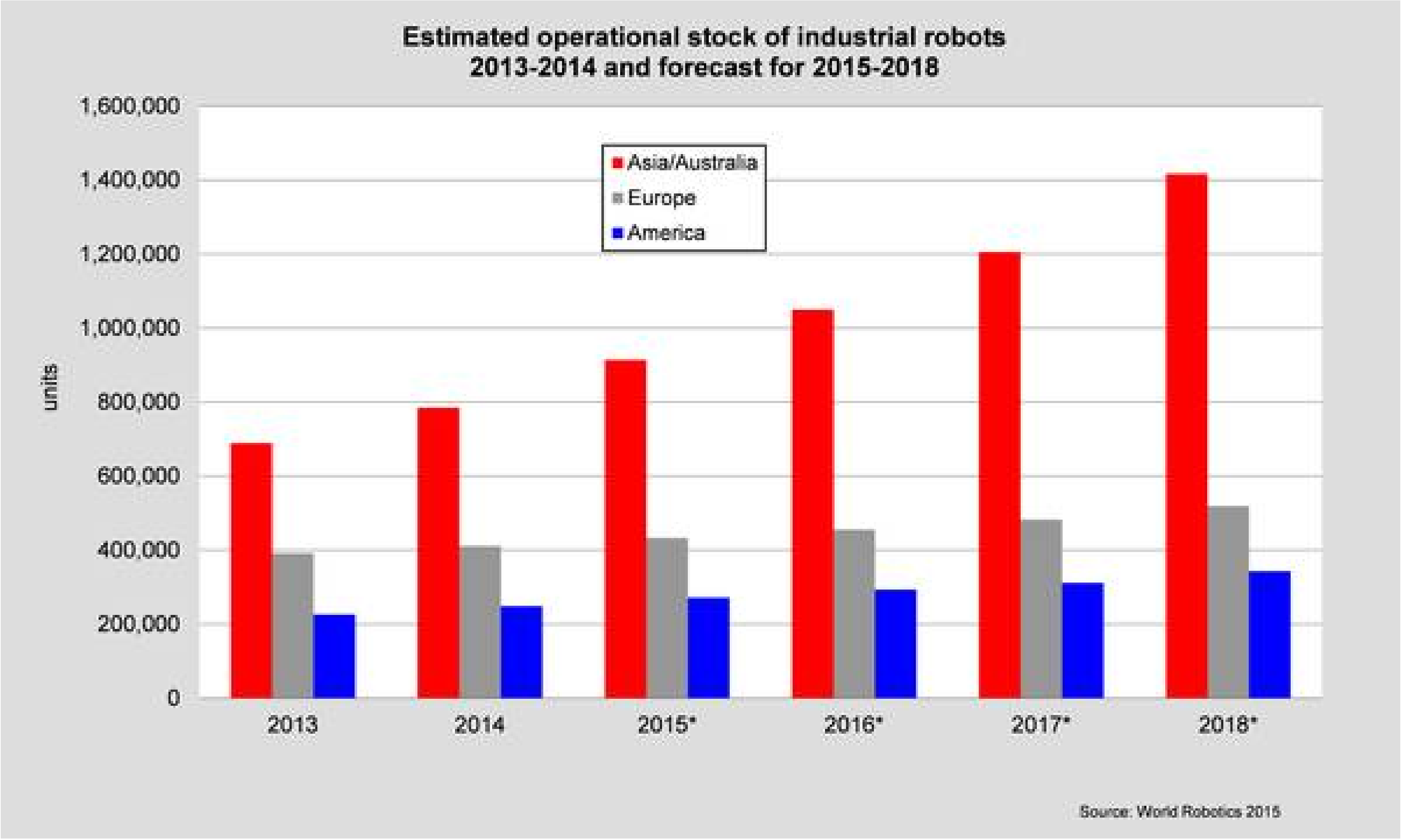


Industrial robot

is and automatic device with the following abilities (in larger or smaller degree) [I.M. Havel 1980]

1. Manipulation abilities.
2. Automatic autonomous performance.
3. Its program can be modified easily.
4. Universality.
5. Feedbacks.
6. Concentrated in the space.

Numbers of deployed industrial robots by continents



Numbers of deployed industrial robots by countries

Estimated operational stock of multipurpose industrial robots at year-end in selected countries. Number of units

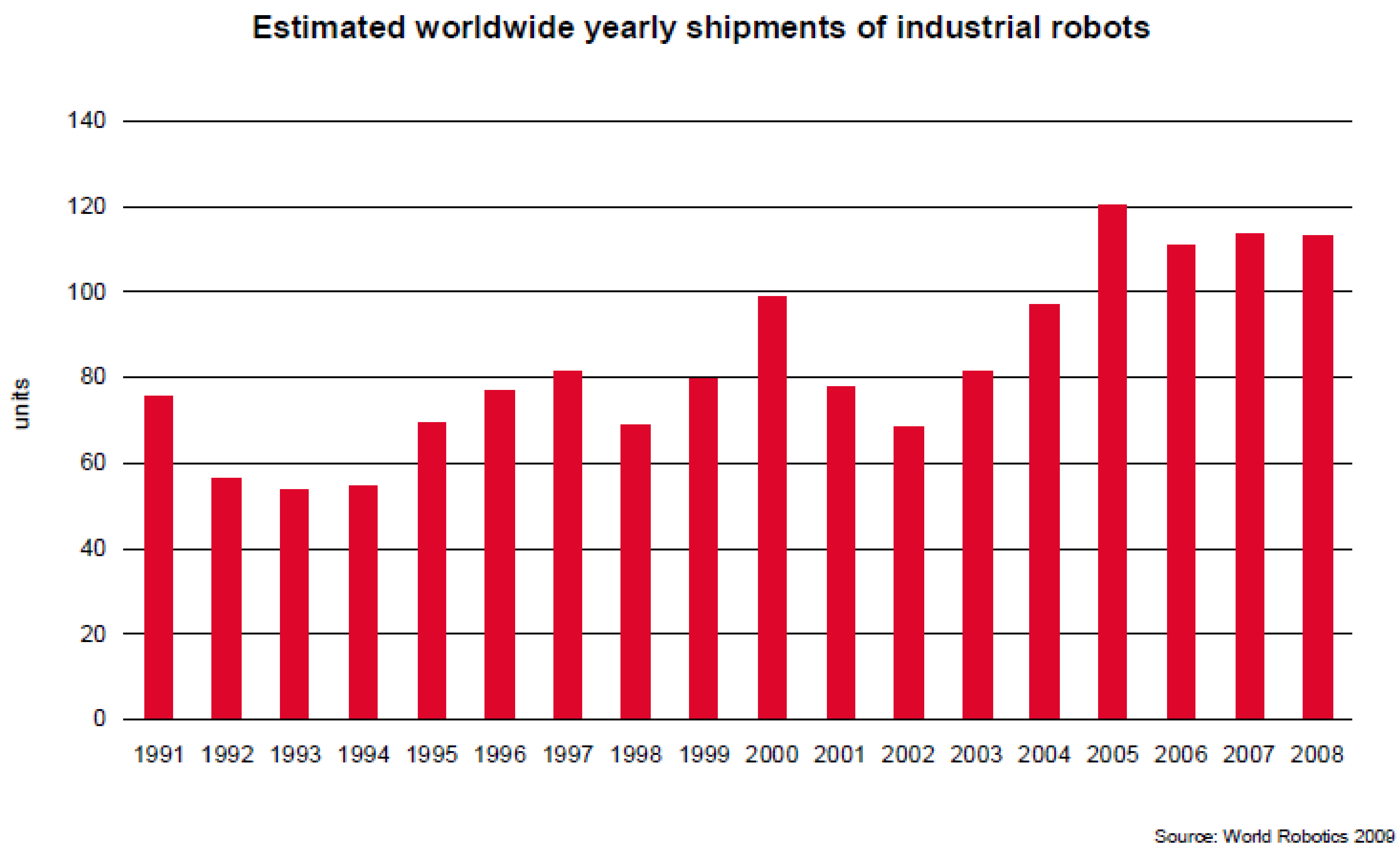
Country	2013	2014	2015*	2018*
America	**226,071**	**248,430**	**272,000**	**343,000**
Brazil	8,564	9,557	10,300	18,300
North America (Canada, Mexico, USA)	215,817	236,891	259,200	323,000
Other America	1,690	1,982	2,500	1,700
Asia/Australia	**689,349**	**785,028**	**914,000**	**1,417,000**
China	132,784	189,358	262,900	614,200
India	9,677	11,760	14,300	27,100
Japan	304,001	295,829	297,200	291,800
Republic of Korea	156,110	176,833	201,200	279,000
Taiwan	37,252	43,484	50,500	67,000
Thailand	20,337	23,893	27,900	41,600
other Asia/Australia	29,188	43,871	60,000	96,300
Europe	**392,227**	**411,062**	**433,000**	**519,000**
Czech Rep.	8,097	9,543	11,000	18,200
France	32,301	32,233	32,300	33,700
Germany	167,579	175,768	183,700	216,800
Italy	59,078	59,823	61,200	67,000
Spain	28,091	27,983	28,700	29,500
United Kingdom	15,591	16,935	18,200	23,800
other Europe	81,490	88,777	97,900	130,000
Africa	**3,501**	**3,874**	**4,500**	**6,500**
not specified by countries**	21,070	32,384	40,500	41,500
Total	**1,332,218**	**1,480,778**	**1,664,000**	**2,327,000**

Sources: IFR, national robot associations.

*forecast

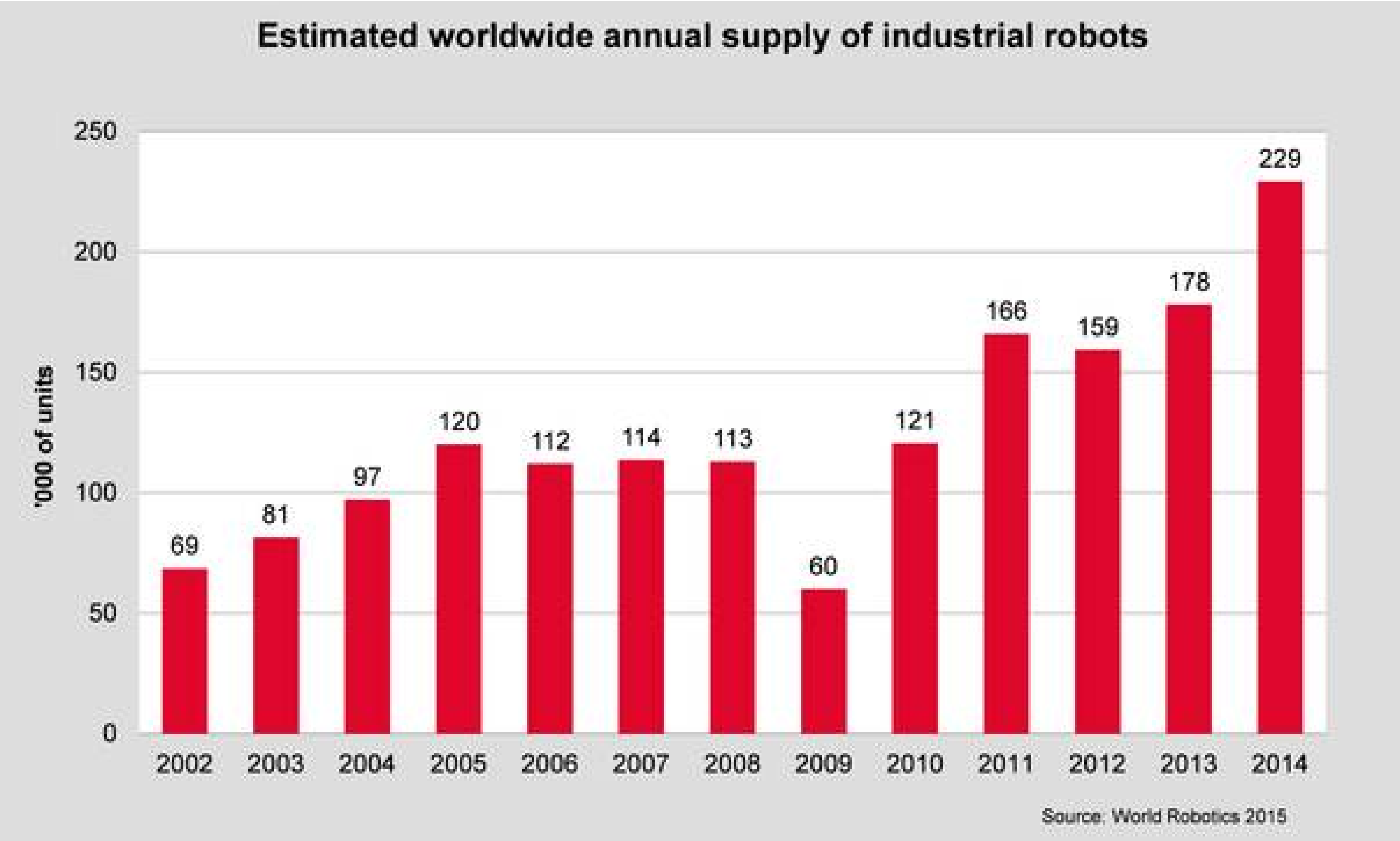
** reported and estimated sales which could not be specified by countries

Industrial robots, yearly deployment 1991-2008



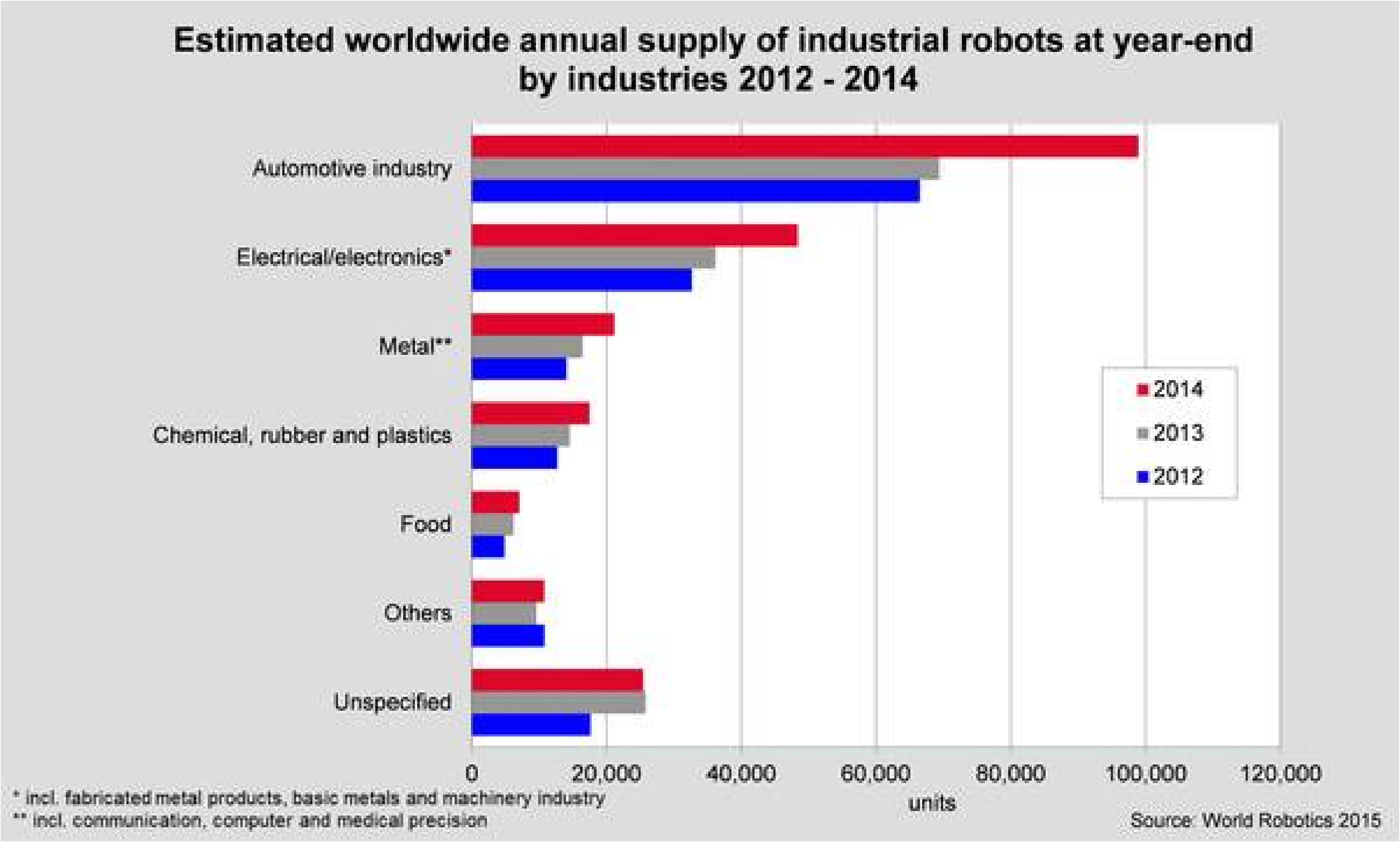
Number of deployed robots in industry, in thousands.

Industrial robots, yearly deployment 2002-2014

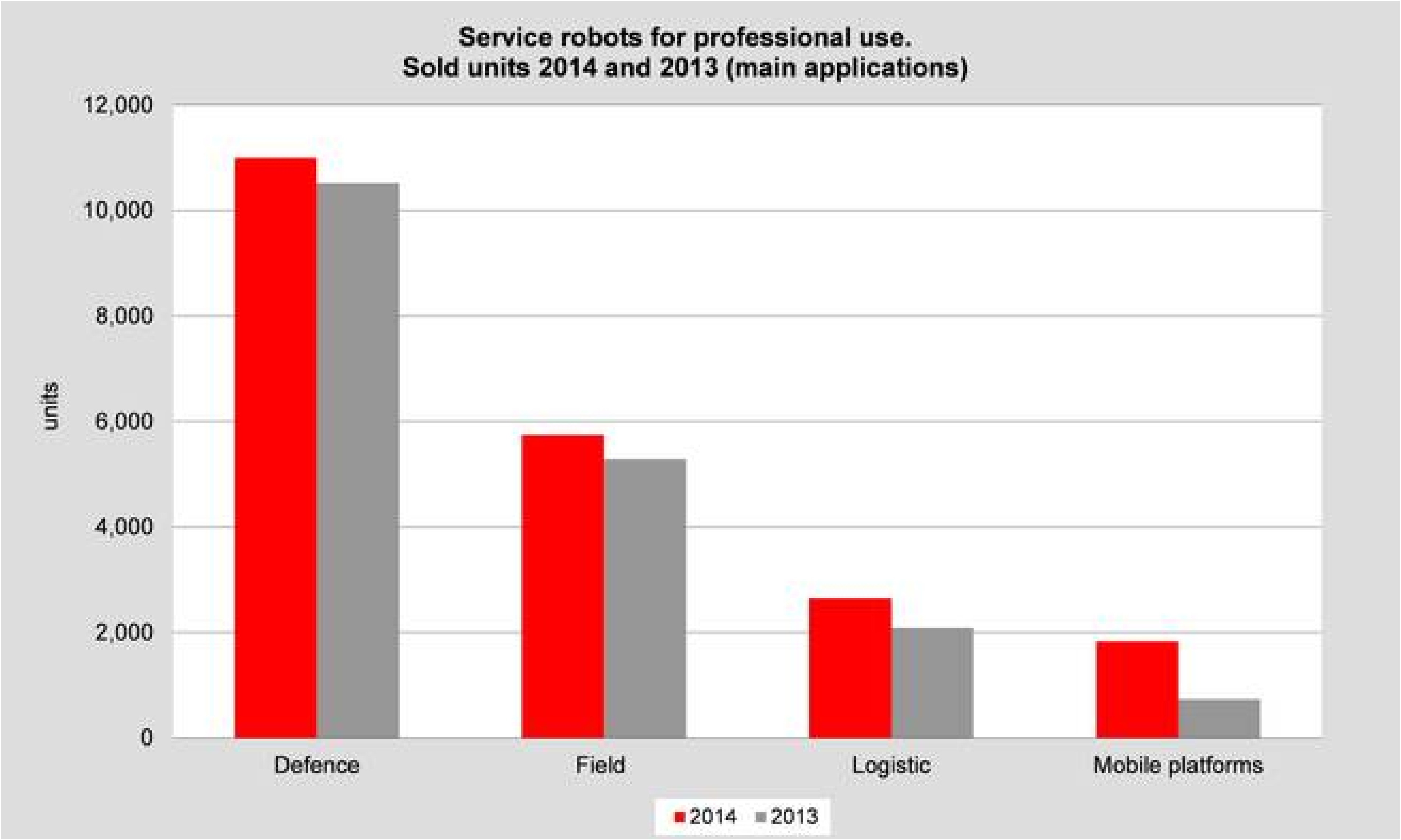


Number of deployed robots in industry, in thousands.

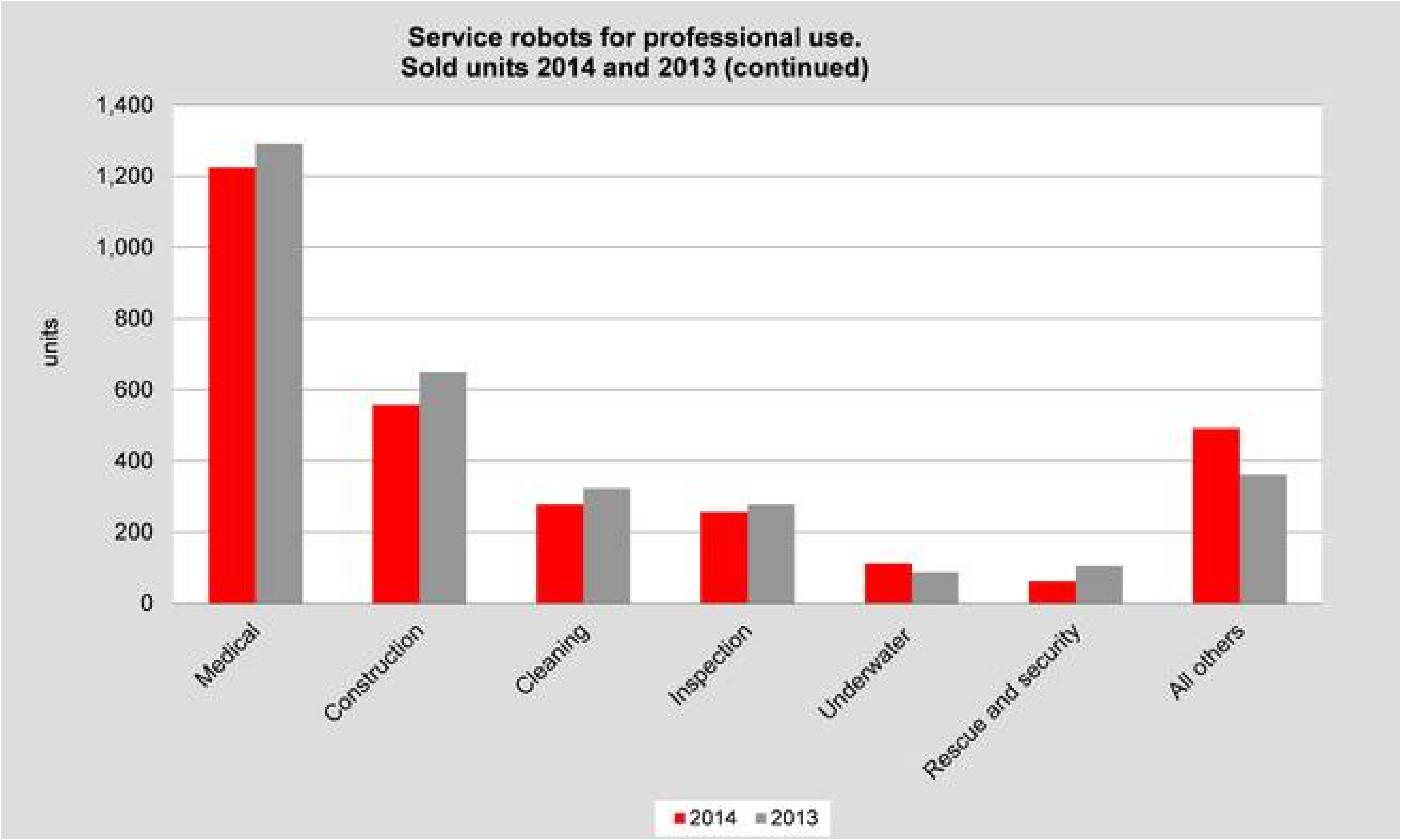
Industrial robots, sector statistics



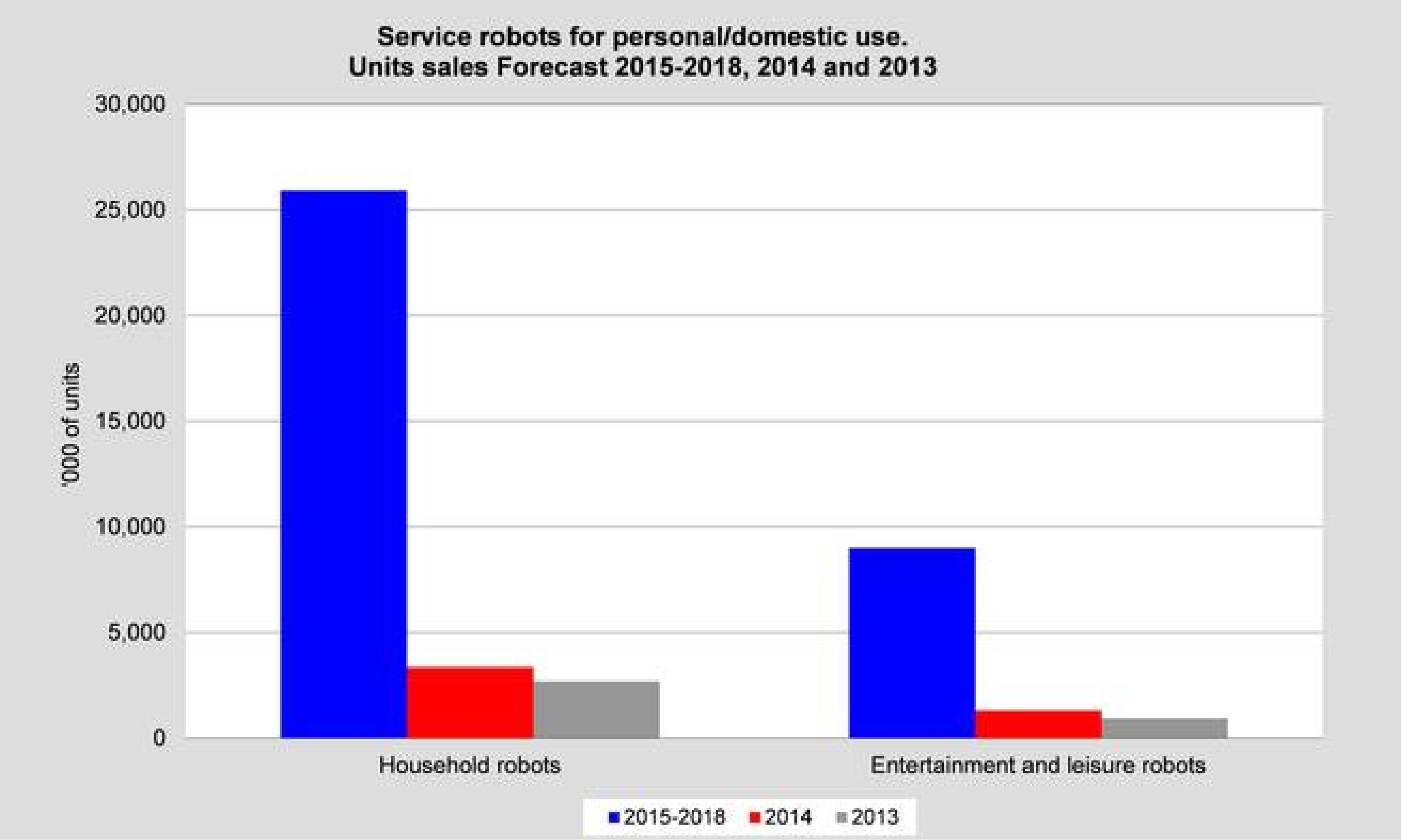
Professional service robots, statistics 1



Professional service robots, statistics 2



Household and entertainment robots



Industrial revolutions

1st industrial revolution	$\sim$ 1800	human labor replaced by mechanical one, driven by water wheel, steam engine
2nd industrial revolution	$\sim$ 1900	production electrification, mass production
3rd industrial revolution	$\sim$ 1960	elecronization, robotization of production, software-based control systems
4th industrial revolution	now	cyberphysical systems, everything is connected to internet

A German government initiative Industry 4.0, first use in 2011, promotes the computerization of manufacturing. It is based the technological concepts of cyber-physical systems, the internet of things.

Production and its automation

Proliferation of mechanization, automation and robots $\Longrightarrow$

- decrease of the human presence in production,
- shortening the production time (namely auxiliary one),
- increase of performance and productivity of labor.

Notes

- Technical, economic and social viewpoints.
- Automation decreases the influence of the human factor to the quality of production.
- The qualification structure of the work force is changed.
- The number of workers decreases which influences the unemployment.

Concepts related to industrial robotics

- Mechanization, automation.
- Machines with partial automation, semiautomatic machines, automata.
- Numerically controled (NC) machines.
- Automatic production line, automatized workcell, automatized workshop.
- Technological process is a collection of technological operations that leads from a semi-finished article to a product.
- Technologic operation, technologic position.
- Operational cycle

  periodic: clock rate, cf. synchronous automaton.

  flexible: flexible changes according to conditions, cf. asynchronous automaton.

Mechanization, automation in the agriculture – two trivial examples

Cow stable mechanization – manure carrier.

Automatic cattle drinking water feeder.

Production types according to number of produced articles

Production	Automation
Single piece	Flexible automation means
Small series	
Mass	Hard automation

To which production type is the industrial robot usually deployed. Why?

Towards flexibility in automation

Substantial sources of the labor productivity increase:

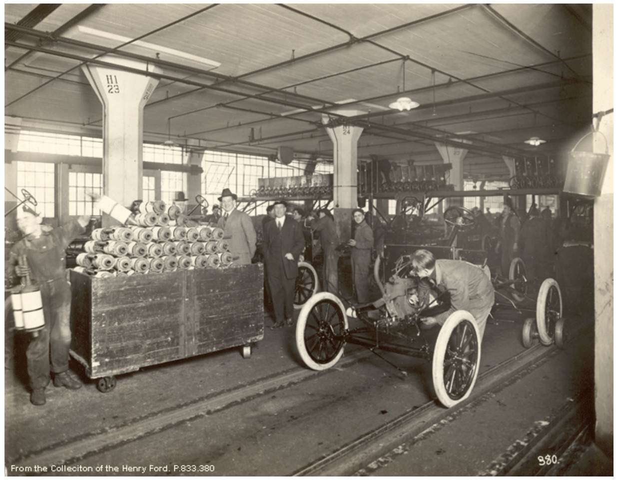
1860 Replaceable parts, standardization.

1913 Conveyer belt (Henry Ford) and machines in a fixed positions (the disadvantage: the failure of one machine stops the whole line).

1994 Interchangeable production lines, universal machines and flexible transport of articles.

- Structured $\sim$ effectiveness.
- Unstructured $\sim$ flexibility.

1913 Flywheel magnetos.



1915 Car bodies Model-T.

Charlie Chaplin, movie Modern Times 1936

Industrial appetizer 1
– dual-arm assembly

Industrial appetizer 2 – the bakery

Industrial appetizer 3
Ten most common robot applications in industry

Industrial appetizer 4
Robot end effector tools

Robotics tomorrow

Cognitive systems

- **Artificial cognitive systems** $\equiv$ artificial systems that perceive, understand, learn and develop through individual or social interaction with their environment.
- **Societal needs** (which manifest themselves in financing of research):
  - to create and develop a scientific foundation for artificial cognitive systems.
  - ...also by taking inspiration from the study of natural cognitive systems.
- Artificial cognitive systems research is expected to provide an enabling technology for all sorts of applications involving interaction with the real-world environment and its inhabitants.

Research in cognitive robotics today

DARPA Urban Challenge
November 2007

European humanoid robot
Aldebaran Robotics, France

Challenges of cognitive robotics

- **Ability to learn from experience** – allows the cognitive system to adapt to the outer conditions.
- **Robustness** – performance shouldn't degrade much with unexpected events and observations.
- **Effectiveness** – performance should improve because a cognitive system can predict or anticipate what might happen at some point in the future, near or far.
- **Naturalness** – performance should be tolerant to the ambiguity and uncertainty that is a consequence of dealing with humans and performance should improve with time.

Robotics – a melting pot of different disciplines

- Artificial intelligence.
- Computer vision.
- Natural language processing.
- Robotics.
- Human-computer interaction.
- Mathematics.
- Psychology.
- Cognitive science.
- Computational neurosciences.
- Philosophy of mind.
- Various branches of engineering.
- Software development.

and **integration, embodiment . . .**

Dreaming and playing is useful

Fairy tales. A miraculous instrument is usually sought that would allow us to perform what has been impossible until now *(e.g., to develop a flying carpet and float in the air)*.

Toys. Various models are created which imitate dreams of the fairy tale stage although they are too far from any practical exploitation, *(e.g., a model glider which is already flying)*.

Prototypes fulfil practical requirements, a little at the beginning, and more and more later on, *(e.g., an airplane)*.

- Thinking in a fairy tale manner is an effort to perceive the result demanded.
- Toys clear up the principles and check whether it is possible to realize this or that dream.

Fairy tales = proposals; Toys = demos

- In research projects proposals, fairy tales that can become real have a much higher chance to succeed.
- Making fairy tales real poses problems that may not be achievable through one or even several research projects.
- In reality, there is a progress, of course, but the “components” are not yet fully grasped.
- There should also be the space to slow down, go back, rethink and consolidate the components.
- The commission designers of funding programmes and proposers alike have the delicate task to balance between dreams and applicable outcomes.

- Demos are the vital tool not to loose the contact with the reality.

Fairy tales = projects designs; toys = reality

- The criticizer of the fairy tale metaphor could object that research in cognitive systems is not enough grounded in reality.
- The transition from fairy tale $\rightarrow$ toy $\rightarrow$ prototype is possible only because the research effort is deeply embedded in a rich back-drop of mathematical, scientific, and technological progress.
- The pursuit of this transition also motivates and drives these component areas forward.
- A very healthy (and necessary) symbiosis.

iCub robot, U of Genova

Courtesy Giorgio Metta

Grand challenges, positive influence

- Help to focus the efforts.
- Can be of lower cost and less bound to current technology than DARPA Urban Challenge.
- Examples of:
  - NSF Semantic Robot Vision Challenge: room with objects, simple mobile robot (embodied agent), gets list of objects, has to pick them up.
  - NoE PASCAL challenge: contest of machine learning algorithms.

Winner June 2008
Univ. of British Columbia

Example 1, industrially funded

Stabilized camera platform for UAVs

Example 2, industrially funded

Lamps inventorying in the British cities

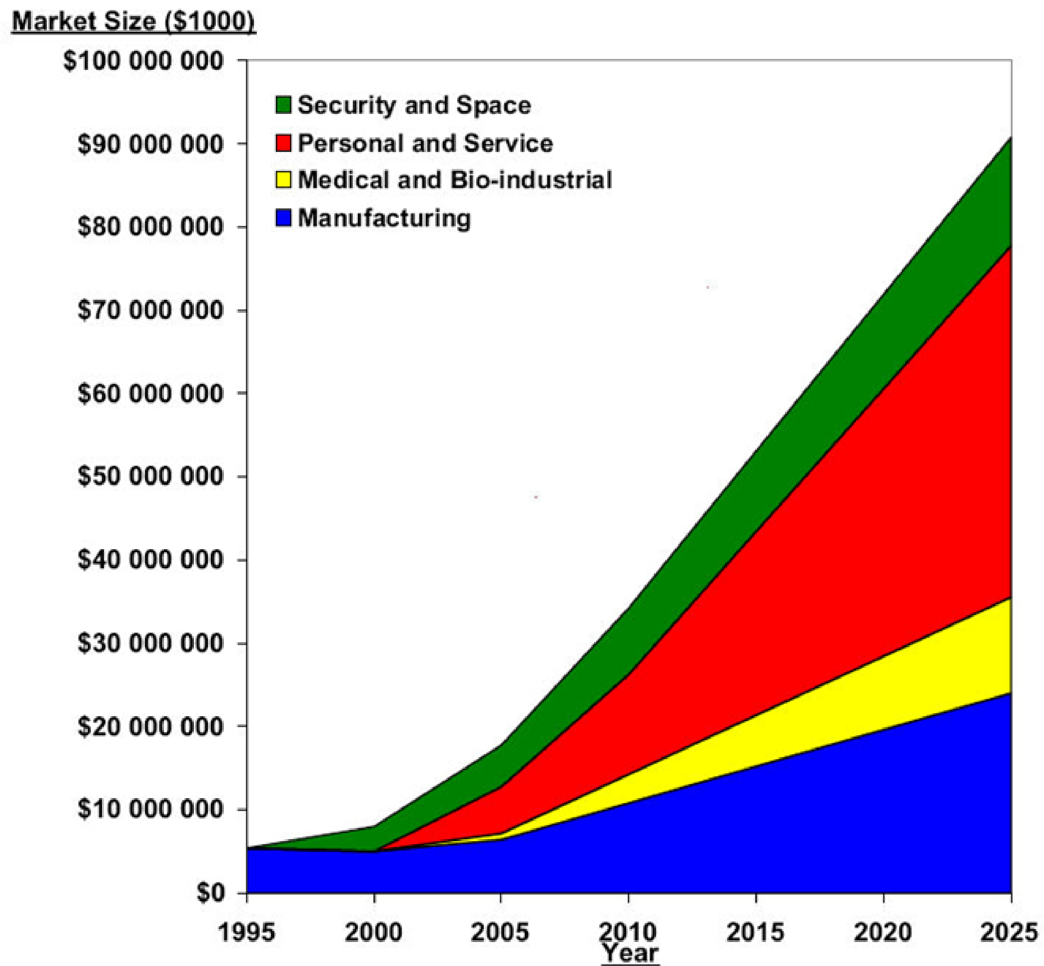
Courtesy P. Doubek, J. Matas, CTU Prague

Example 3, funded by the European Commission

Pedestrian detection from omni-cameras

Courtesy project DIRAC, T. Pajdla, CTU Prague

Cognitive robotics, the expanding discipline



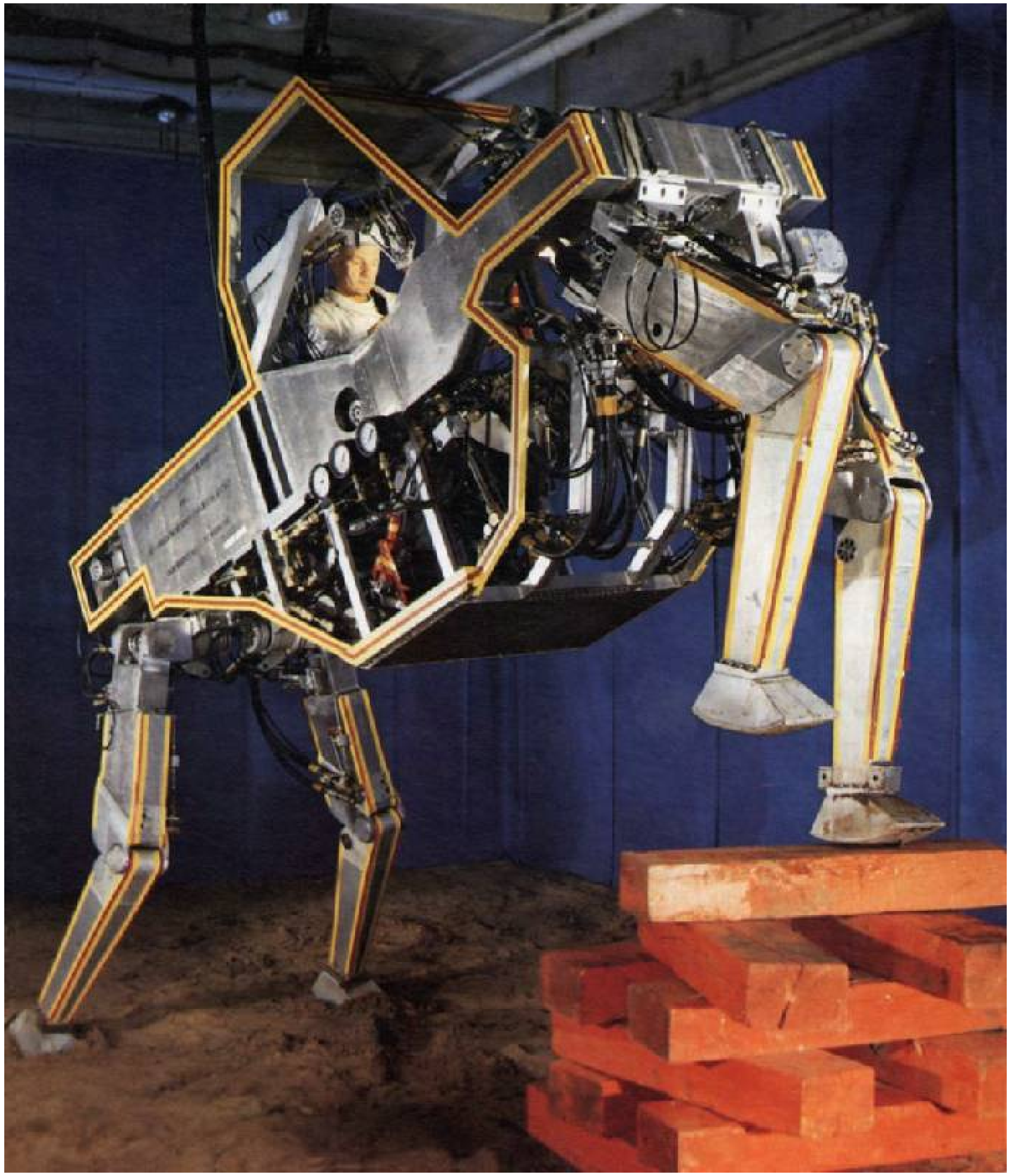
Source: Japanese Robotics Association

Remotely controlled explosive carrier, 1942

Nacistické Německo, po třech drátech dálkově ovládané vozítko (elektrický pohon, typ 302; později kvůli ceně a složitosti spalovací motor, typ 303).

Leichter Ladungsträger Goliath (Sd.Kfz. 302/303a/303b)

G.E. Walking Truck 1960



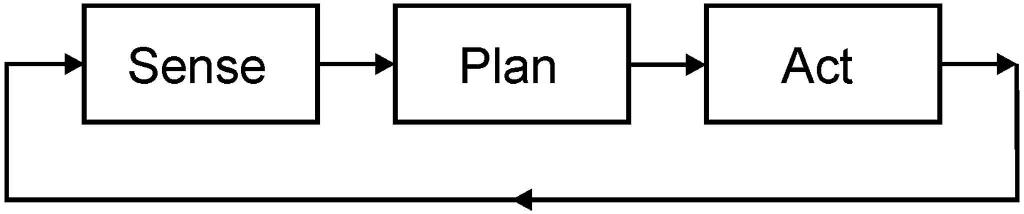
Remotely controlled mechanisms, soccer

Walking without intelligence and motors

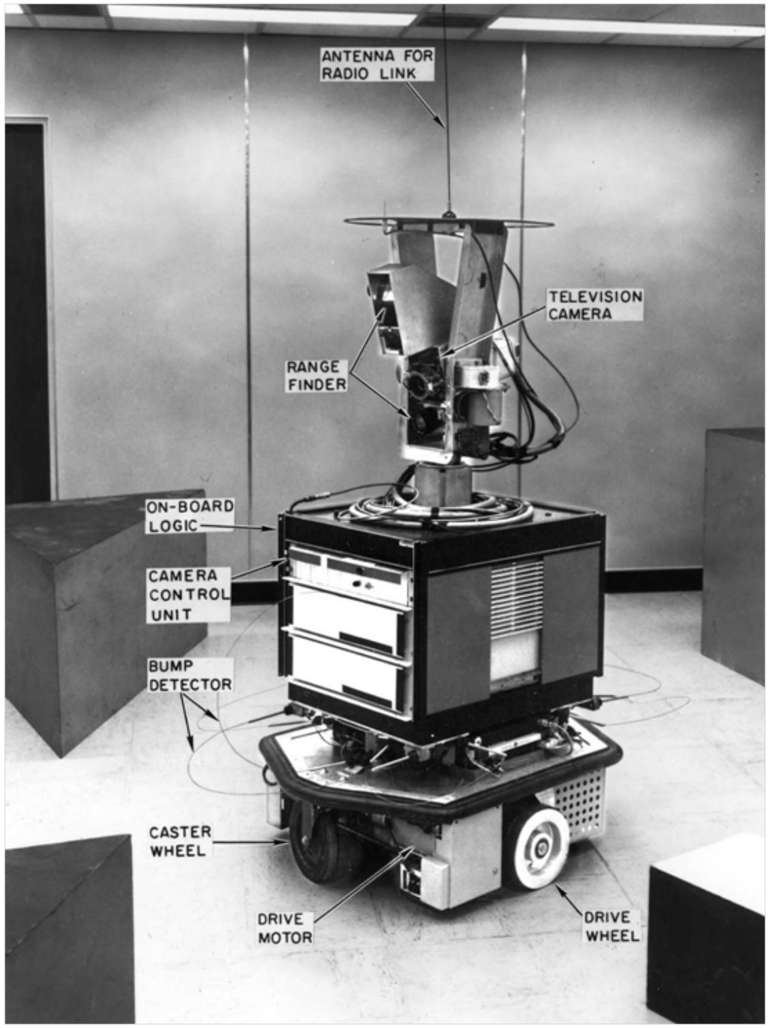
Trends in robotics

- Delibaerative (classical) robotics, after 1965.
  - Exact outside world models.
  - No sensors.
  - In research intelligent robots with sensors, it was anchored in "good old" artificial intelligence.
- Reactive robotics, after 1990.
  - No outside world models.
  - Relies on 'good' sensors.
- Hybrid and uncertainty robotics, after 1990.
  - Relies on models in higher-control layers.
  - Reactive behavior on lower-control layers.
  - Smooth integration between sensors and models.
  - Unprecise models. Unprecise sensors.

Deliberative (classical) intelligent robotics

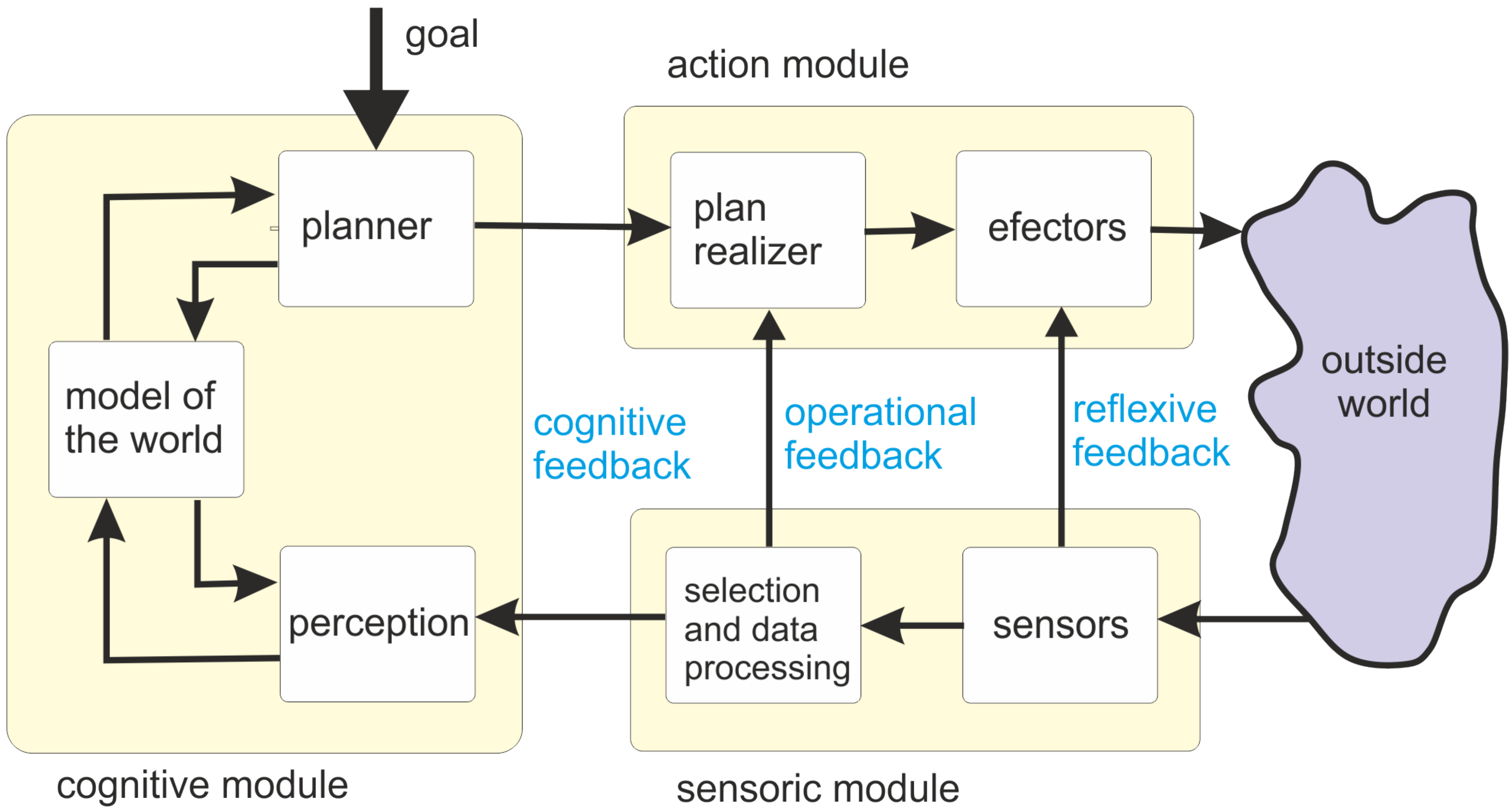


- Focus on automated reasoning and knowledge representation.
- STRIPS (Stanford Research Institute Problem Solver): Perfect world model, closed world assumption.
- Shakey robot: find boxes and push them to a given positions.



Shakey robot, SRI 1969

Cognitive robot, a block diagram



Cognitive robot (1)

System capable on autonomous interaction with real world environment able to fulfil given goals.

It has varied degree of abilities of:

- Perceiving and recognizing its outer environment (sensoric module).
- Creating and updating internal representation of outer environment (cognitive module, model of the outer environment).
- Solving unexpected events in the environment (dynamic model of the environment).
- Solve autonomously tasks based on model of the environment and formulated goal (problem solving and planning module).

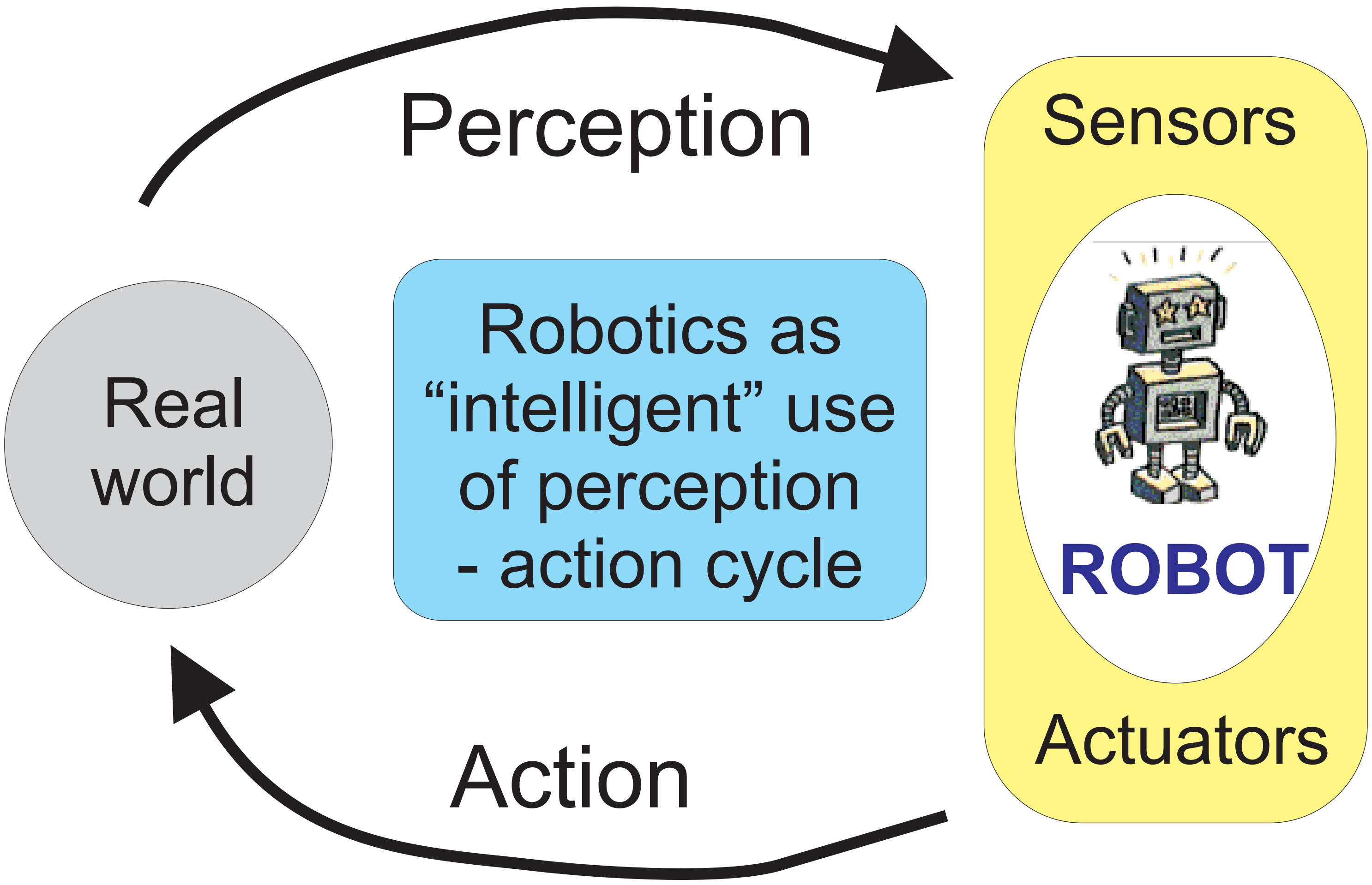
Cognitive robot (2)

- Autonomously fulfilling plans of activity in the environment (realizer of plans, motoric module).
- Actively influencing environment by manipulating objects in it by its (effectors).
- Communicating and cooperating with other agents in the environment including interaction with humans (communication module).
- Perceiving and recognizing the situation including other agents in the environment, ability to learn and imitate. (behavior module).
- Formulating it own goals (goals generator).

CMU: Moravec chart, 1973

1. Devět obrázků okolí, významné body, výpočet hloubky v těchto bodech.
2. Sdruž informaci z jednotlivých pohledů do globální mapy světa.
3. Páruj současné obrazy s dřívějšími a odhadni vektor pohybu robotu.
4. Na základě současné polohy, rychlosti, cíle cesty urči, kam se nyní pohybovat.
5. Vykonej pohyb.

Robotics as the perception – action cycle



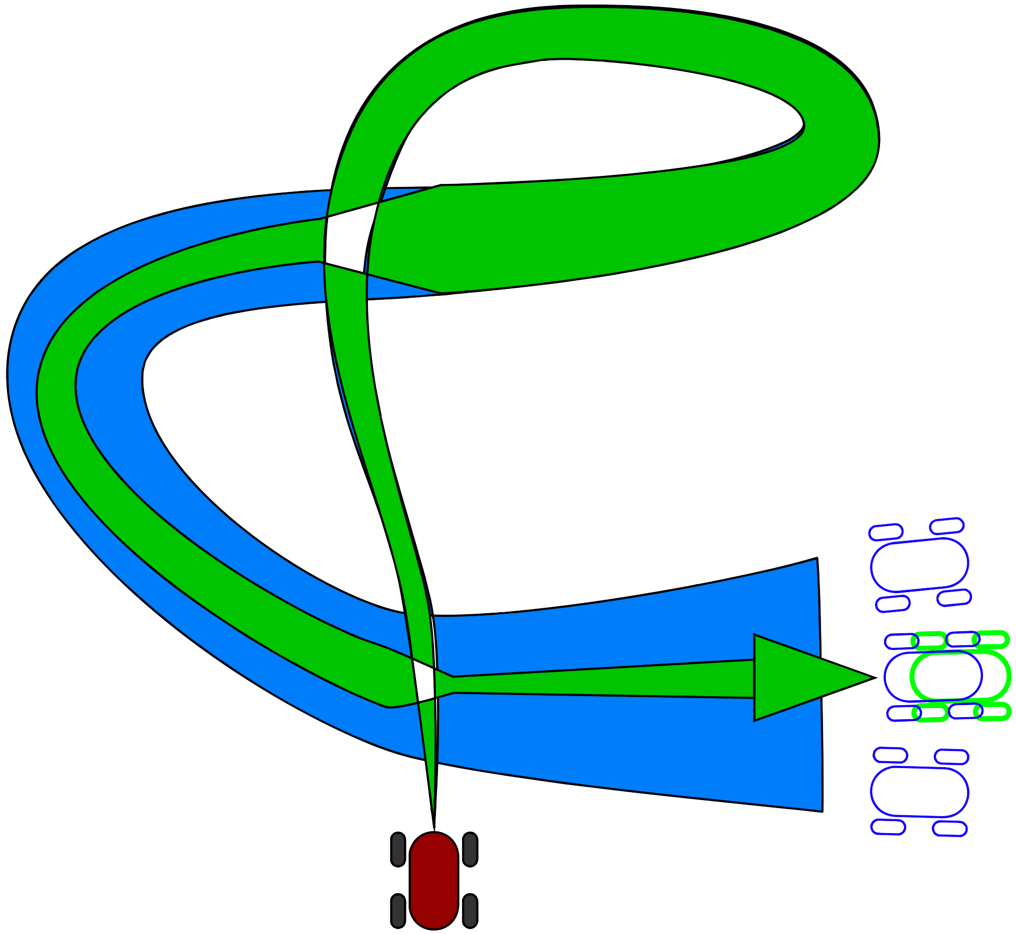
Odometry vs. SLAM

Odometry

- Incremental growth of the position uncertainty.
- Optimization methods used.

Visual SLAM

- Carthographic memory.
- Closing the loop ⇒ decrease of uncertainty.



Visual odometry example

From Google Street View to
3D City Models

Input Omnidirectional Image Sequence

A. Torii, M. Havlena, T. Pajdla

Czech Technical University in Prague

Conclusions

- Robotics and cognitive systems research makes our way forward towards machines endowed with ‘human’-like abilities.
- Many innovations appear as a side effect.
- Project selection is as good as the referees who decide about proposals.

- **Thank you for your attention.**

Poděkování: projekt RobotCub
José Santos-Victor, IST Lisbon