



Robotics 1

Service robotics

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DIPARTIMENTO DI INGEGNERIA INFORMATICA
AUTOMATICA E GESTIONALE ANTONIO RUBERTI



SAPIENZA
UNIVERSITÀ DI ROMA

Some application domains



- extreme environments
 - space
 - underwater
- medical robotics
 - assistive
 - rehabilitative
 - surgical
- home cleaning
- agriculture
- lawn mowing
- food industry
- mine exploration
- de-mining
- civil and naval construction
- automatic refueling
- museum guide
- fire fighting
- inspection and surveillance
- emergency rescue
- entertainment
- humanoids

professional & personal service robots

Service robots on the market!



Bluebotics Esatroll - Paquito 2.0
logistics in factory floor



Yujin GoCart2
elderly and health care



Cyberdyne HAL
exoskeleton for walking



Lely Vector automated feeding

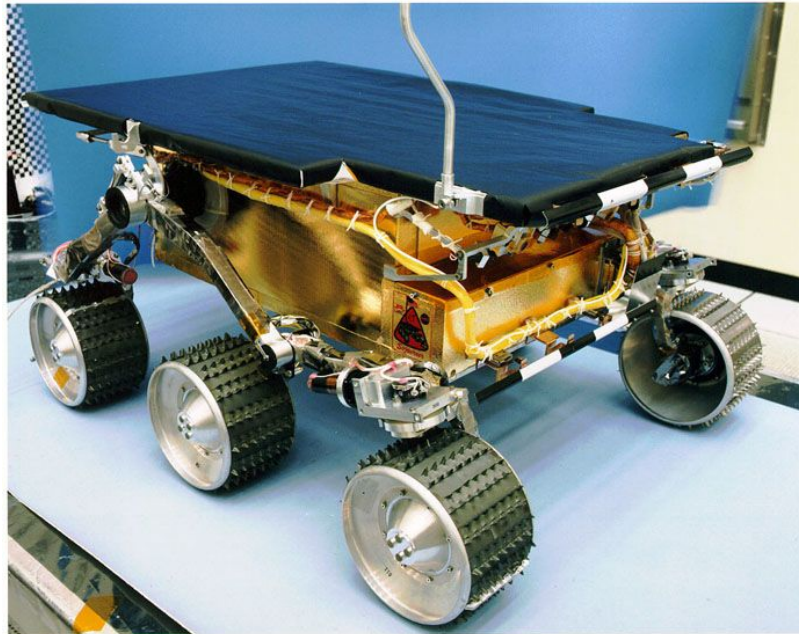


Vorwerk
vacuum cleaner

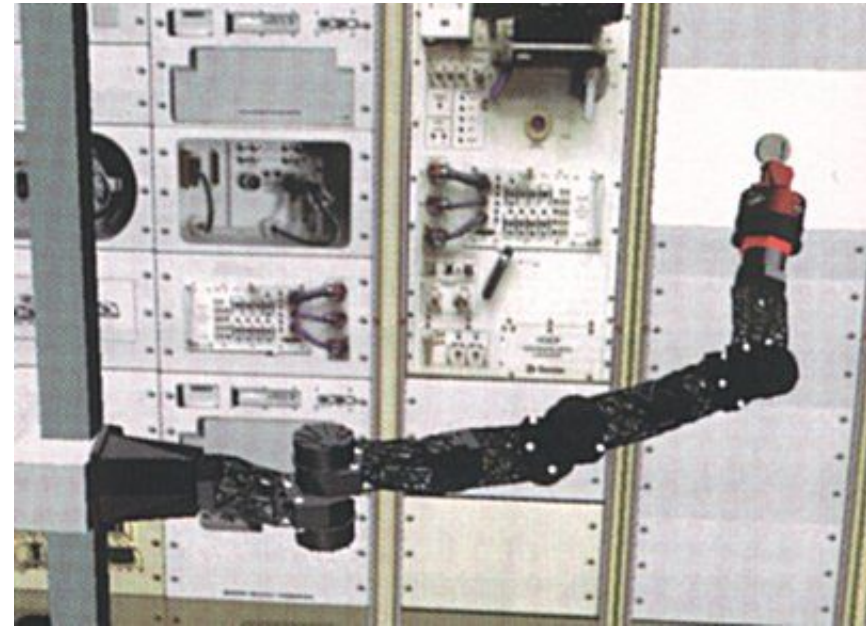


Thymio educational
mobile robot

Space robotics



- NASA *Sojourner*, first robot to explore Mars in 1997



- DLR *Rotex* robot arm in a set of experiments of the Spacelab-D2 mission on the Columbia shuttle in 1993

Space robotics

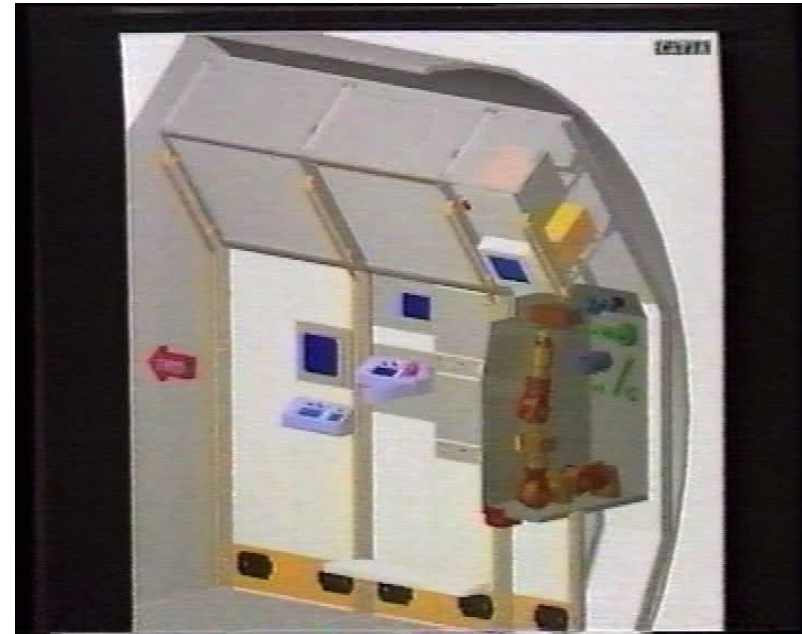


video



wheels untrapping
on sandy soil

video

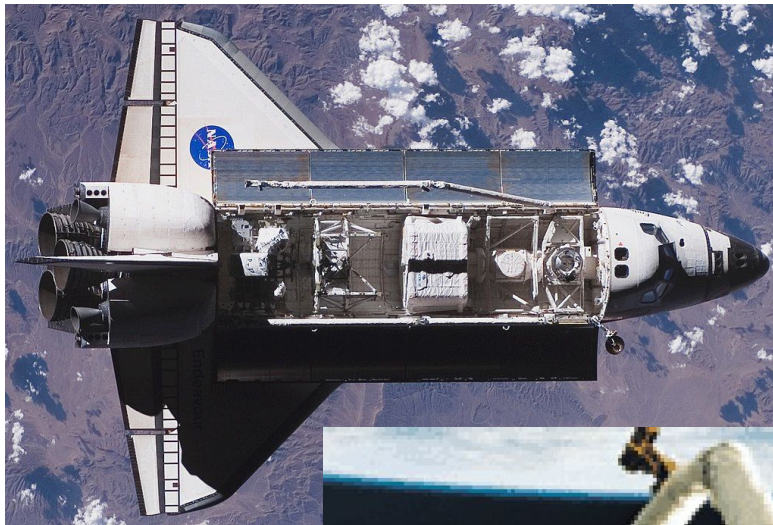


assembly tasks and
catching floating objects
with *Rotex*

Space robotics



- robotic arm *SSRMS (Canadarm)* in operation on the Space Shuttle, with outstretch of about 17 meters



- service manipulator *SPDM (Dextre)* on the International Space Station (ISS), mounted on a supporting rail and used to refuel satellites

Robots on ISS



video



video



Canadarm2 delivering Destiny Lab
from Space Shuttle Endeavour to ISS
(about 2007)

service manipulator and Robonaut
on the ISS (artistic views)

Underwater robotics



- Odyssey-IV (MIT)



- Odin-III, **omni-directional** (University of Hawaii)

- typically actuated by thrusters (directional forces on the tail)
- cannot translate sideways ("maneuvers" are necessary)



- ROMEA in Antarctica (CNR, Automazione Navale, Genova)

Underwater robotics



Ansaldo underwater arm performing a cable hooking task (SAUVIM project)

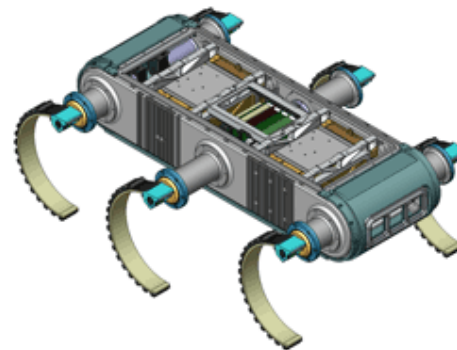
video

video

UBC Gavia underwater robot (University of British Columbia)

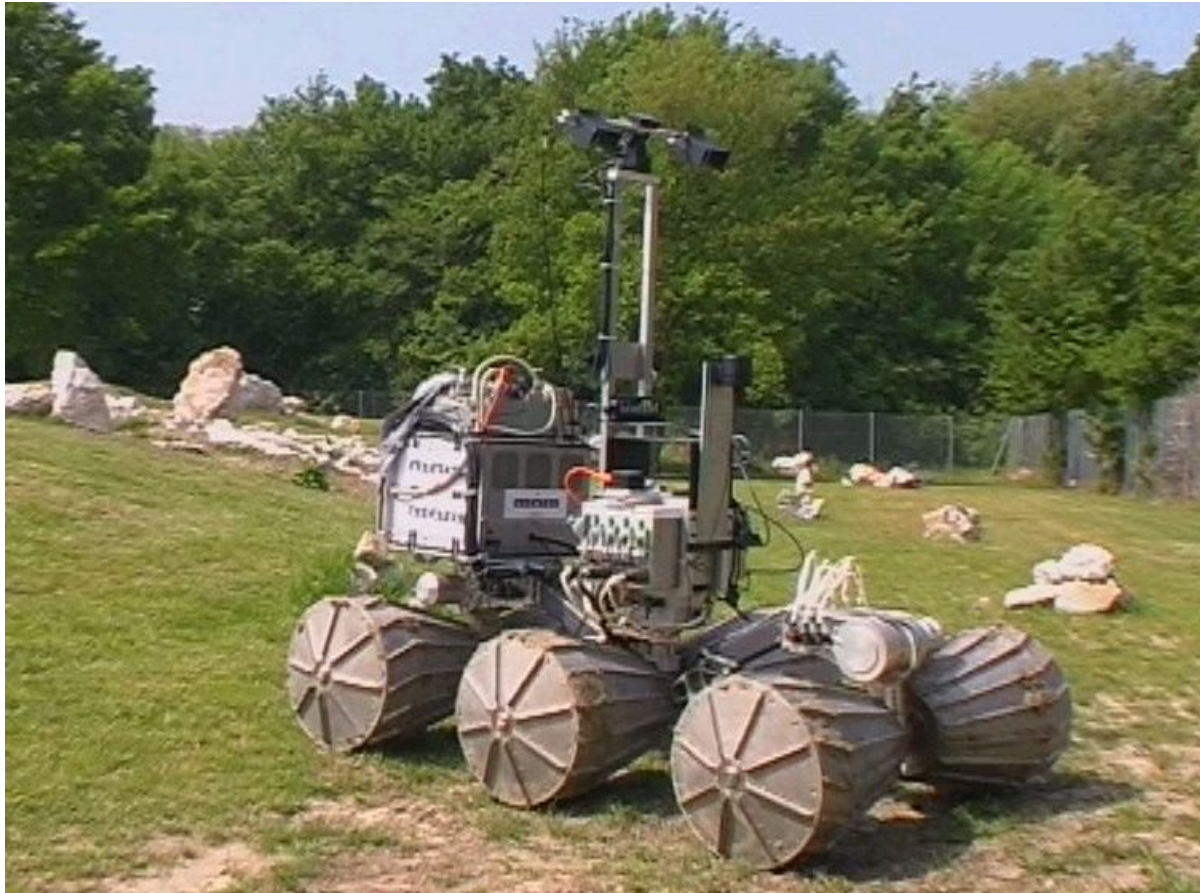


Underwater robotics



- Aqua robot, amphibious robotic vehicle (McGill University)
- size and weight: 50x65x13 cm, 18 kg
- locomotion: through six independently actuated flippers
- maximum depth: 37 m
- sensors: two cameras (front/back), acoustic sensor for localization (sonar), tri-ocular sensor (structured light)
- power source: 48V lithium battery

Outdoor exploration



- the *LAMA* robot at CNRS-LAAS (Toulouse) is a french-russian cooperation

Volcanology



video

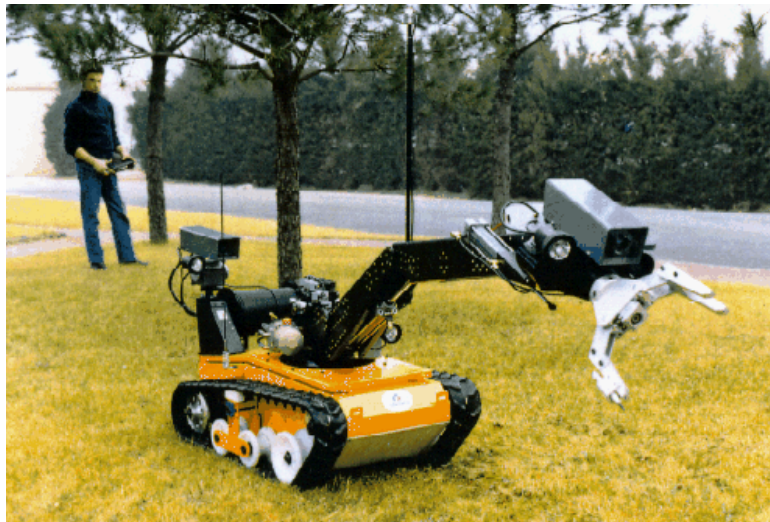


video



RoboVolc vehicles on the surface
of the Etna volcano:
wheeled and tracked robots
(University of Catania, 2003)

De-mining



- teleoperated mobile robot on tracks used by the police for bomb disposal



- PEMEX lightweight anti-personnel mine detector (EPFL, Lausanne)
- weight: 16 kg, max 6 kg for wheel
- two 70 W DC motors (vel 2 m/s)
- oscillating sensorized head

Medical robotics

patient aid



- deambulation support system
PAM-AID (Trinity College, Ireland)

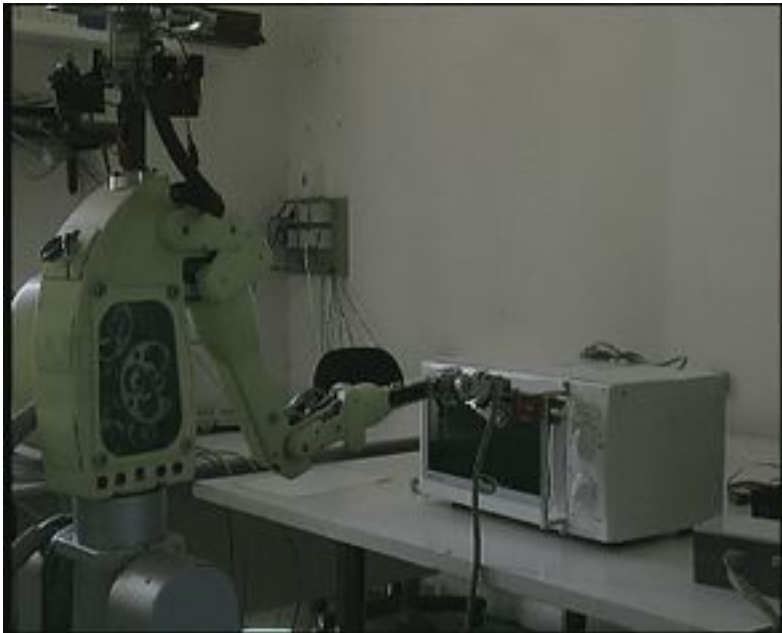


- *MOVAID* project for the aid of disabled people in home activities (Scuola Sup Sant'Anna, Pisa)

MOVAID project



video

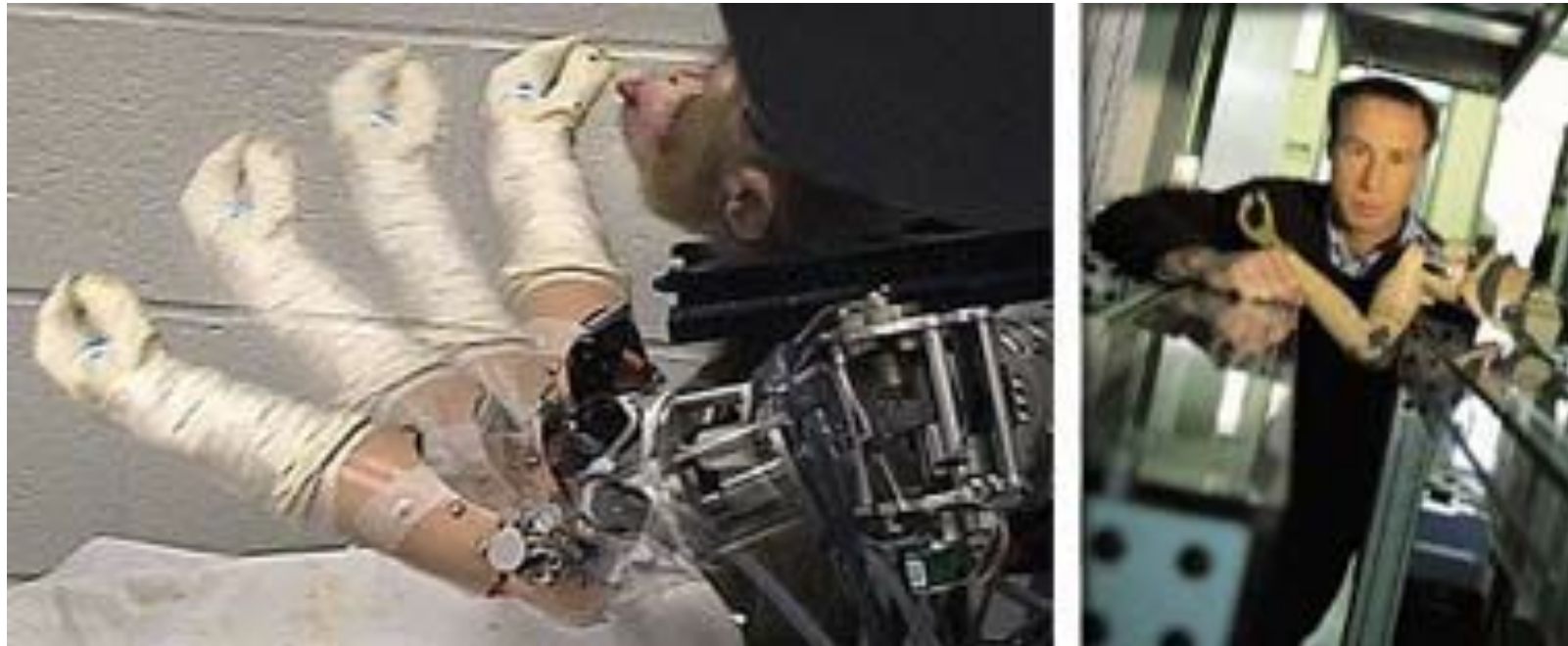


video



domestic activities using the 8R *Dexter* arm

Medical Robotics rehabilitative



- robotic arm with shoulder and elbow having full mobility and with a gripper hand (Pittsburgh University)
- in tests on monkeys (with immobilized upper limbs), motion commands sent to the arm by the central nervous system (brain) are measured by a set of electrodes and used to command the robotic arm

Medical robotics rehabilitative



- commercialized by Ossur (Iceland)
- a prosthesis sensorized at the knee (angle and force), capable of processing sensor data and of extracting a gait model of the user, so as to adapt its dynamical behavior (knee motion and stiffness)

Medical robotics rehabilitative



- "RUPERT" Robotic Upper Extremity Repetitive Therapy (Arizona State University + Kinetic Muscles, Inc.)
- sustains the human arm with pneumatic muscles (McKibben actuators)
- it can be programmed for the execution of cyclic exercises of rehabilitation

Exoskeletons



video



SARCOS master-slave for teleoperation

Medical robotics

hospital and nursing



video



- *HELPmate* mobile robot (USA) works in hospitals as auxiliary personnel



- user interface of the *Care-O-Bot* robot nurse (IPA Fraunhofer, Germany)

Surgical robotics



overview of the operating room



command station



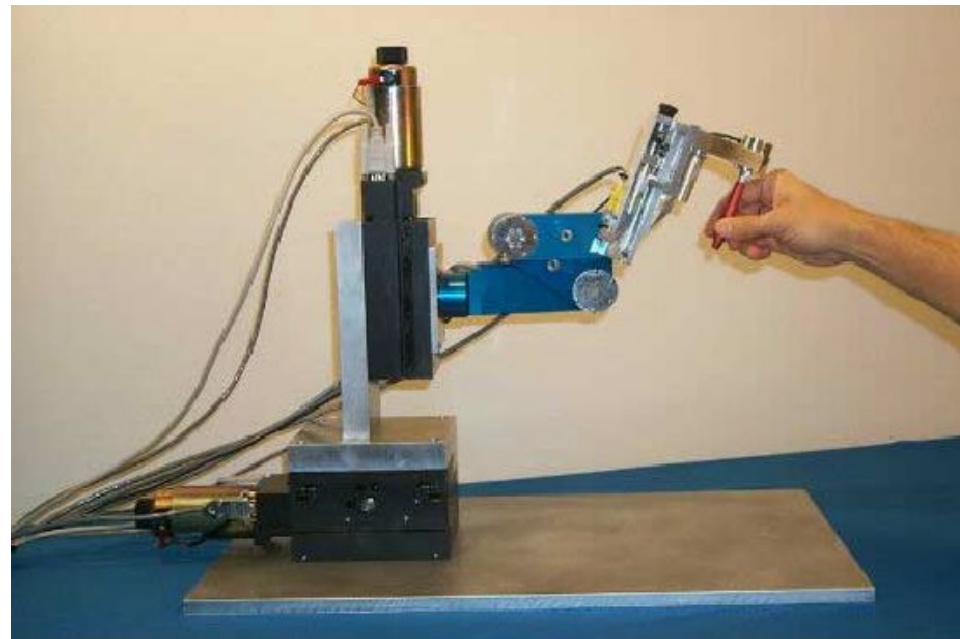
(haptic) interface

- da Vinci[©] system (Intuitive Surgical Inc.)
[see the course "Medical Robotics"]

Surgical robotics

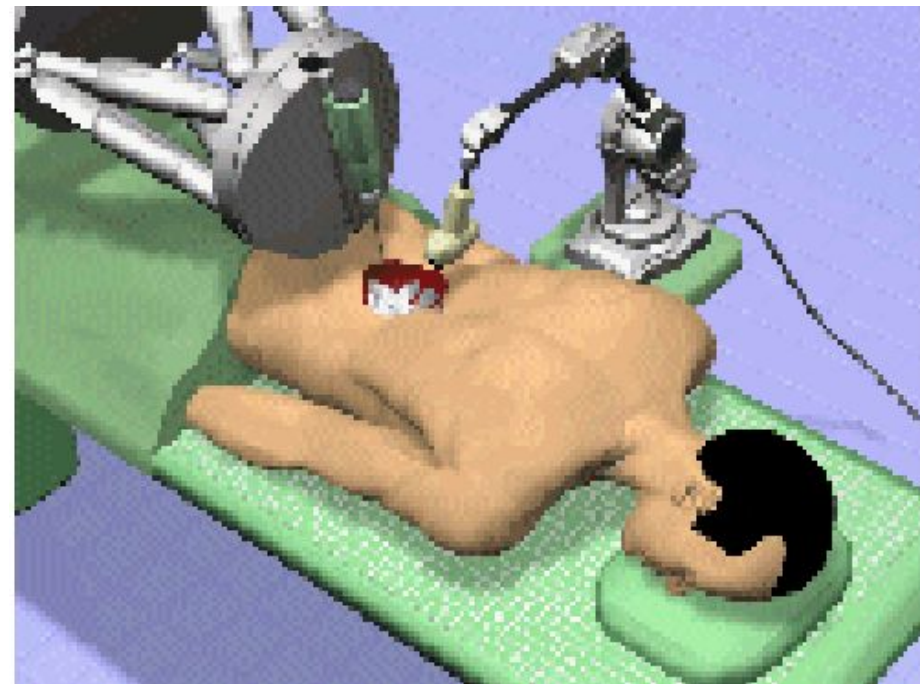
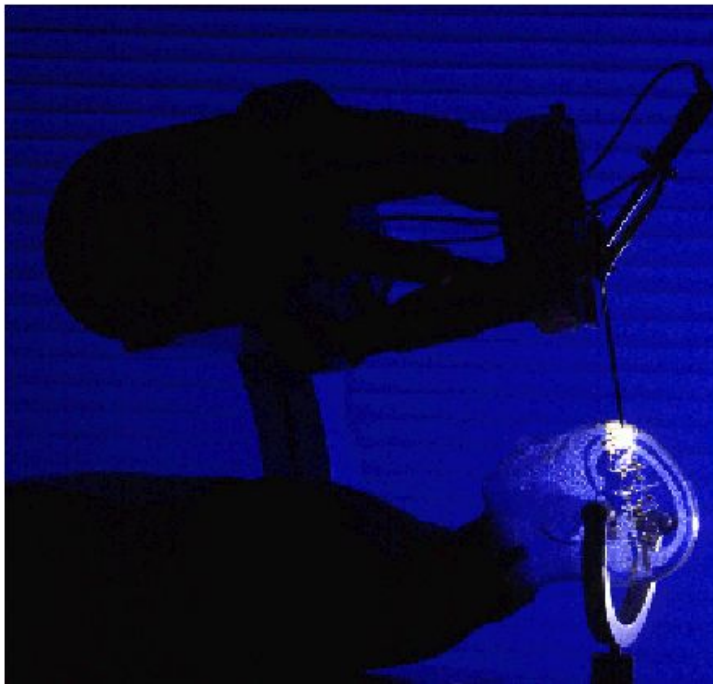


- *Robodoc* by Integrated Surgical Systems (USA) was used first for orthopedic surgery (ankle replacement)



- *Steady-Hand* force-assisted system (Johns Hopkins Univ) improves accuracy and repeatability of surgeons allowing task-driven compliance

Surgical robotics



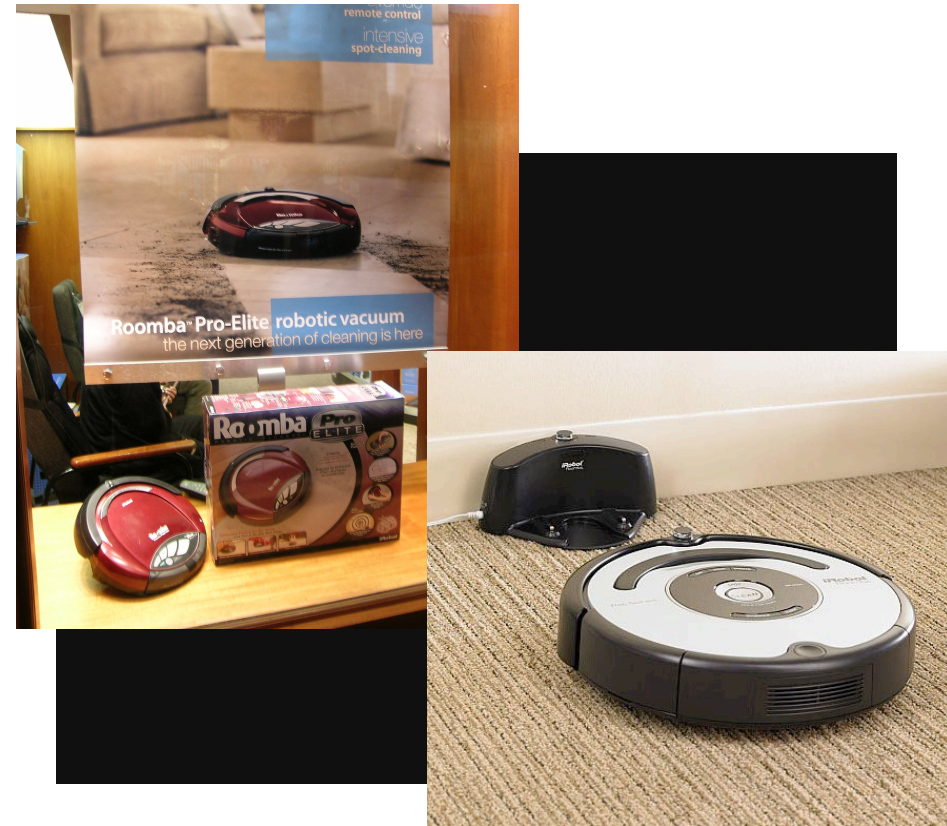
- emulation of a laser brain surgery operation and graphic rendering of a surgery intervention on the spinal cord patient is first "mapped" off-line by a series of CAT scans; data are then "localized" in the actual operation field (IPA Fraunhofer)



Home cleaning



- vacuum cleaner robot
Trilobite by Electrolux (Sweden)



- commercial **video**
iRobot *Roomba 560* (USA)
— now available everywhere!

Cleaning robot contest



- competition among robot vacuum cleaners in home environments (IROS'02, Lausanne)

Cleaning of external surfaces



- *Skywash* cleans civil airplane bodies and is “the largest robot worldwide” (AEG/Dornier/FhG-IPA/Putzmeister)
- a robot prototype for cleaning large glass windows of civil buildings

Lawn mowers



video

- *Automower* autonomous robot by Husqvarna (Sweden) has low power consumption (biocut) and solar recharge

Food industry



video



- *Ulixes* robot by IMT (Germany) aligns 10000 sausages per hour



- *AdeptOne* SCARA robot with 4-sausage gripper

Automatic refueling

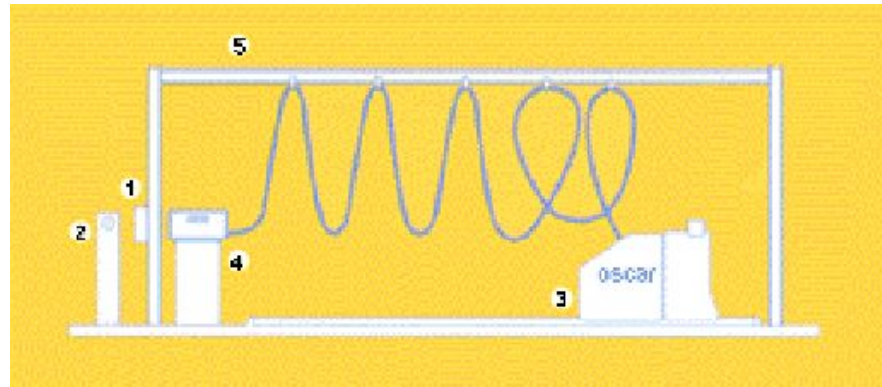


- cooperation of Reis Robotics, Mercedes, BMW, and IPA Fraunhofer



- *Smart Pump* system (USA)

Automatic refueling



- OSCAR robot (France) for gasoline refuel of fleets of transportation busses



Automatic refueling



a "kit" is available for all car models:
tank cap, transponder, pipe union

Autofill system in two tank stations of
OK (Mörgby, Sweden) and BP (USA)

Inspection and surveillance



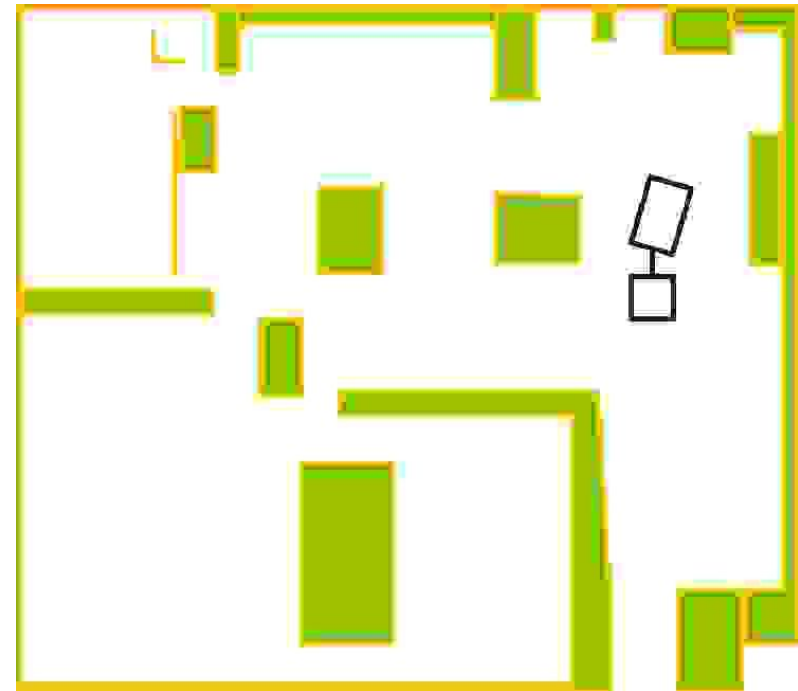
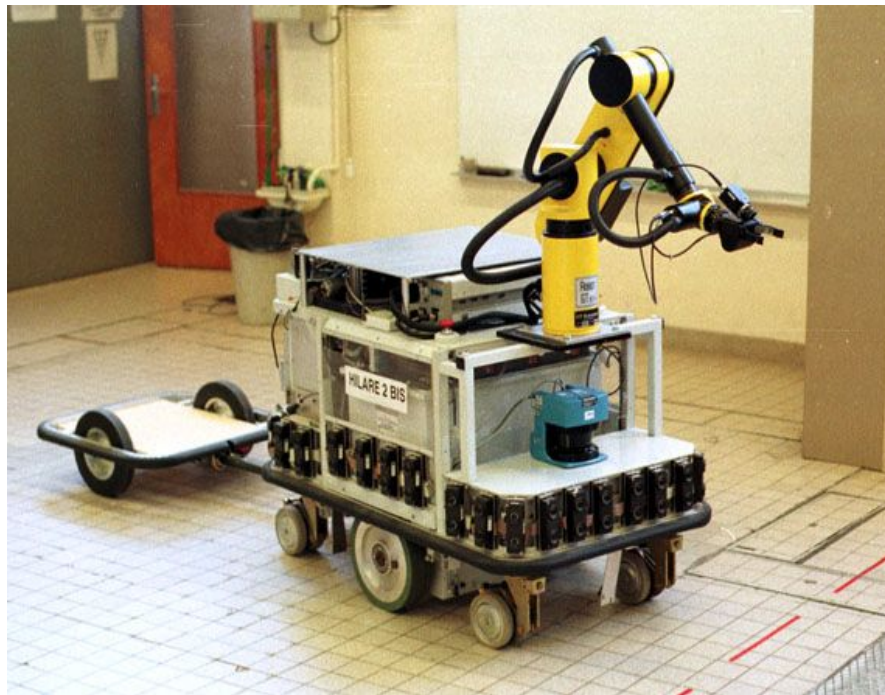
- 6-dof *Puma* arm mounted on the *Nomad XR400* (multiple steering wheels, synchro-driven)



- 5-dof *Scorbot* arm mounted on a *ATRV-JR* (fixed wheels, skid-steering vehicle)

two examples of
mobile manipulators

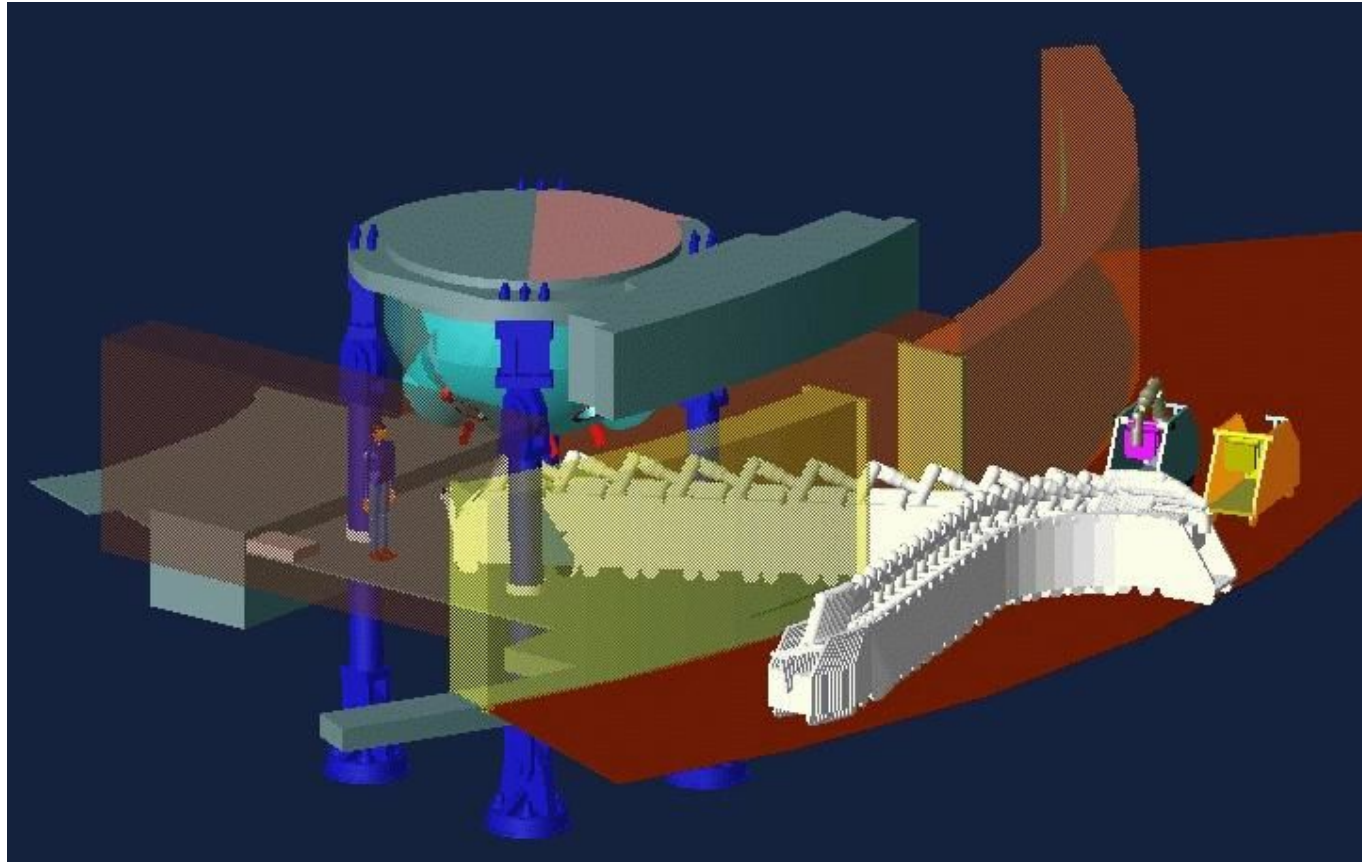
Inspection and surveillance



- *Hilare 2bis* mobile robot (LAAS), with trailer and manipulator arm, and its localization on a indoor map

sensors: encoders (on wheels and arm joints),
ultrasound, SICK laser, and camera on end-effector gripper

Inspection and surveillance



- motion planning of a robotized inspection task inside an electricity power plant (*Move3D* simulation)

Mine exploration



- *Groundhog* (Carnegie Mellon)
- 750 kg, double axes, articulated
- movable SICK laser (rangefinder)
- gas and immersion sensors
- SLAM algorithm (Simultaneous Localization And Mapping)

RoboCup and RoboRescue



- RoboCup middle-size league (wheeled mobile robots, here with omni-directional vision)
- *Orpheus* robot won the RoboRescue (exploration and search of victims in a disaster environment)

2003 edition, Padova Fair

DARPA Grand Challenge



5 SICK lasers for mapping and localization on the 2005 winning VW Touareg "Stanley"



the "Ghostrider" motorcycle testing in Nevada

- competition for fully **autonomous** vehicles on a long mixed-type track

DARPA Grand Challenge



video interview

video



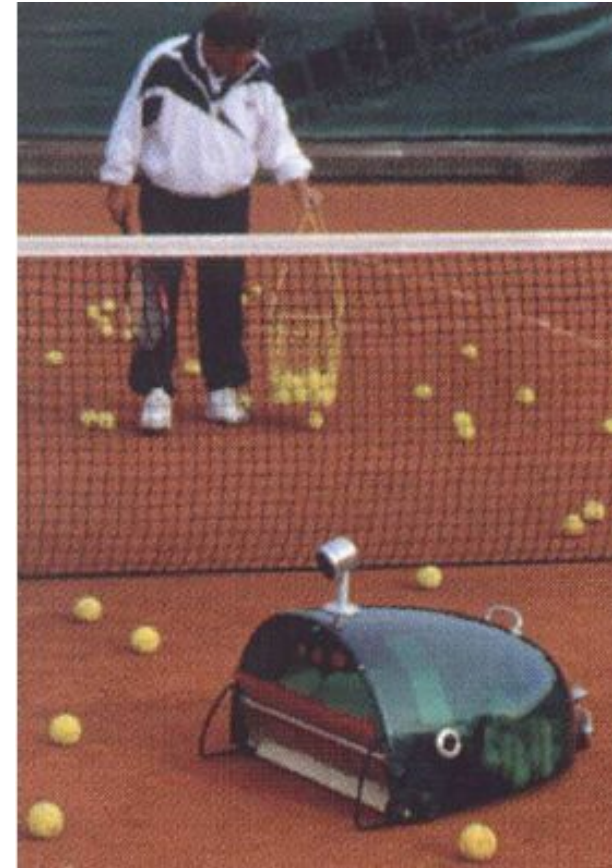
S. Thrun of **Stanford Racing**
(Stanford Univ+VW America+many more)

A. Levandowski of **Blue Team**
(LaRaison Inc+Univ Berkeley+Texas A&M)

Stanley navigation:
GPS, laser scanners,
vision, radar

Ghost Rider navigation:
GPS, inertial unit, motorcycle
dynamics, stereovision

Free time



- bartender robot by Erhardt+Abt (Germany)
- the robotic ball boy (RWI and Carnegie Mellon Univ, USA) that won in 1996 the "Clean up the tennis court!" competition of the AAAI



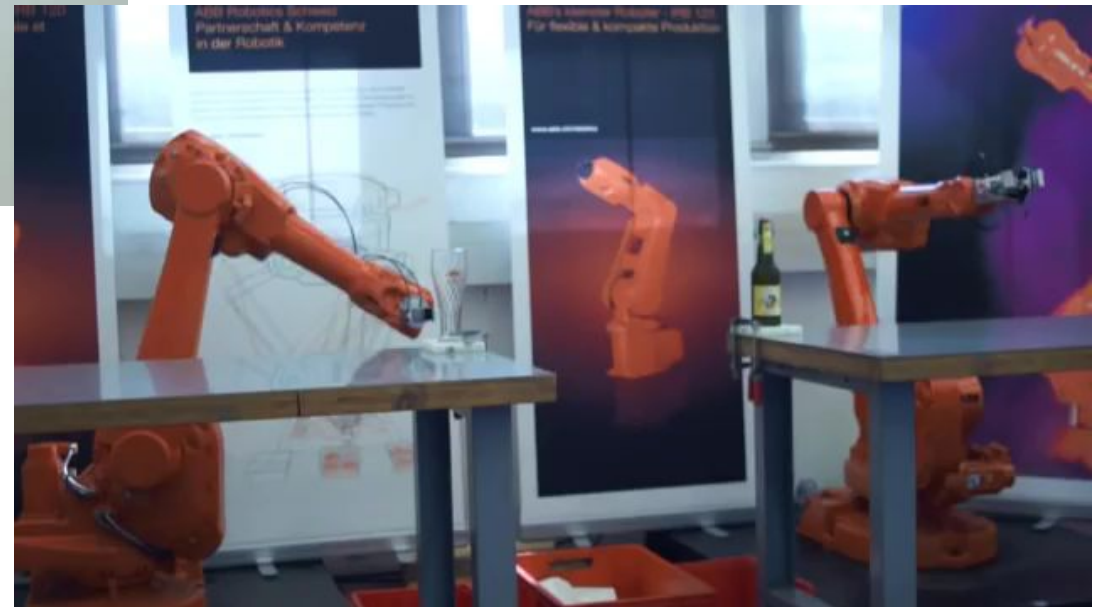
Robots filling a glass of beer



a single KUKA robot

video

two cooperating ABB robots



video

Museum guidance



- three mobile robots for museum guidance (Museum für Kommunikation, Berlin)

Entertainment



- the *Anaconda* robot (Edge Innovations, USA) weights various tons, has 60 artificial spinal vertebrae, is 12 meters long, and is actuated by hydraulic motors so as to reach a speed of up to 60 km/h

Human motion replication



- the anthropomorphic robot by Sarcos Entertainment Systems (USA) replicates the movements of a human wearing a sensorized exoskeleton

Human-Robot Interaction



- **physical** and **cognitive** interaction between a Sarcos robot and a human
intrinsic mechanical compliance in the robot structure
is here more important than accuracy in motion execution

Human-Robot Interaction (HRI)



video



cognitive interaction (cHRI)
in **Robot@CWE** EU Project

video



physical interaction (pHRI)
in **PHRIENDS** EU Project

Human-robot collaboration

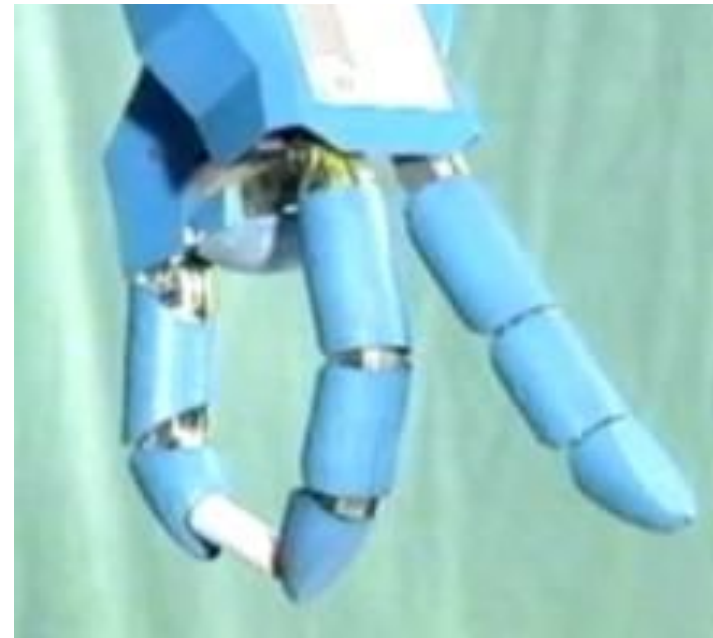
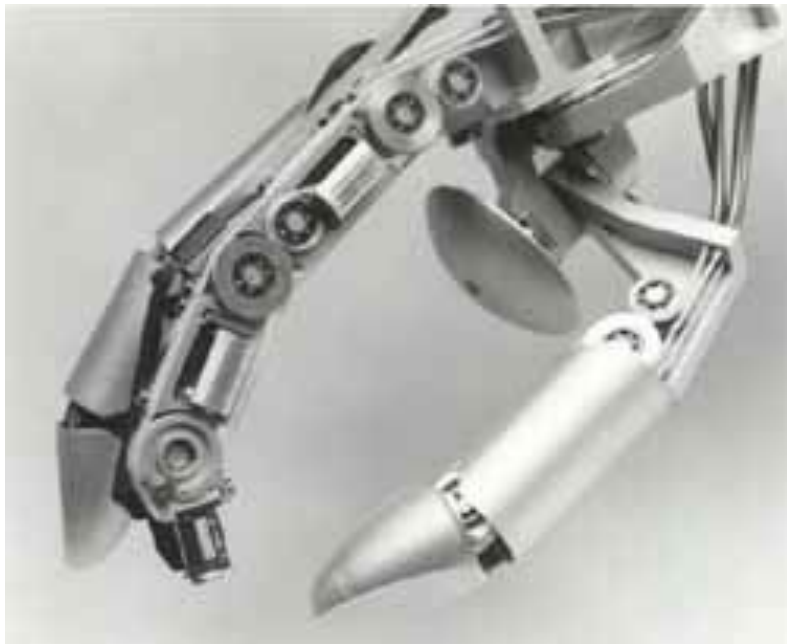


- *Mr. Helper* (Tohoku Univ) collaborates in carrying heavy and/or large loads



- *CoBot* scooter-like robot for mounting car doors (General Motors)

Robot hands



- the *UBHand* series of robot dexterous hands (Univ Bologna)
 - 3 fingers with 9 degrees of freedom, tendon actuation, supporting palm, and tactile sensors on all phalanges

Anthropomorphic UBHand IV

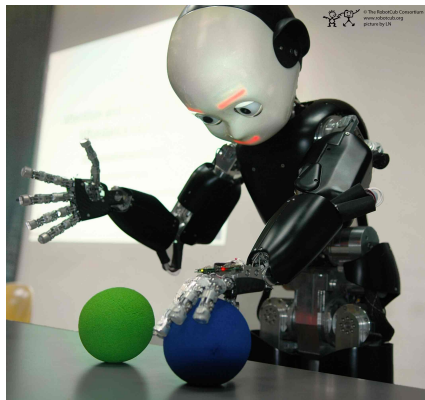


video

← data glove
for motion
capturing

- the *UBHand IV* has **deformable** elements as joint hinges (compliant mechanisms); the endo-skeletal structure with **5 fingers** may host distributed sensors and continuous compliant cover (G. Vassura, Univ Bologna)

New robot hand for the iCub



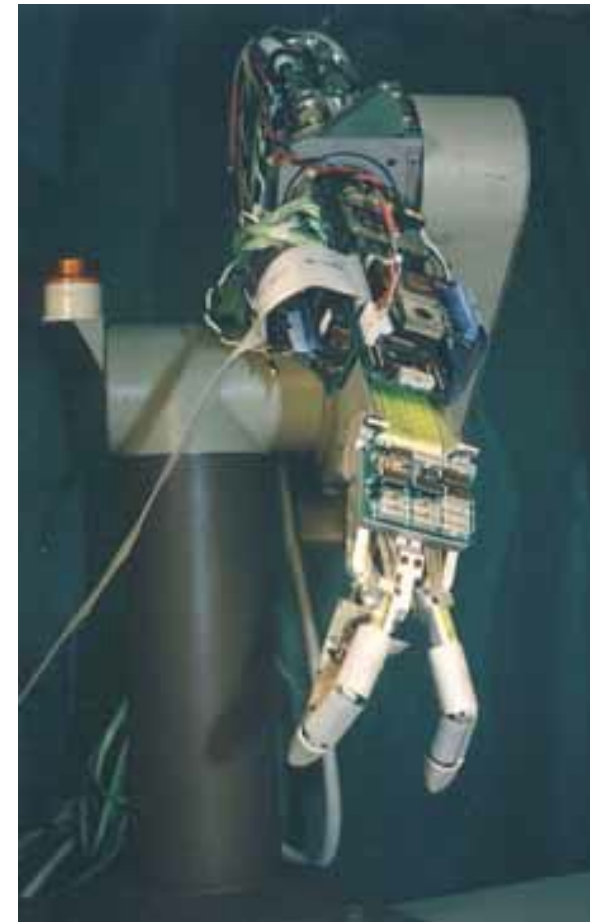
video

- *iCub* robot is like a 3.5y old child, developed by IIT Genova in 2005 in the [RobotCub](#) EU Project (platform distributed openly, with open-source SW)

Integration of robot hand + arm



- the complete *UBHand II*, with electrical motors and electronics presented at EXPO92 in Seville
 - integration in the forearm of the *Unimation PUMA 560*



... “minimalistic” solutions



video

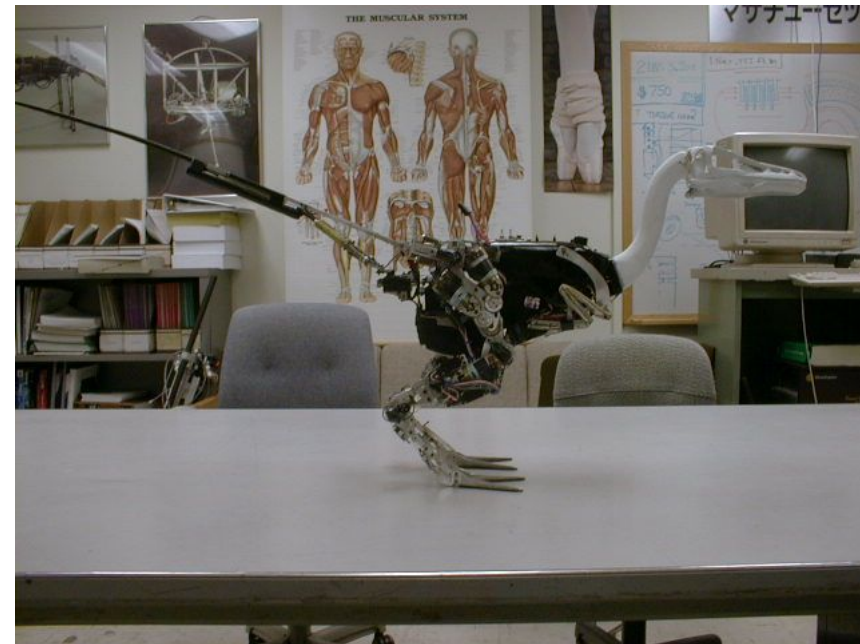
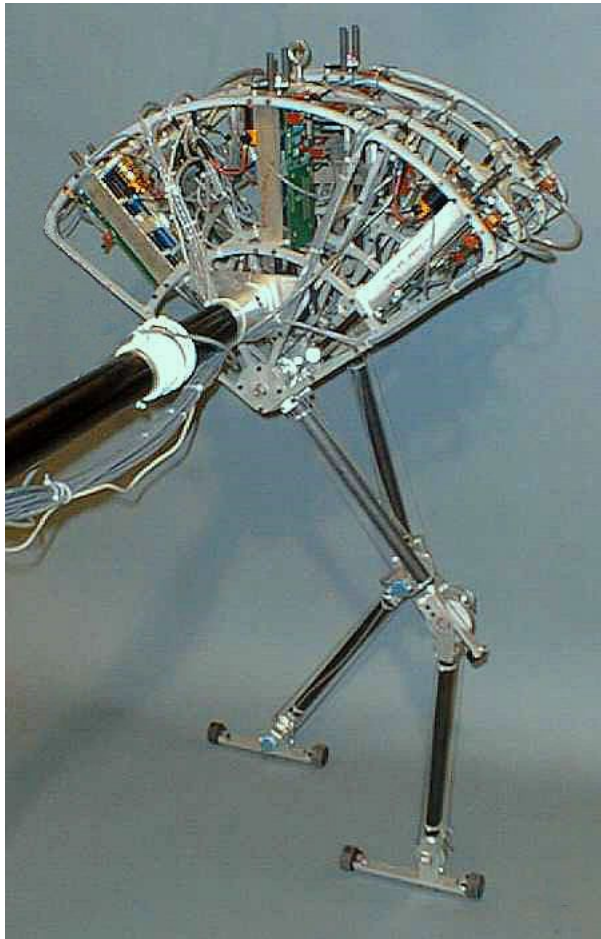


- **5D manipulation** of objects having arbitrary form, using only two linear actuators and sensorized contact surfaces (Univ Pisa, about 15 years ago)



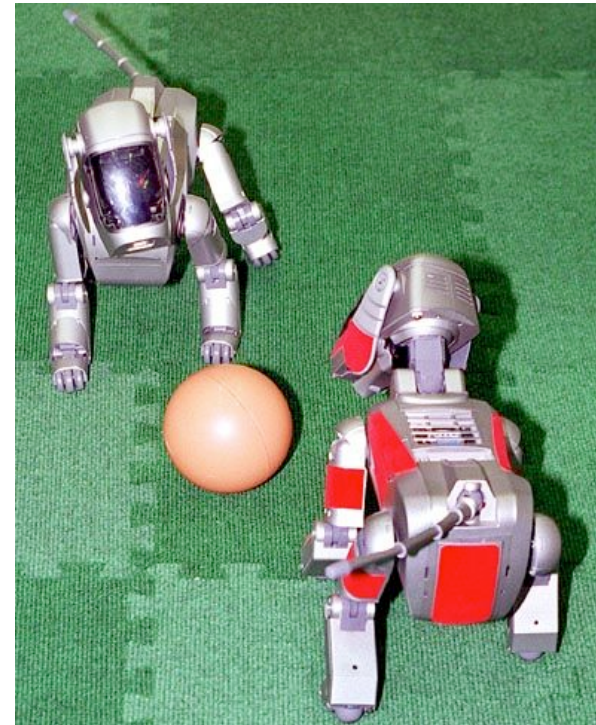
- **1 motor only** for the *Soft Hand*, an articulated and compliant robotic hand of human size and synergy (Centro “E. Piaggio”, Univ Pisa – IIT, 2014)

Biomorphic robots



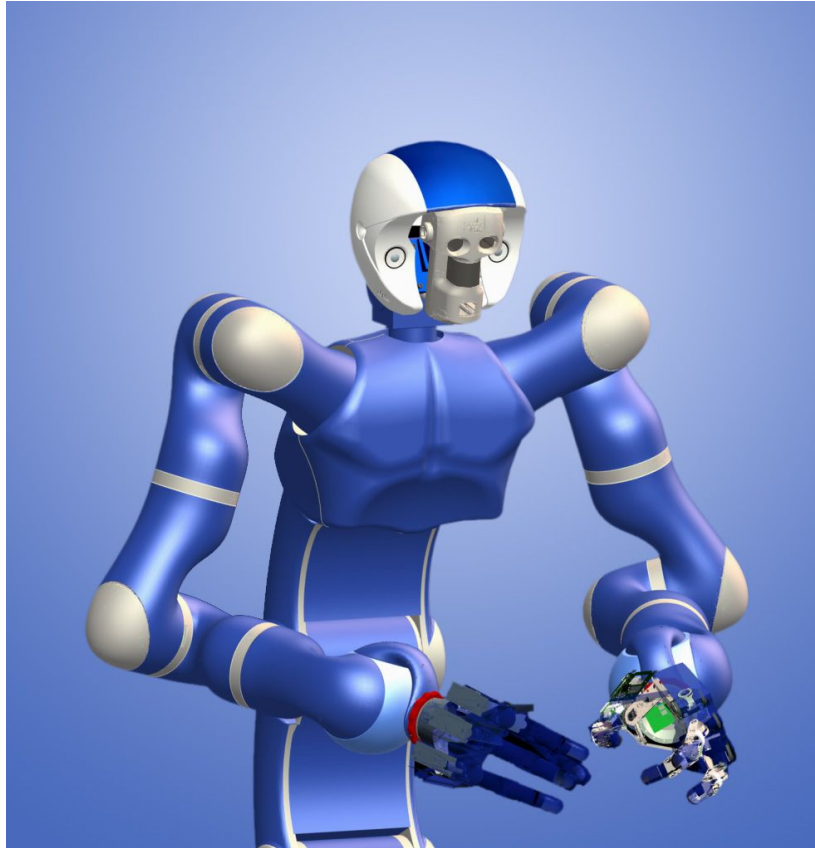
- biomorphic robots by MIT Leg Lab, USA:
Troody dinosaur and *Flamingo* bird

Four-legged locomotion

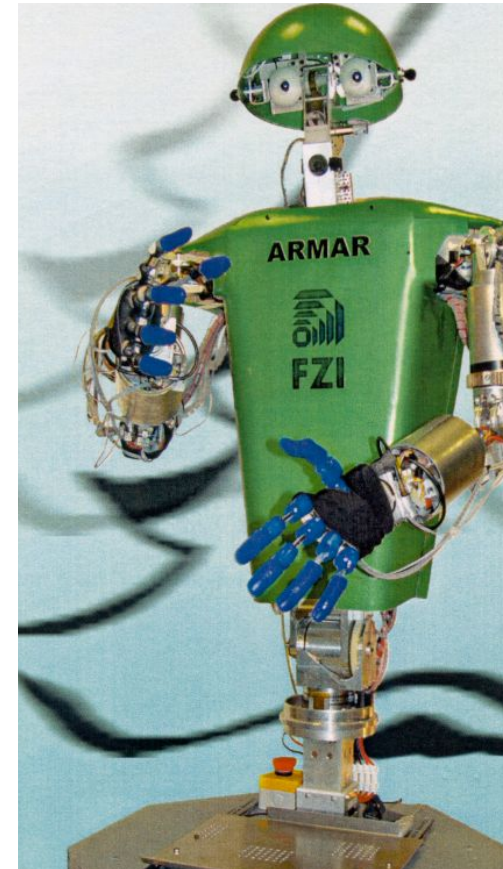


- *AIBO ERS-210* by Sony, playing on the soccer field of RoboCup
 - 16 actuated dofs with encoders, color camera, 3 accelerometers, ultrasound sensors, tactile and micro-switch (feet), battery: everything in 1.6 kg!

Anthropomorphic upper limbs



- *Justin* robot has 7+7+3 degrees of freedom + many dofs in the two hands (DLR, Germany)



- the robot developed in the German national project on humanoids

Justin robotic system @ DLR



video



Justin

A humanoid upper body system for two-handed manipulation experiments.

 Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Leibniz-Gemeinschaft

Humanoid robots

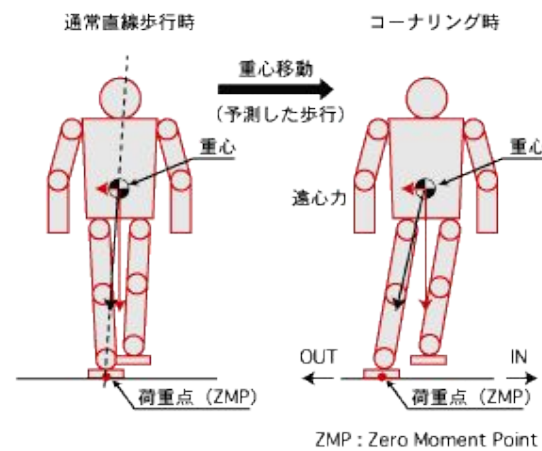


- Metropolis (Fritz Lang, 1927)



- Pino by ZMP (2003)

Humanoid robots



- the *ASIMO* project by Honda started in 1986



ASIMO in action

ASIMO
climbing stairs
(Robodex 2003)



first and
second series
(smaller size)

video



video

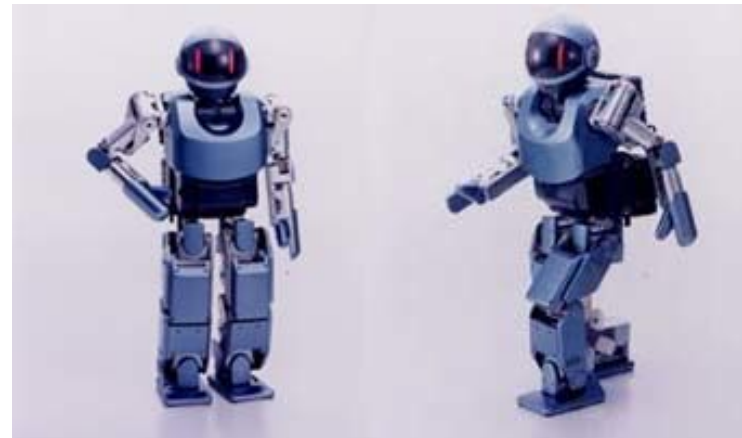




Humanoid robots



- *HRP-2*
(58 kg, 150 cm, 30 dofs)
2002 Tokyo Univ



- Sony *SDR-3X*
(about 60 cm)



- humanoid robot
(Q. Huang, PR China)

Sony Q-RIO



group dancing [video](#) (2003)

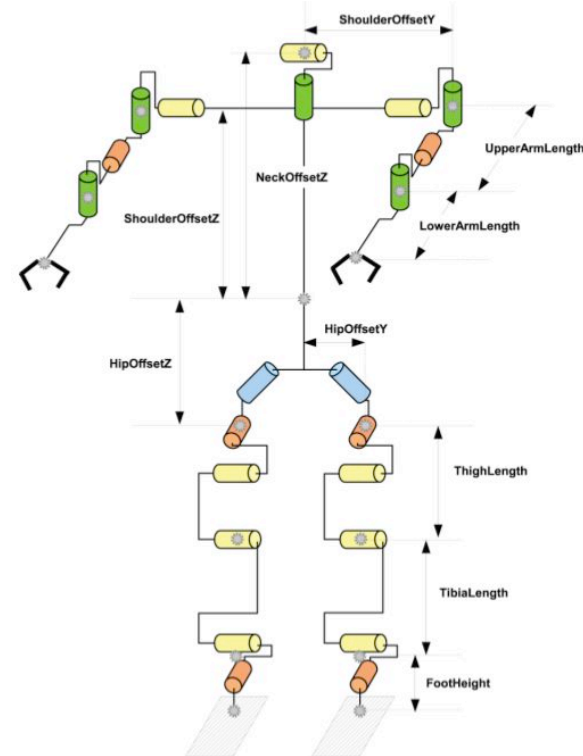
- Sony *Q-RIO*
the first robot able to balance on a surf and stand up from the floor
(dead in 2006...)



Humanoid robots



height = 57 cm
weight = 4.5 kg



kinematic
description

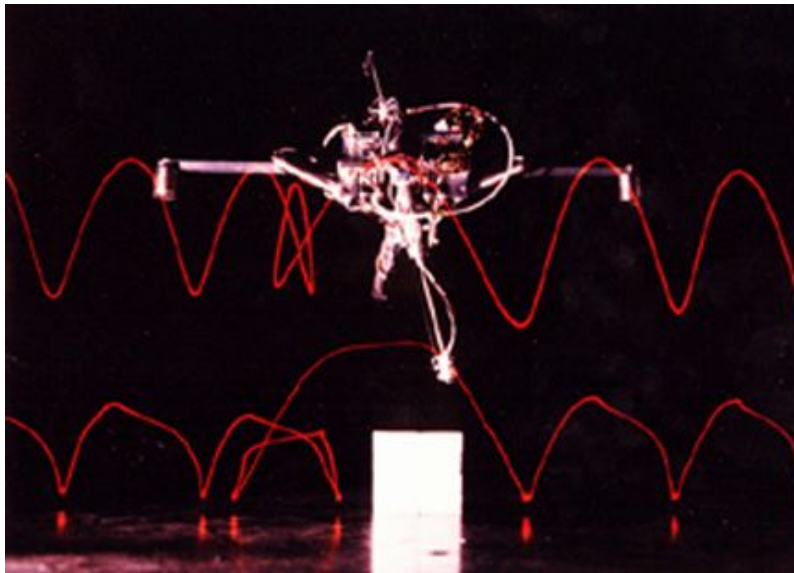
- NAO, Aldebaran Robotics
since 2008, replaces AIBO quadrupeds in RoboCup standard league

NAO playtime



Aldebaran Robotics
commercial [video](#)

... what about dynamic stability?



video

- the *One-Leg Hopper* robot (MIT, USA) demonstrated back in 1982 the feasibility of maintaining a purely **dynamic** equilibrium during motion

we could go on and on, forever...

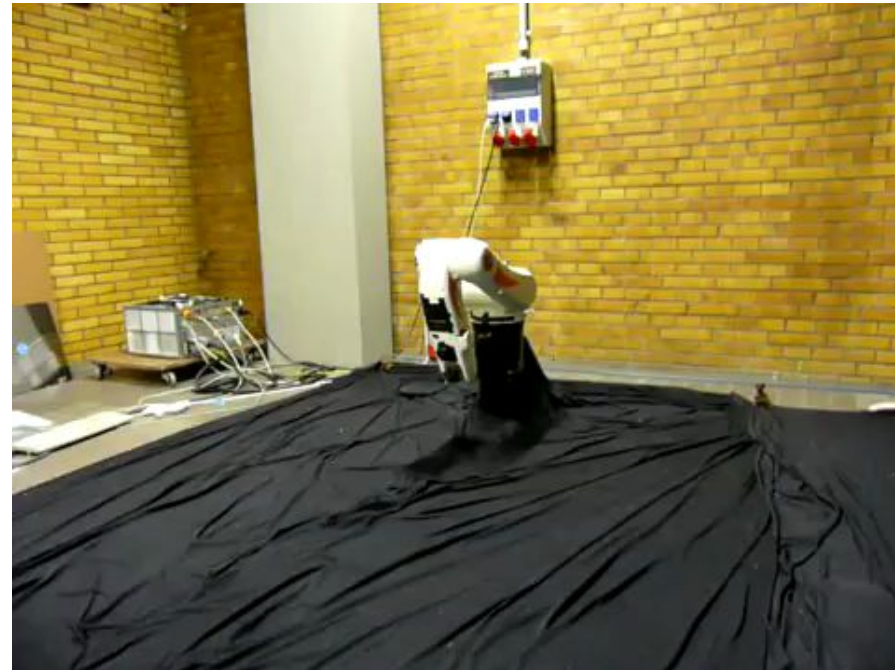


video

video



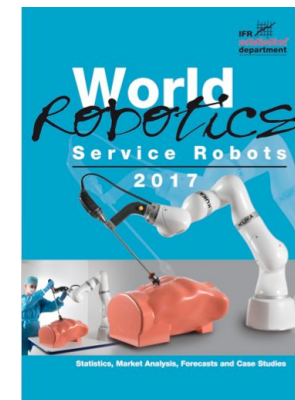
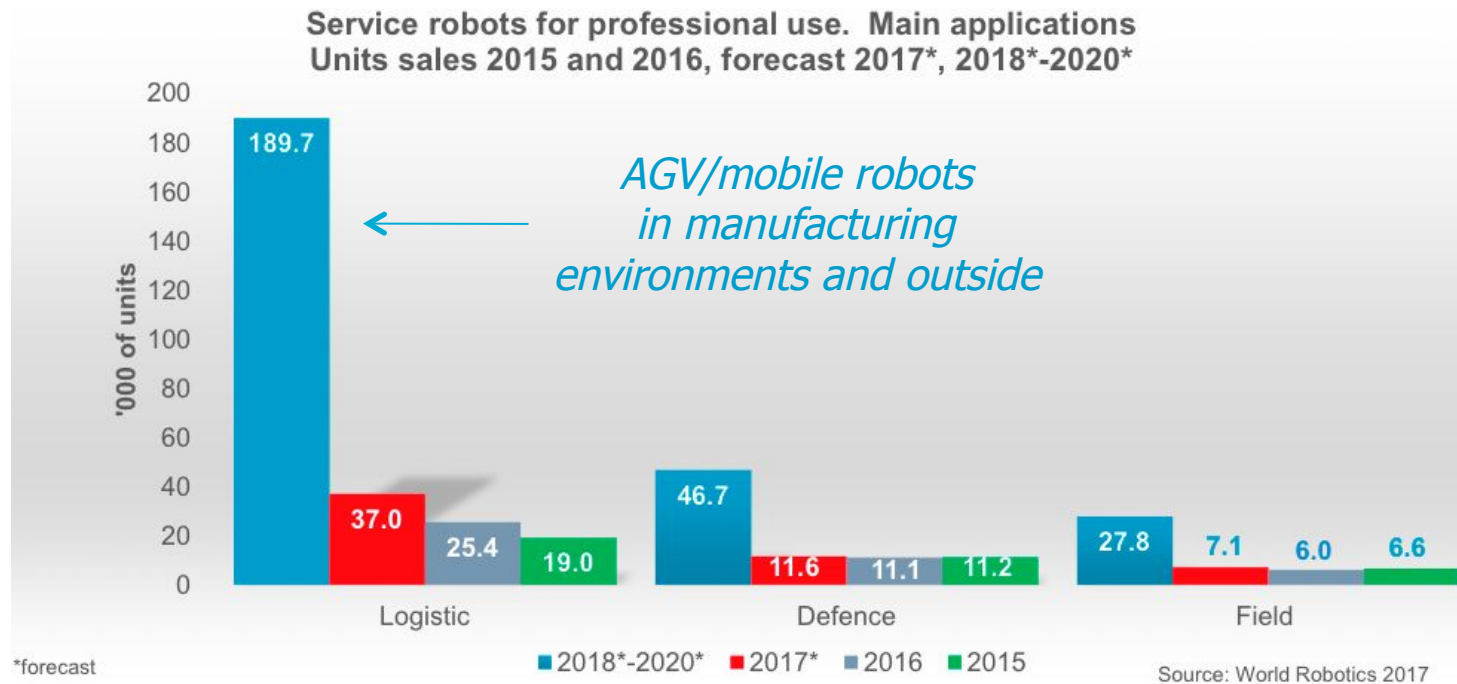
MIT planar two-legged robot doing a flip (1984)



ping-pong with KUKA KR5 robot

the beauty of **dynamics** and **juggling**

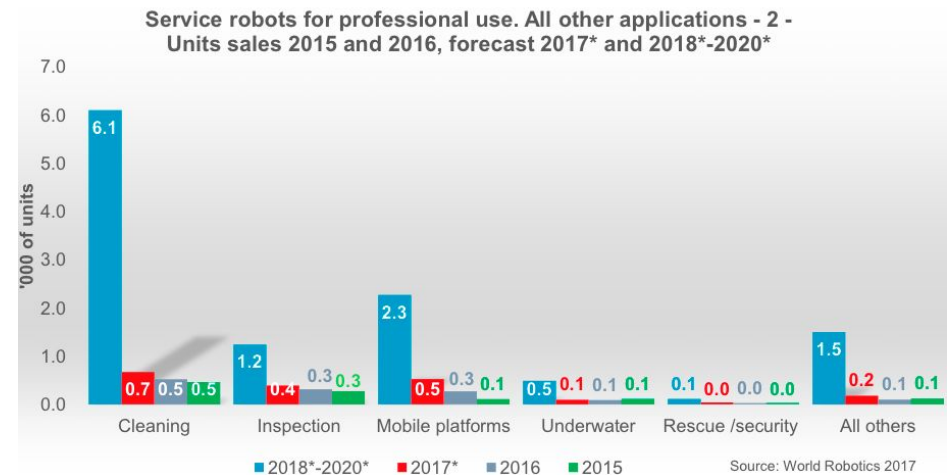
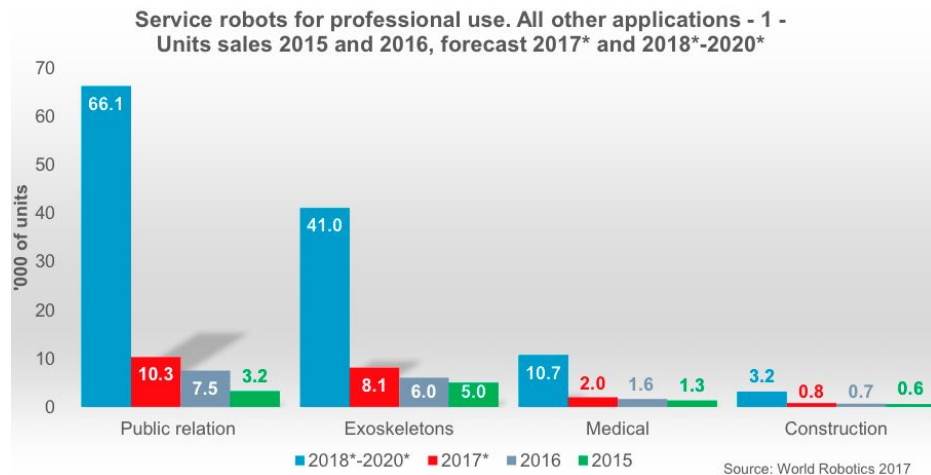
Diffusion of service robots for professional use



World Robotics
Report 2017

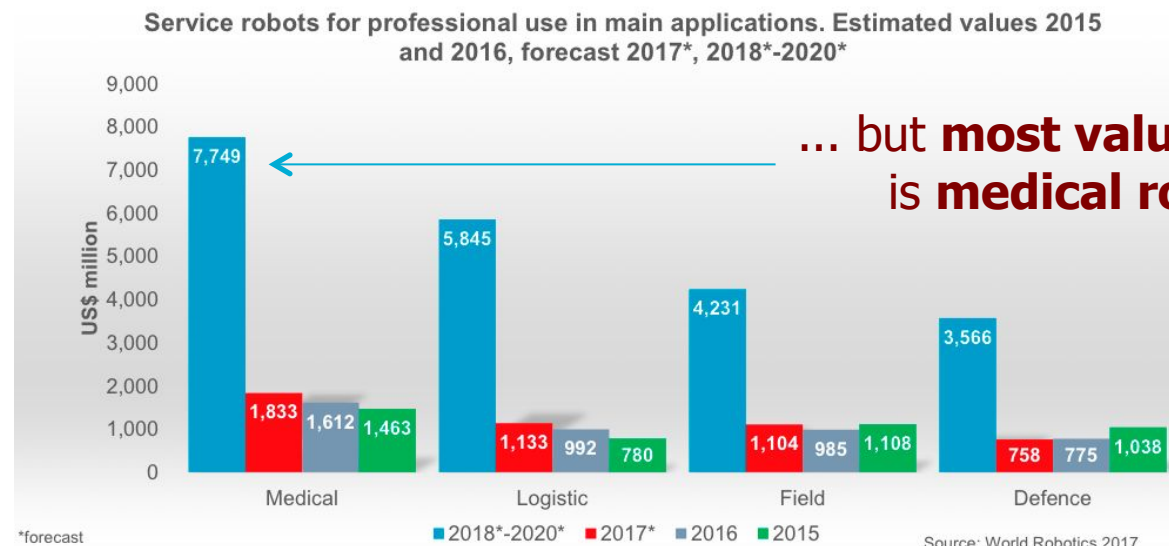
- main applications: logistic, defense (mostly, UAV), field robots (e.g., milking)
- almost **60,000** (+24%) service robots for **professional** use sold in 2016
- ~ **400,000** new service robots for professional use to be sold in 2018-20* (+45% estimate over last period)
- > 50% of professional service robots are manufactured in the Americas

Diffusion of service robots for professional use



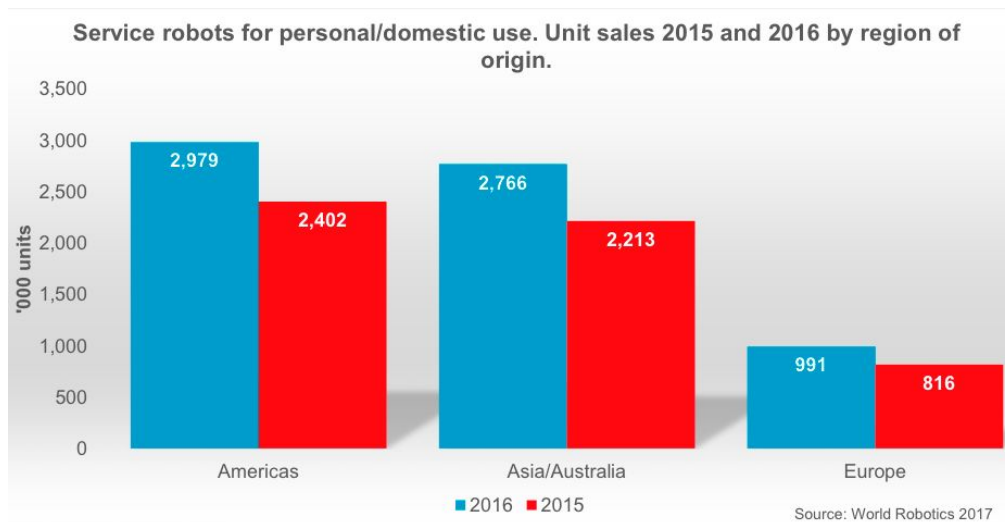
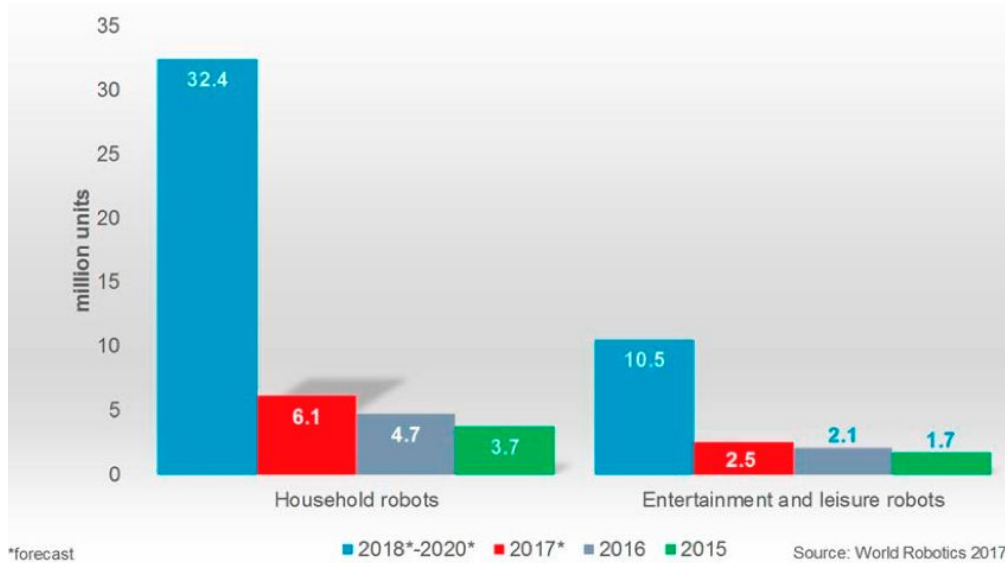
other applications: **social** (↗), exoskeletons (↗), medical systems (↗), construction, cleaning, inspection, agriculture, underwater, rescue...

public relation robots also expect significant increase in turnover (4.5 M\$ in 2018-20*)



... but **most valuable** market is **medical robotics!**

Diffusion of service robots for personal/domestic use

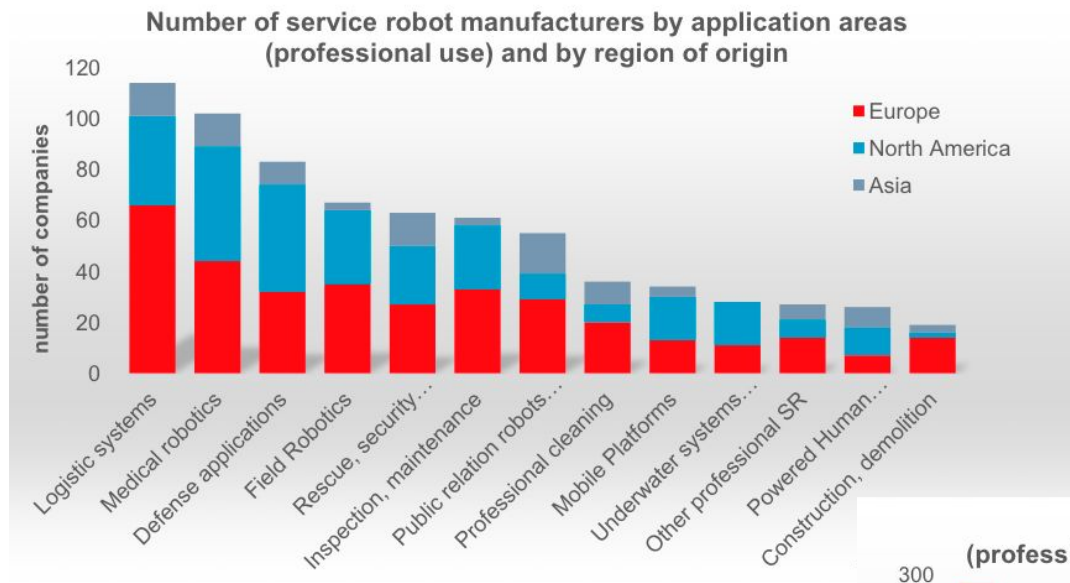


- personal/domestic robots market is **huge**: hard to assess figures due large variety in products and lifetime
- **6.8M units** sold in 2016 (+25%), for a value of **2.6 G\$** (+15%)
- forecast 2018-20*: **43M units**
- vacuum and floor cleaning robots
- lawn-mowing robots
- entertainment (e.g., Mindstorm) and leisure
- robots for elderly/handicap assistance



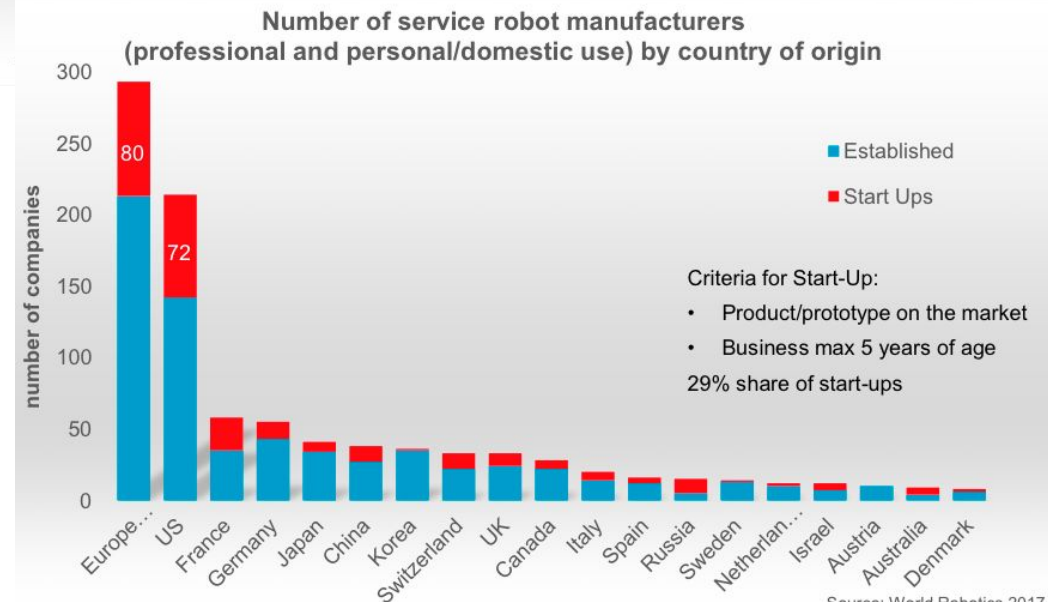
Diffusion of service robots

manufacturers by application areas and regions



- 75% of European service robot suppliers are SMEs
- many start ups ...

- 2/3 of all service robot suppliers use ROS (& other Open Source Systems)
- **key-technologies:** perception, human-machine interaction, mechatronics, safety



Source: World Robotics 2017

Web sites



- <http://ieee-ras.org>

The web site of IEEE-RAS (*Institute of **E**lectrical and **E**lectronics **E**ngineers - **R**obotics & **A**utomation **S**ociety*) with access to conferences, publications, technical committees, etc. – *become a student member of the IEEE-RAS !!*

- <http://handbookofrobotics.org>

Multimedia extension of the *Springer Handbook of Robotics* (2nd Ed, 2016), with >700 *free* robotics videos of historical and state-of-the-art value

- <http://www.eu-robotics.net>

The new *European Robotics AIBSL*, with euRobotics Forum & Week, etc.

- <http://www.euron.org>

***E**uropean **R**obotics research **N**etwork*, with a gallery of robots, videos, European robotics projects (no longer updated since 2012)

- <http://www.youtube.com/user/RoboticsLabSapienza>

YouTube channel of *DIAG Robotics Lab*, with videos of our latest research