



## ***Robotics 1***

# **Service robotics**

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AUTOMATICA E GESTIONALE ANTONIO RUBERTI



**SAPIENZA**  
UNIVERSITÀ DI ROMA

# Some application domains

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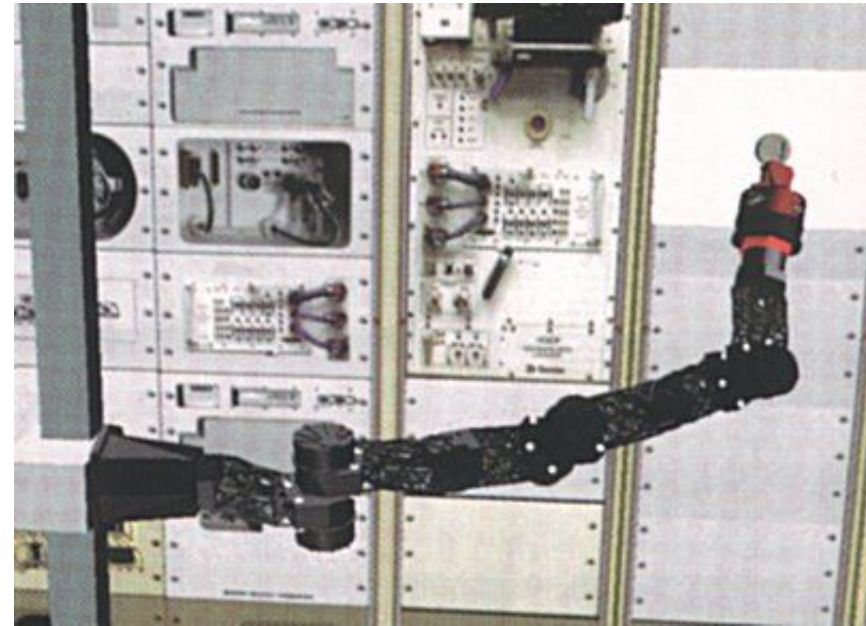
- extreme environments
  - space
  - underwater
- medical robotics
  - assistive
  - rehabilitative
  - surgical
- home cleaning
- agriculture
- lawn mowing
- food industry
- mine exploration
- de-mining
- civil and naval construction
- automatic refueling
- museum guide
- fire fighting
- inspection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

professional & personal service robots

# 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

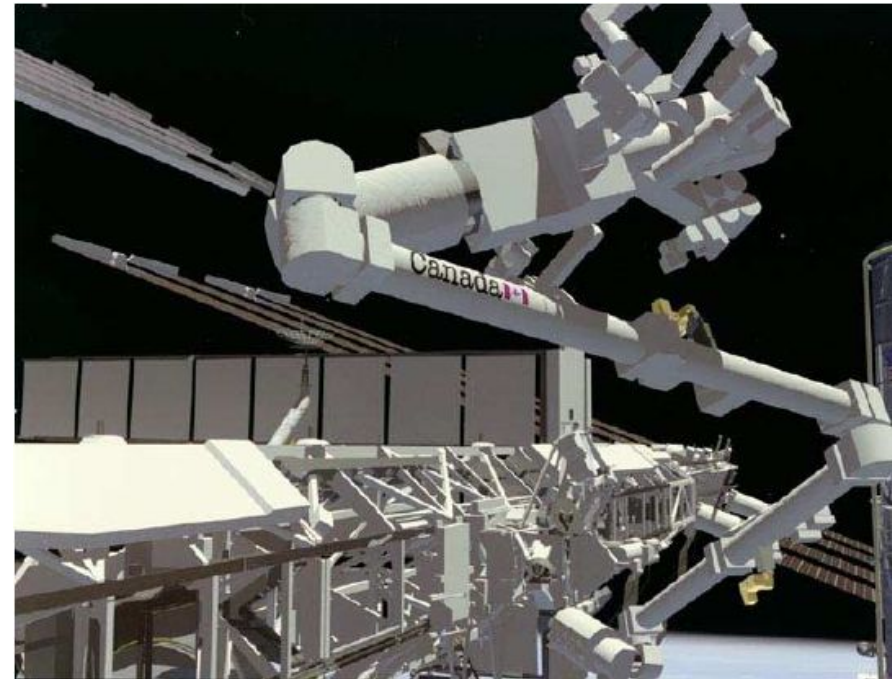


catching floating objects  
with *Rotex*

# Space robotics



- robotic arm *SSRMS (Canadarm)* in operation on the Space Shuttle, with outstretch of about 30 meters



- the service manipulator on the ISS is mounted on a supporting rail

# Robots on ISS



video



Canadarm2 delivering Destiny Lab from Space Shuttle Atlantis to ISS (Feb 2001)

video



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)



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

# Underwater robotics



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

video

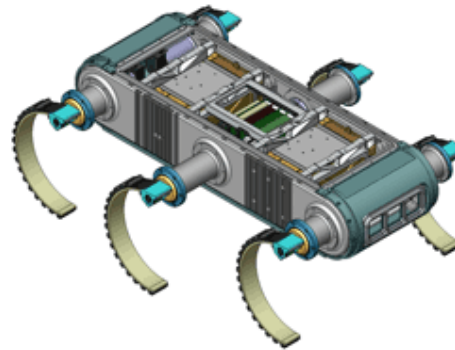
video

UBC Gavia underwater robot (University of British Columbia)



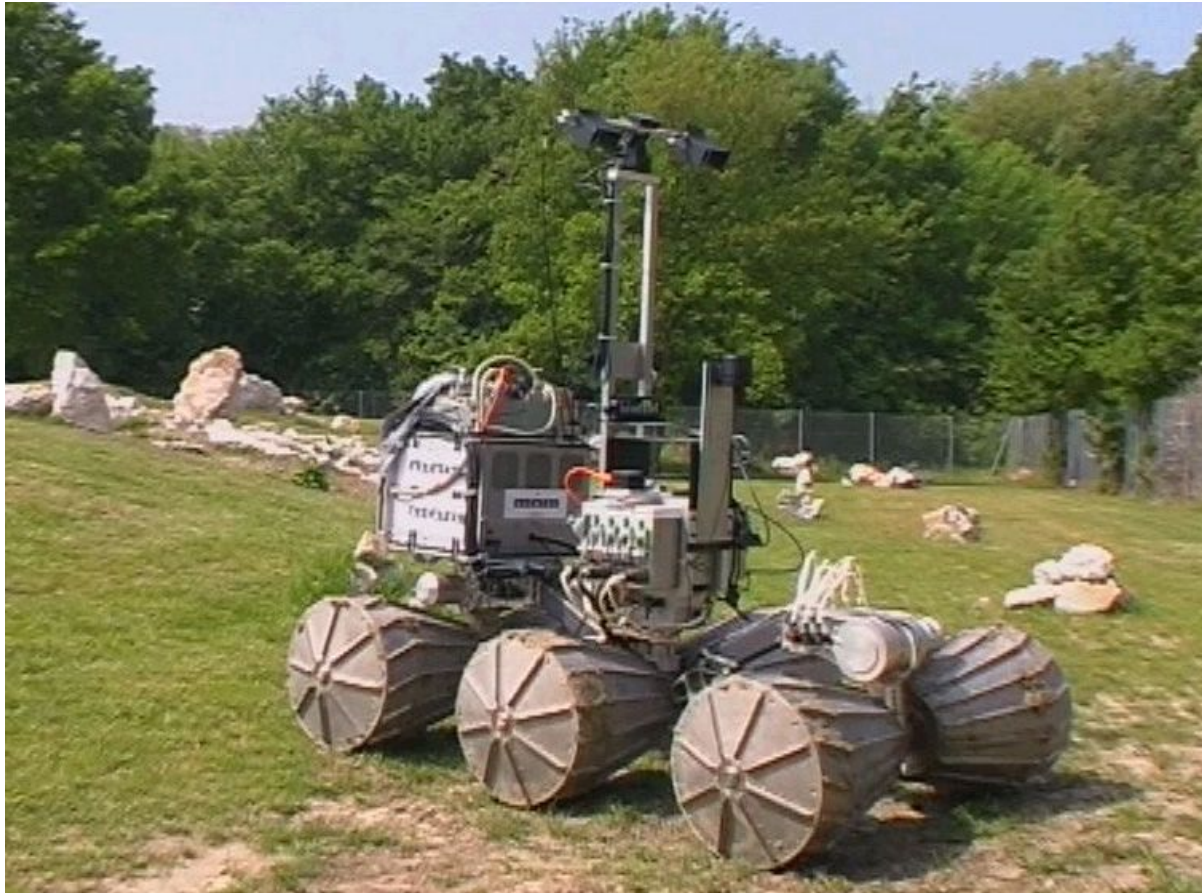


# Underwater robotics



- 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

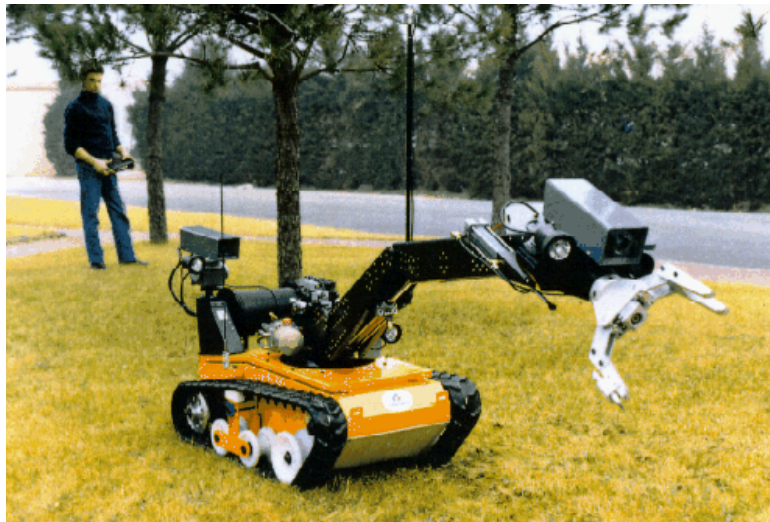


video



*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)

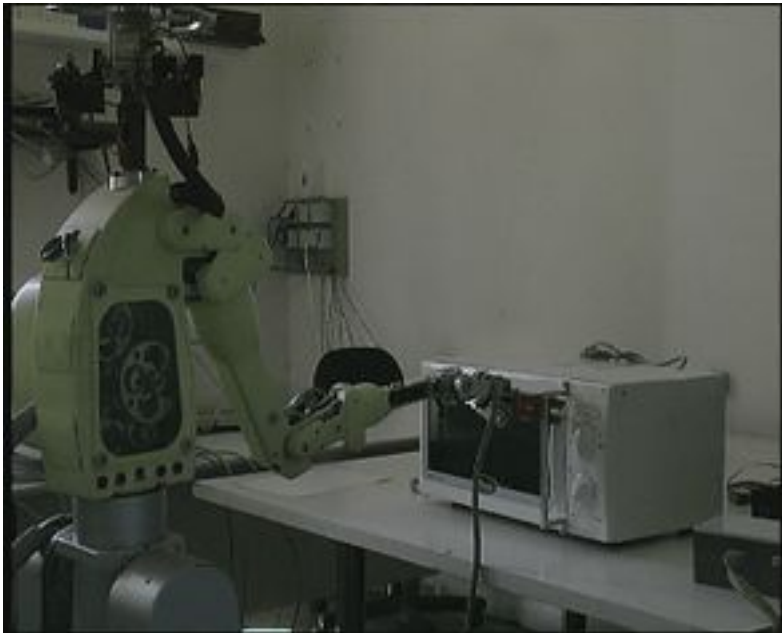


- *MOVAID* project for the aid of disabled people  
in home activities (Scuola Sup Sant'Anna, Pisa)

# MOVAID project



video

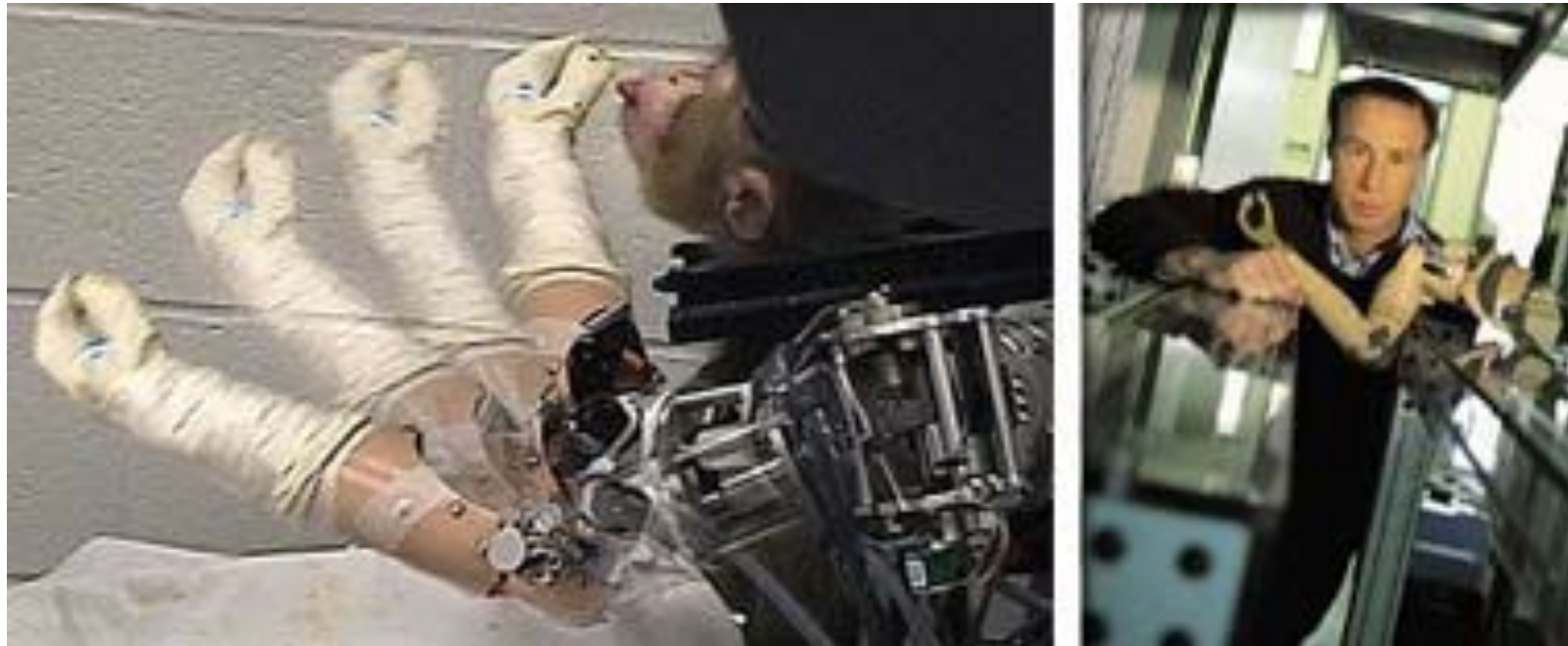


video



domestic activities using the 7R *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

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- 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

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- "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

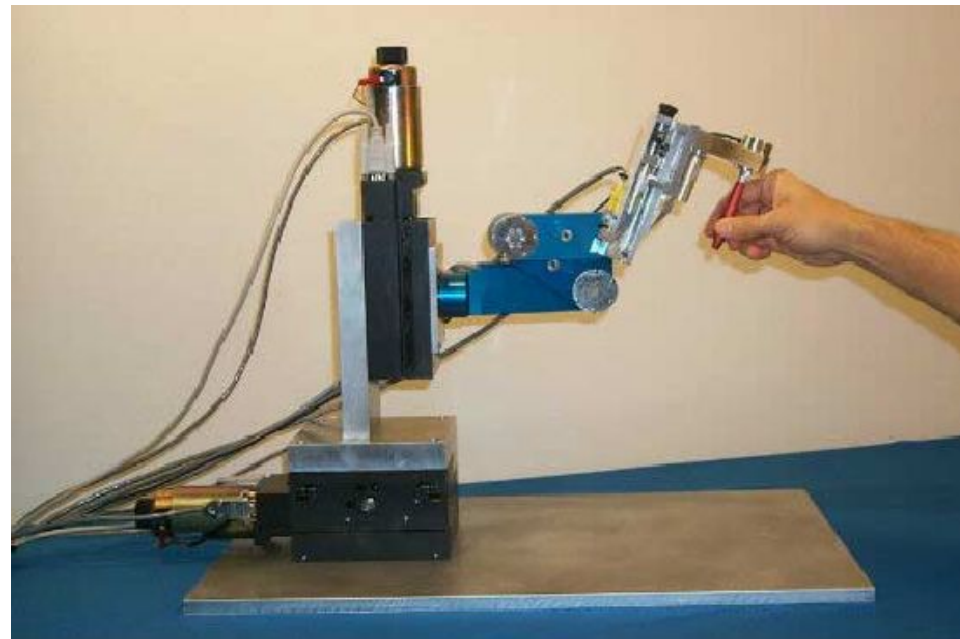


- user interface of the *Care-O-Bot* robot nurse (IPA Fraunhofer, Germany)

# Surgical robotics

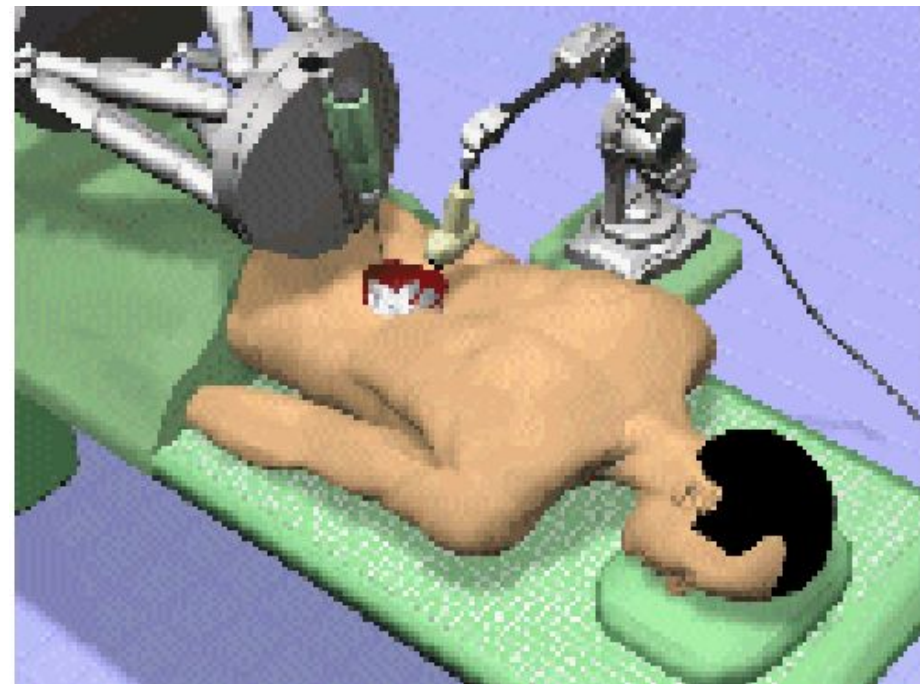
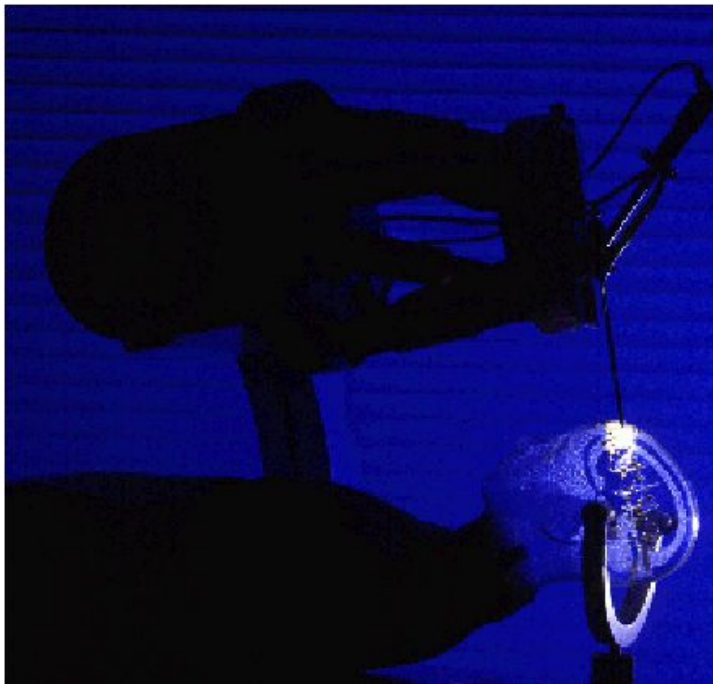


- *Robodoc* by Integrated Surgical Systems (USA) was used first for orthopedic surgery (ankle replacement)



- *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)

# Surgical robotics



overview of the operating room



command station



(haptic) interface

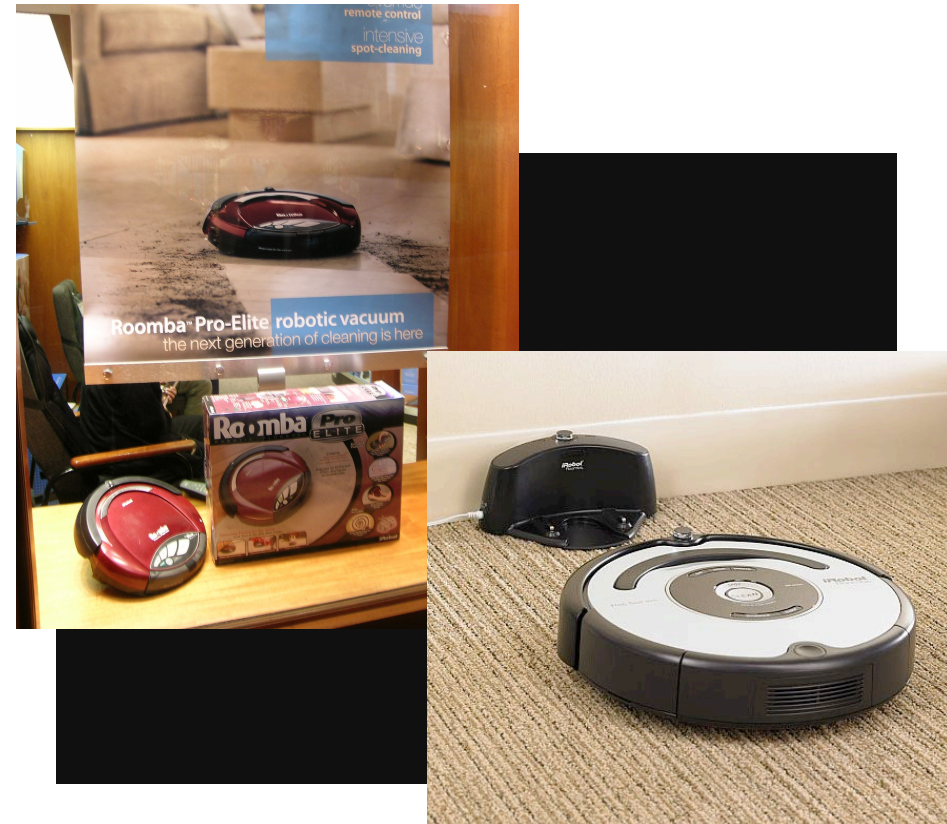
- da Vinci<sup>©</sup> system (Intuitive Surgical Inc.)  
[see the course "Medical Robotics"]



# 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

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video

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

# Food industry



video

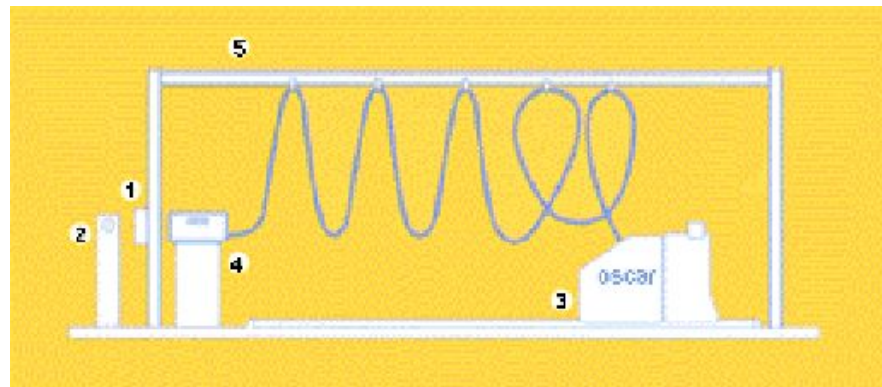


- *Ulixes* robot by IMT (Germany) aligns 10000 sausages per hour



- *AdeptOne* SCARA robot with 4-sausage gripper

# Automatic refueling



- 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)

# Automatic refueling



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



- *Smart Pump* system (USA)

# Inspection and surveillance



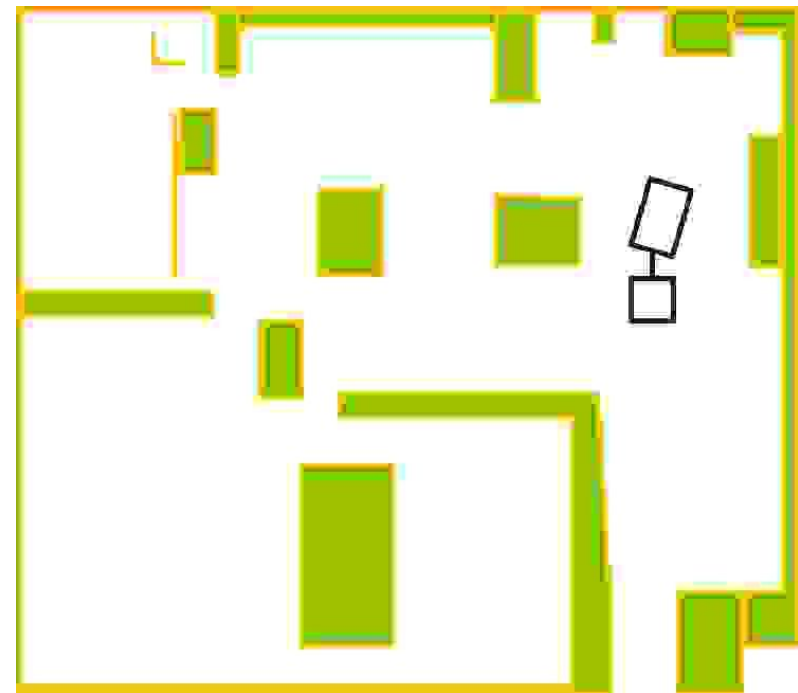
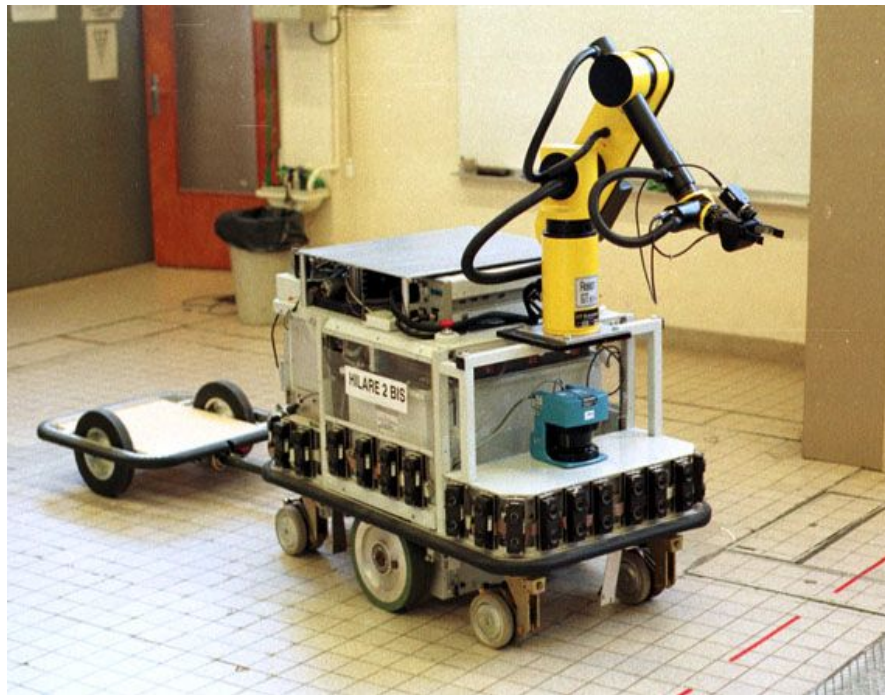
- 6-dof *Puma* arm mounted on the *Nomad XR400* (multiple steering wheels, synchro-driven)



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

two examples of  
*mobile manipulators*

# Inspection and surveillance

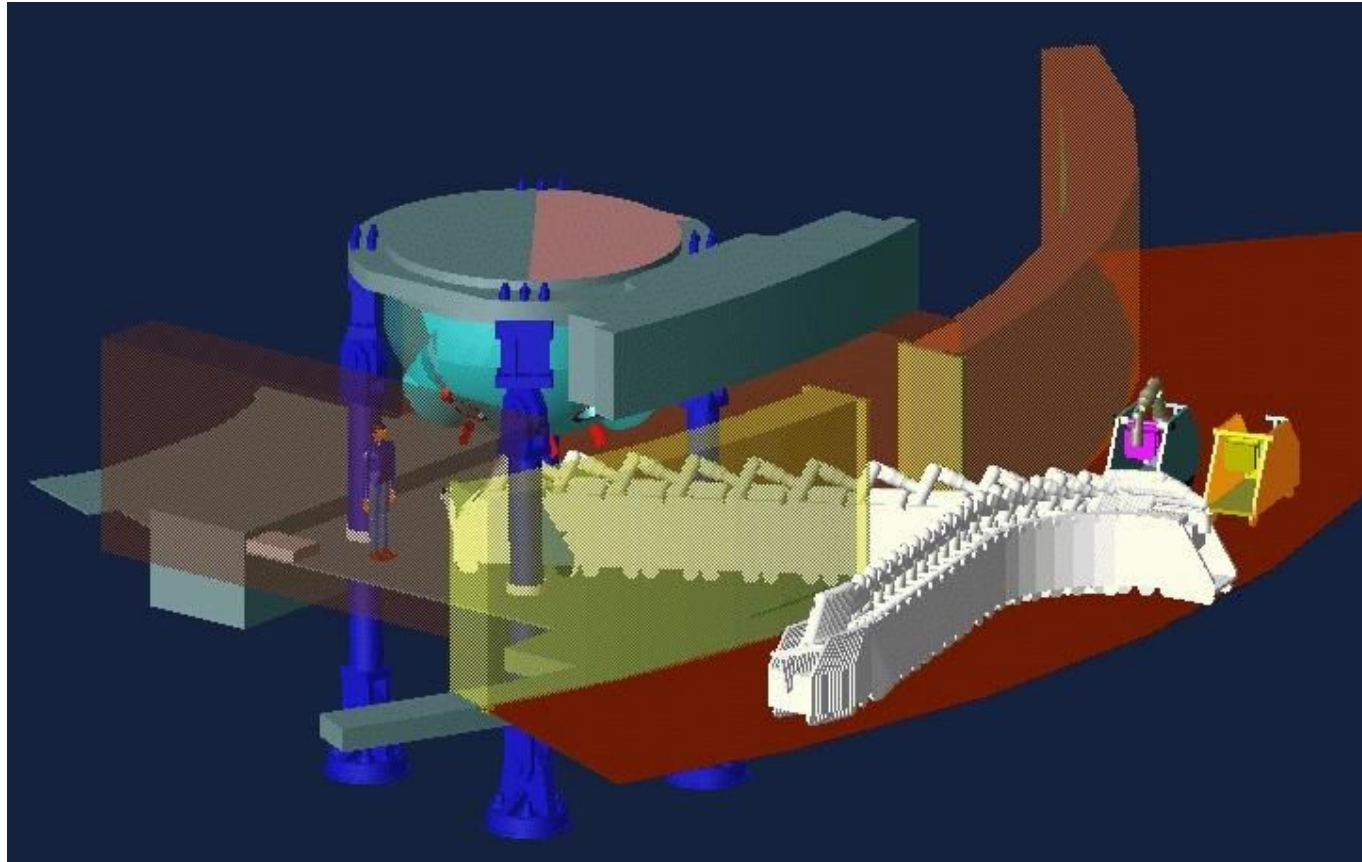


- *Hilare 2bis* mobile robot (LAAS), with trailer and manipulator arm, and its localization on a indoor map

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



# Inspection and surveillance



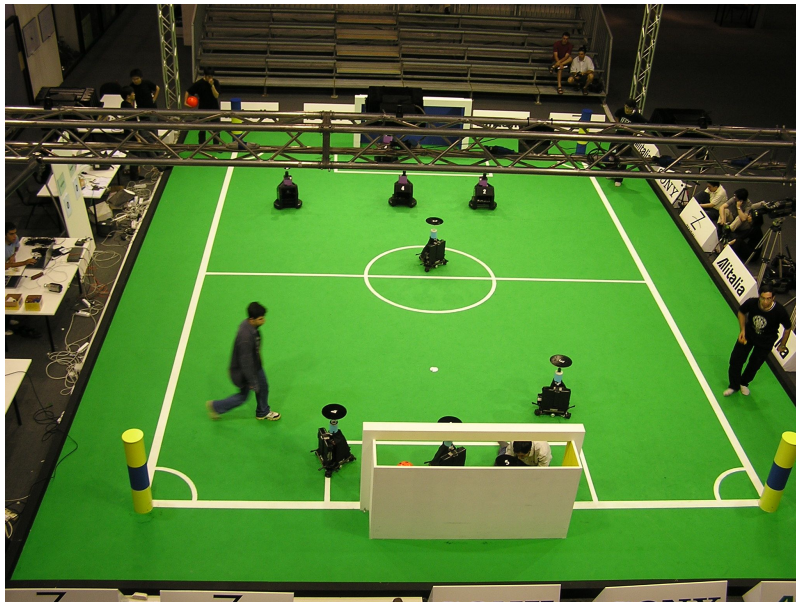
- motion planning of a robotized inspection task inside an electricity power plant (*Move3D* simulation)

# 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



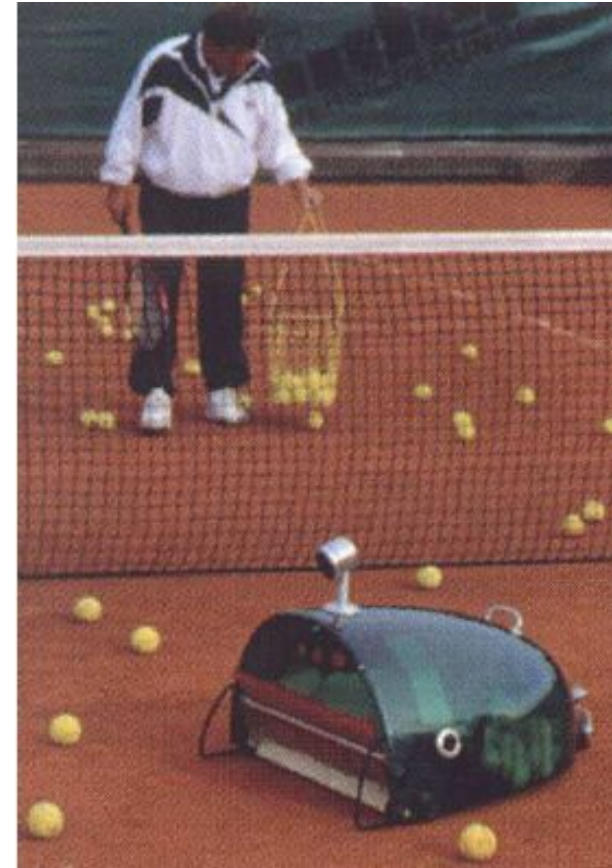
S. Thrun of [Stanford Racing](#)  
(Stanford Univ+VW America+many more)

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

# KUKA robot filling a beer glass

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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

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- 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 cooperation



- *Mr. Helper* (Tohoku Univ) cooperates 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

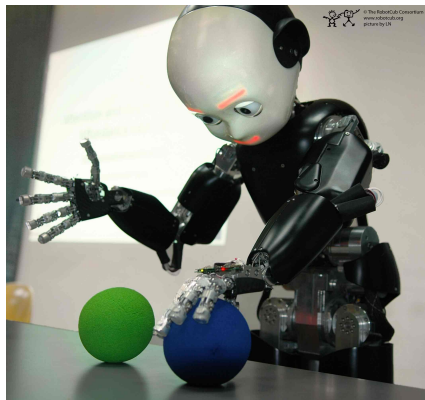


video

← 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

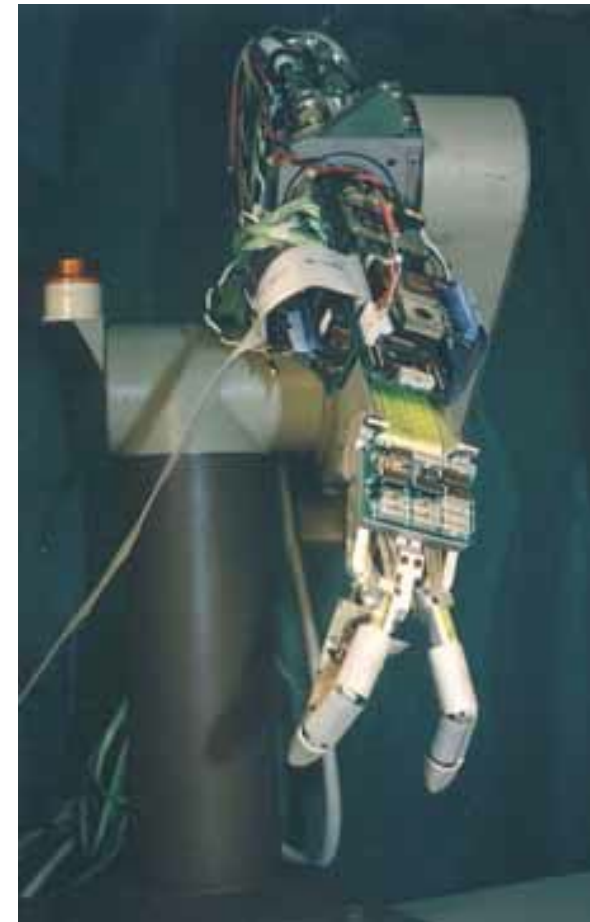
- *iCub* robot is like a 3.5y old child, developed by IIT Genova in 2005 in the [RobotCub](#) EU Project (platform distributed openly, with open-source SW)



# 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*



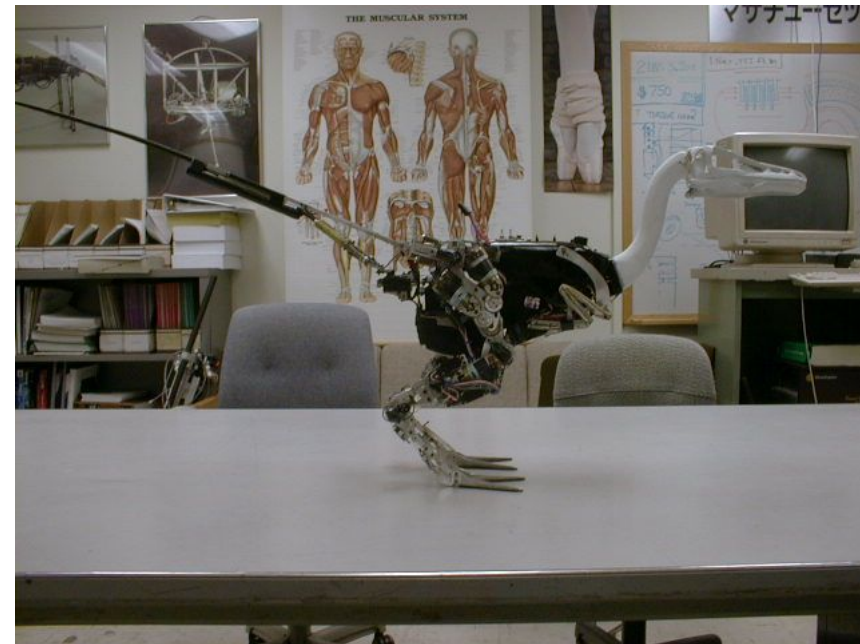
## ... a “minimalistic” solution

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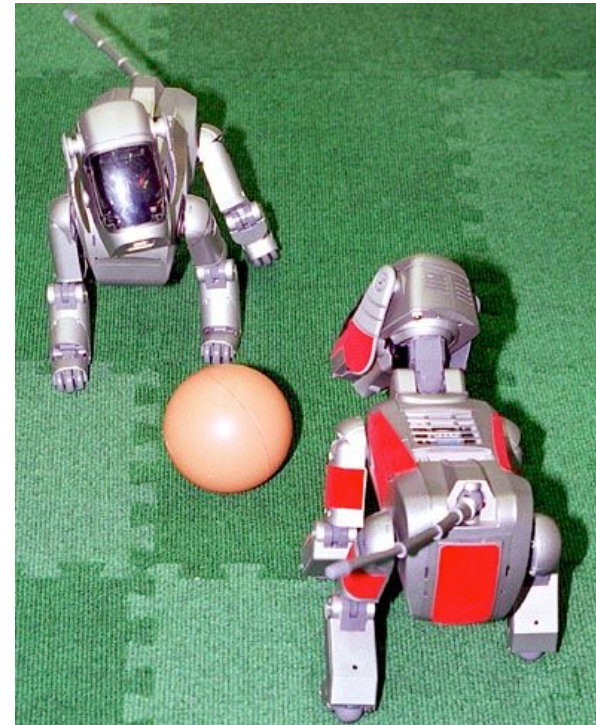
- **5D manipulation** of objects of arbitrary form, using only two linear actuators and sensorized contact surfaces (Univ Pisa)

# Biomorphic robots



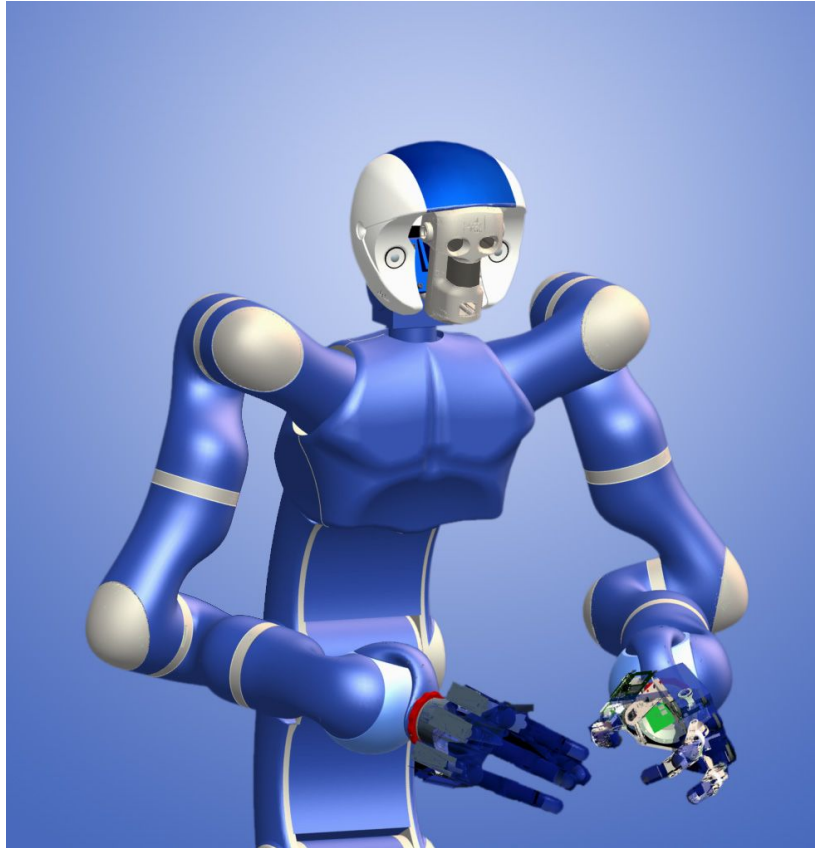
- biomorphic robots by MIT Leg Lab, USA:  
*Troody* dinosaur and *Flamingo* bird

# Four-legged locomotion

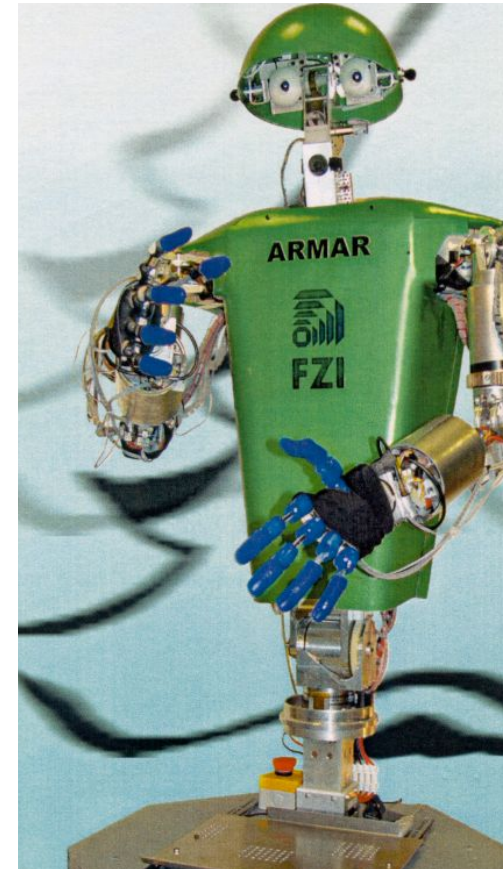


- *AIBO ERS-210* by Sony, playing on the soccer field of RoboCup
  - 16 actuated dofs with encoders, color camera, 3 accelerometers, ultrasound sensors, tactile and micro-switch (feet), battery: everything in 1.6 kg!

# 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 Fraunhofer-Gesellschaft

# Humanoid robots

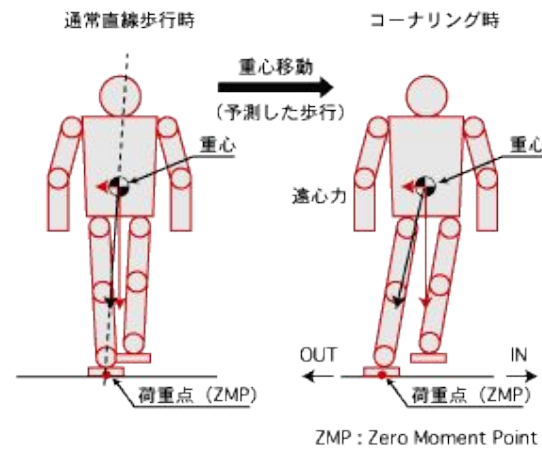


- Metropolis (Fritz Lang, 1927)



- 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



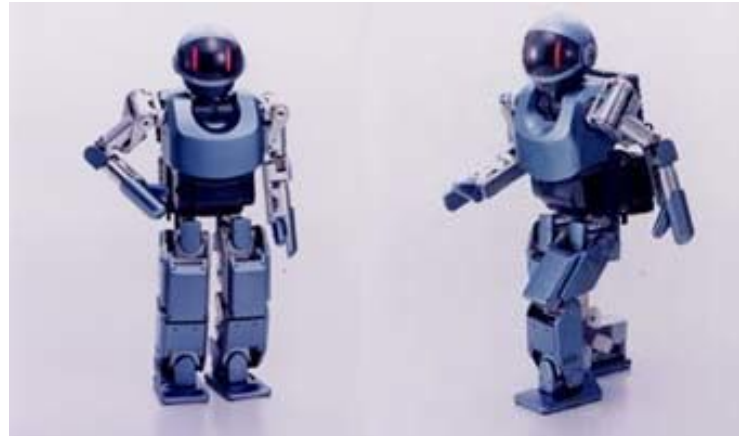
video



# 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)

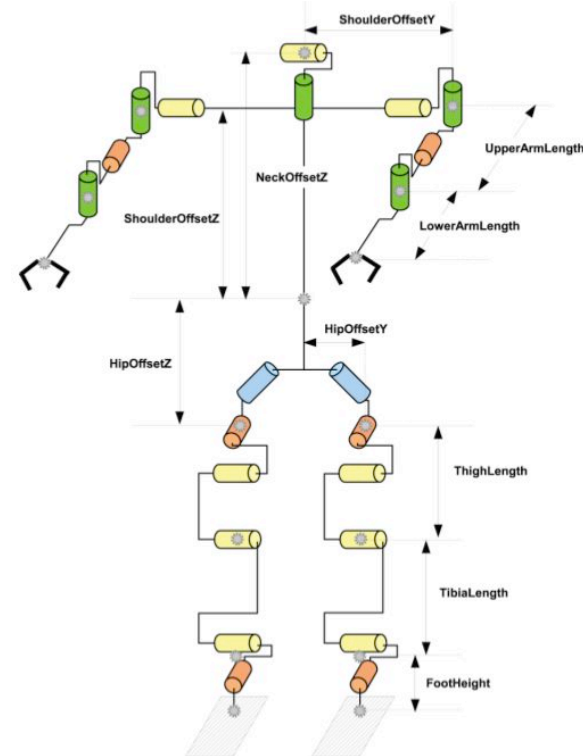
- Sony *Q-RIO*  
the first robot able to balance on a surf and stand up from the floor  
(dead in 2006...)



# Humanoid robots



height = 57 cm  
weight = 4.5 kg



kinematic  
description

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

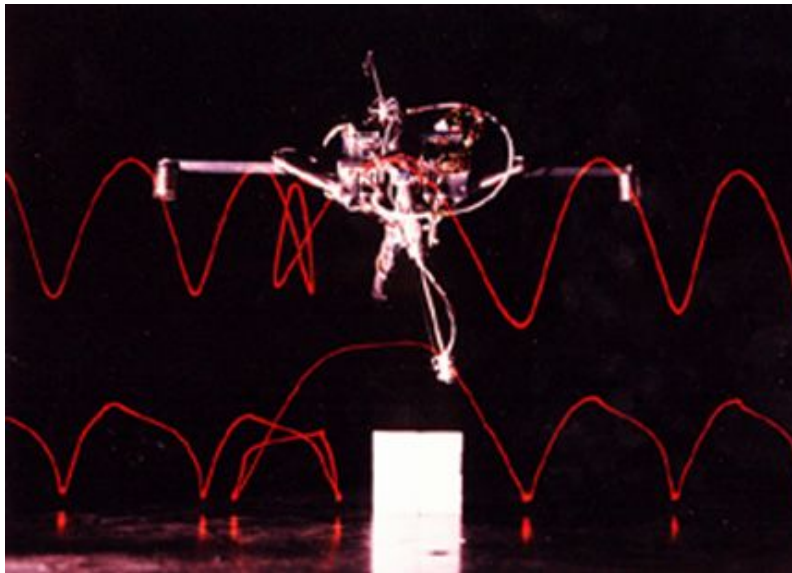
# NAO playtime

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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...

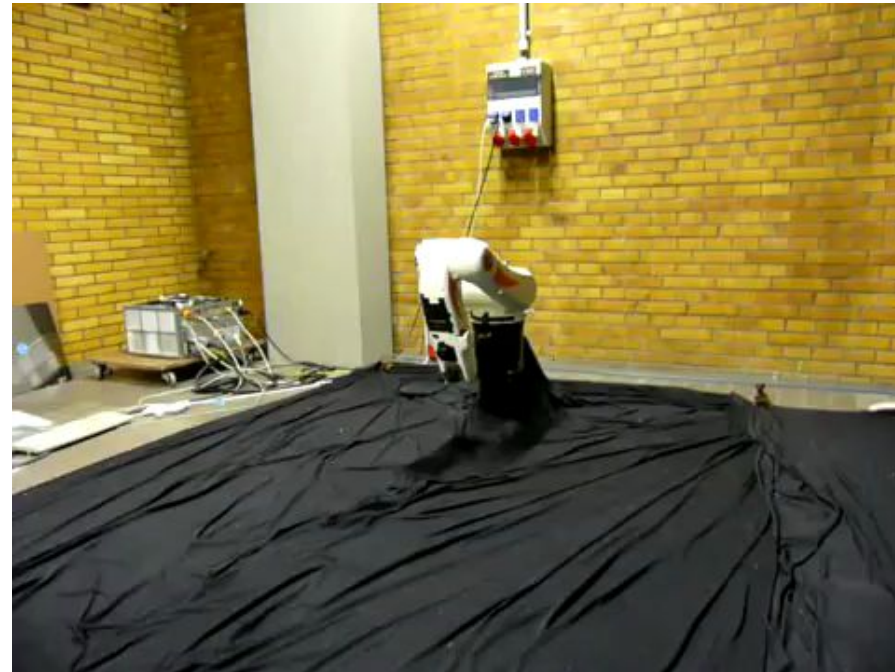


video

video



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



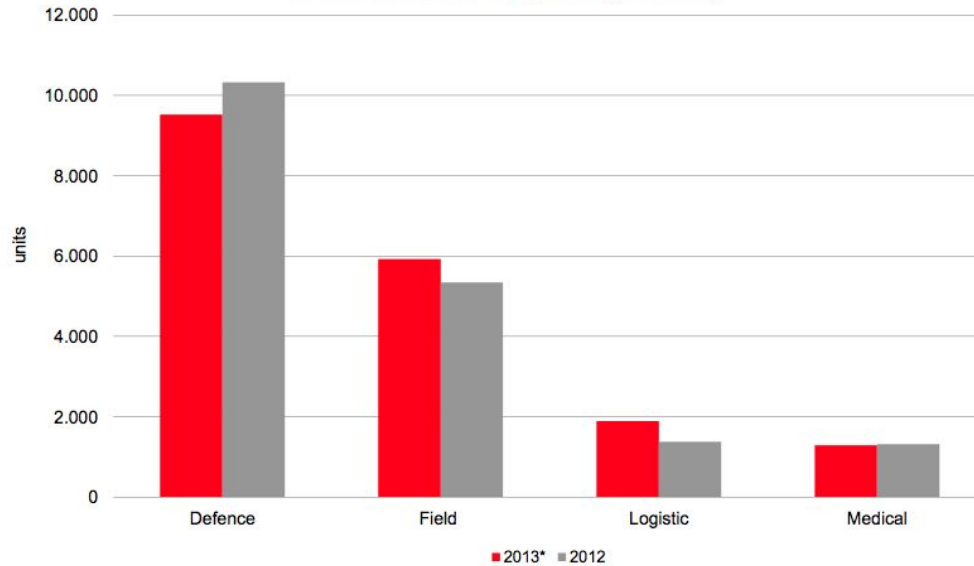
ping-pong with KUKA KR5 robot

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

# Diffusion of service robots for professional use



Service robots for professional use.  
Sold units 2013 and 2012 (main applications)



about 21,000 service robots for professional use were sold in 2013

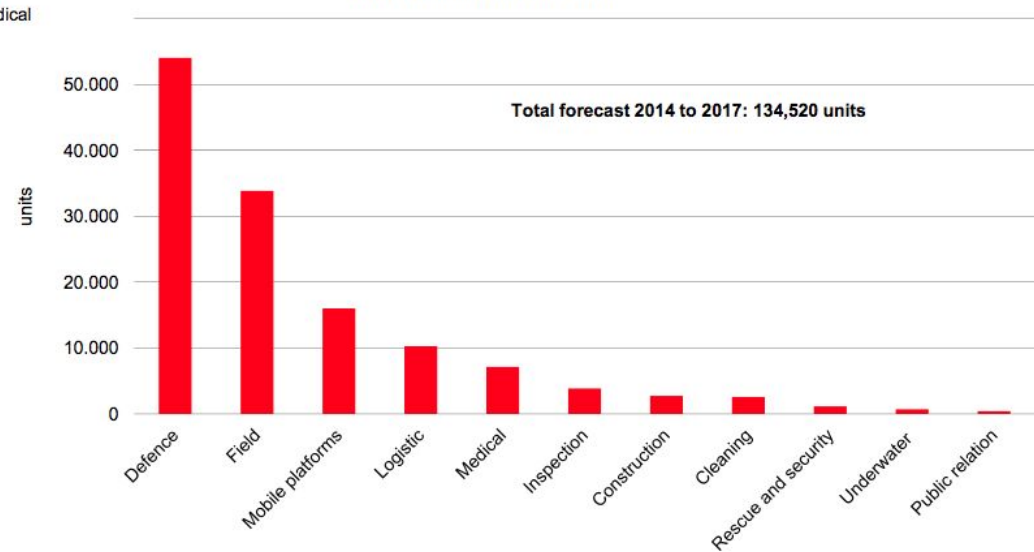
← main sectors with more than 1K sells

smaller markets include: mobile platforms, construction, cleaning, underwater, inspection,

World Robotics 2014

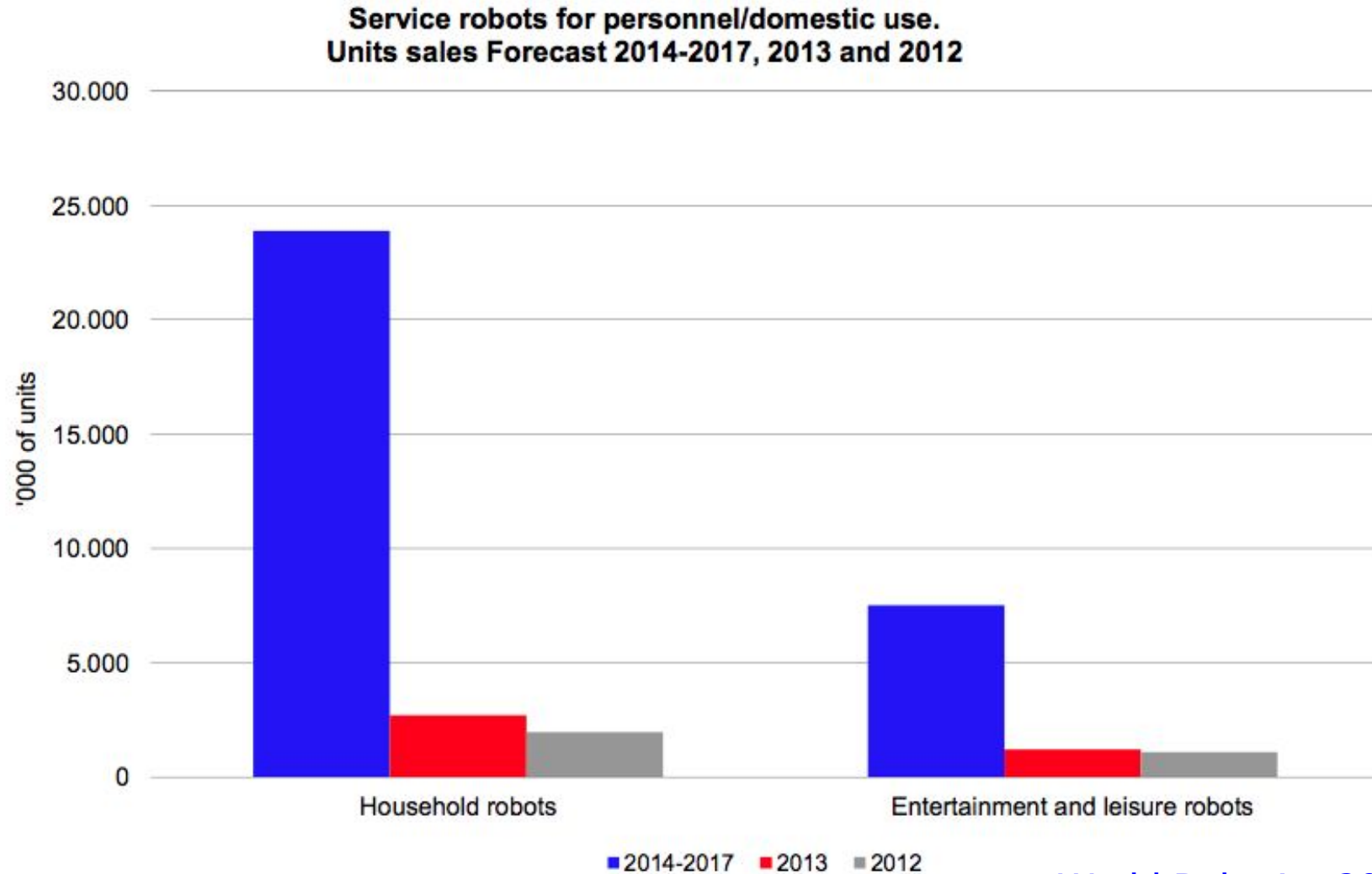
about 134,500 new service robots in 2014-17

Service robots for professional use.  
Unit forecast 2014 to 2017





# Diffusion of service robots for personnel/domestic use



World Robotics 2014

# Web sites



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

Full collection of *440 video clips* from the 1991 to the 2006 editions of the IEEE Int. Conf. on Robotics and Automation (*ICRA*) – **needs log**

– *become a student member of the IEEE **R**obotics & **A**utomation **S**ociety!!!* –

- <http://www.service-robots.org>

Technical Committee on Service Robots of the IEEE (*Institute of **E**lectrical and **E**lectronics **E**ngineers*) - RAS

- <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.eu-robotics.net>

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

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

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