Robotics for industry, research and service: a state of the art in 2012

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Robotics
State of the art 2012

- Robots
- Manipulators
- Mobile
- Humanoids
- Modular
- Conclusion

What is a robot

- Etymology: Karel Capek, 1921, **Robotnik** = worker
- A robot is a **mechanical system** under **automatic control** that performs operations such as **handling** and **locomotion** (Source : IFToMM terminology http://www.iftomm.3me.tudelft.nl)
- Summary

Manipulators	Classical topics (1950)
Mobile robots	
Humanoids	Recent topics (1980)
Modular robots	

- Robotics = Mecha + tronics + Automatic control
- Industrial automates and milling machines will not be treated

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What is an industrial robot

- Industrial Robot according to ISO 8373 (www.ifr.org)
- An **automatically controlled**, **reprogrammable**, **multipurpose** **manipulator** programmable in **three or more axes**, which may be either fixed in place or mobile for use in industrial automation applications
- **Reprogrammable**: whose programmed motions or auxiliary functions may be changed without physical alterations (**Physical alterations**: alteration of the mechanical structure or control system except for changes of programming cassettes, ROMs, etc.)
- **Multipurpose**: capable of being adapted to a different application with physical alterations
- **Axis**: direction used to specify the robot motion in a linear or rotary mode

Industrial manipulators

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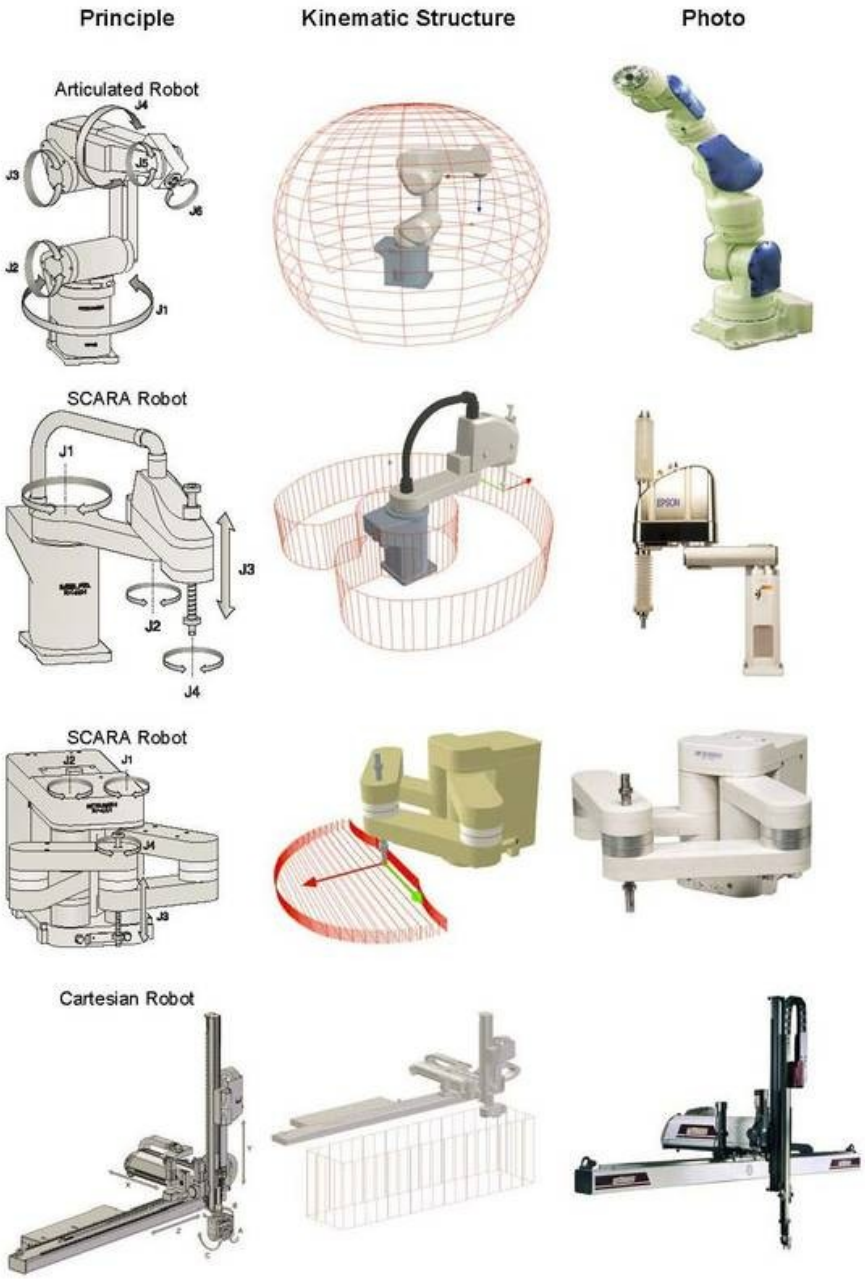
- Industrial overview from International Federation of Robotics

  www.ifr.org

  - ✔ Members from ABB, Adept, Comau, Duerr SYstems, Fanuc, Kuka, Universal Robots, Yaskawa Motoman...
  - ✔ Information letter every 3 months
  - ✔ Industrial statistics: 150,000 new industrial robots were sold all over the world in 2011 (2010 + 30%)



IFR statistics : Robot population

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IFR statistics : Robot supply

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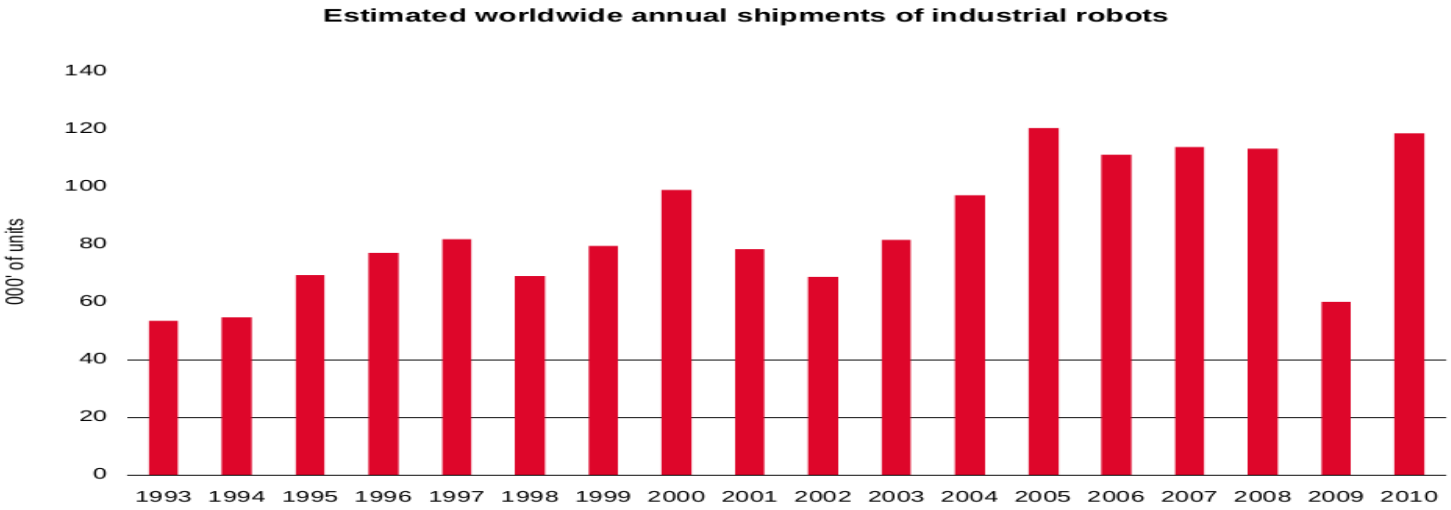

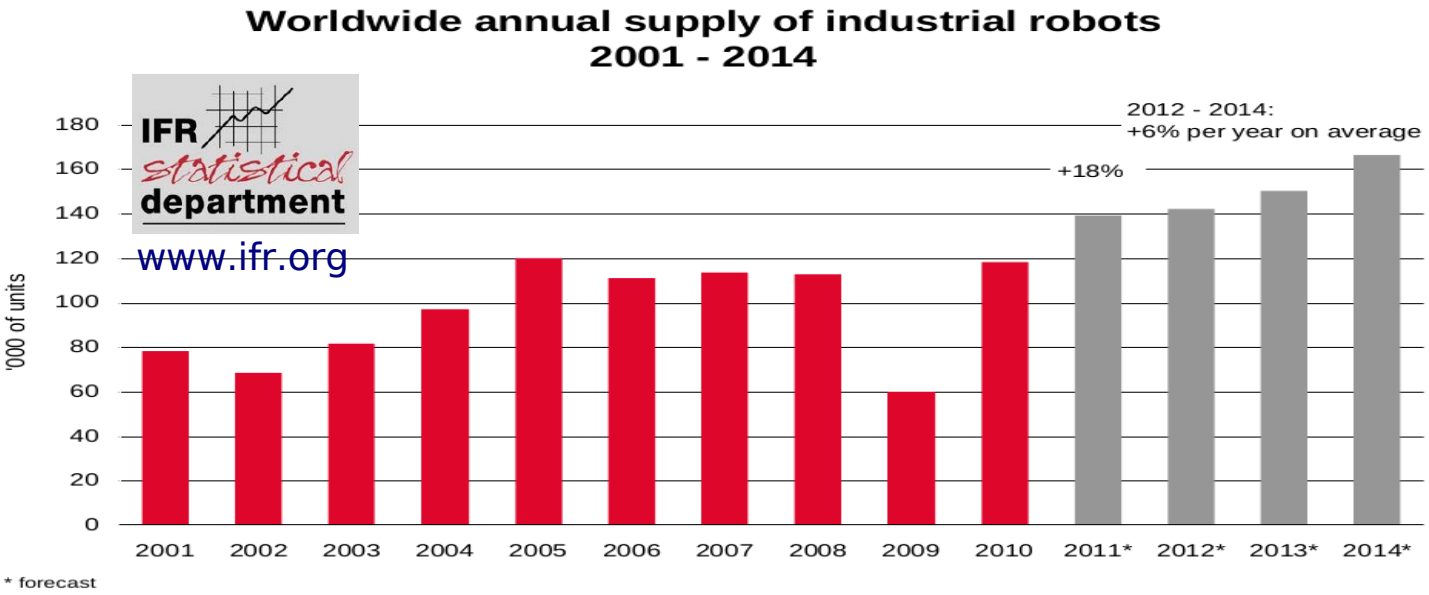

IFR statistics : Supply by continent

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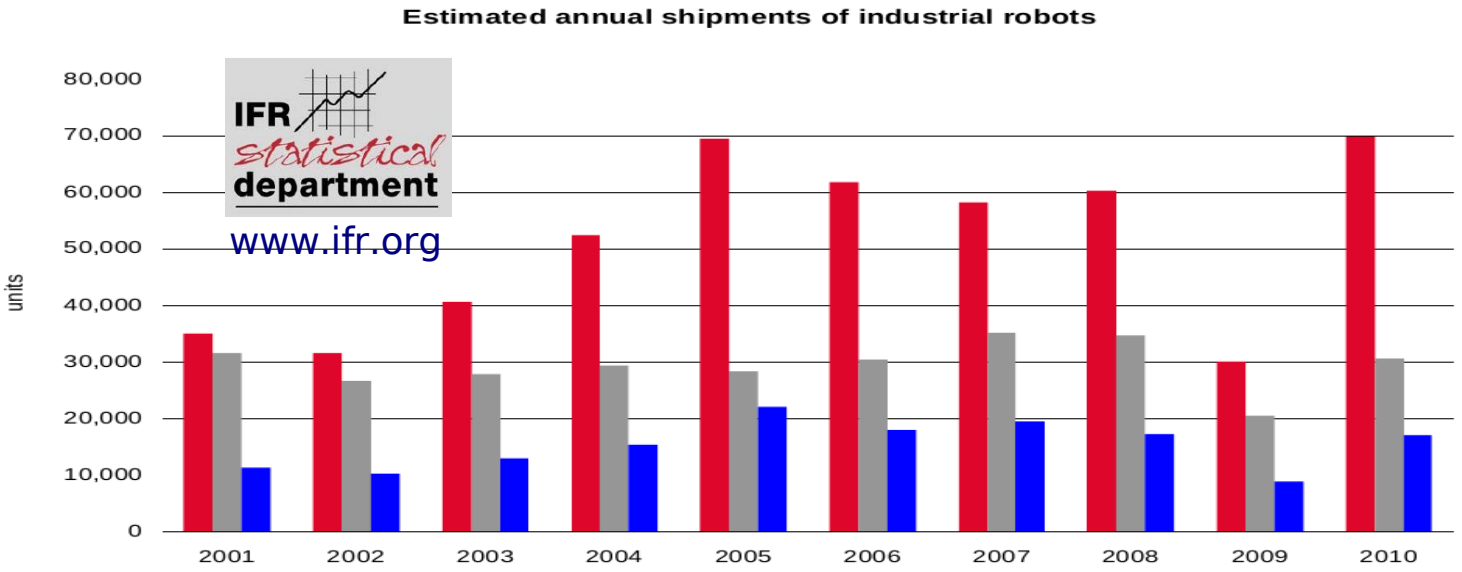

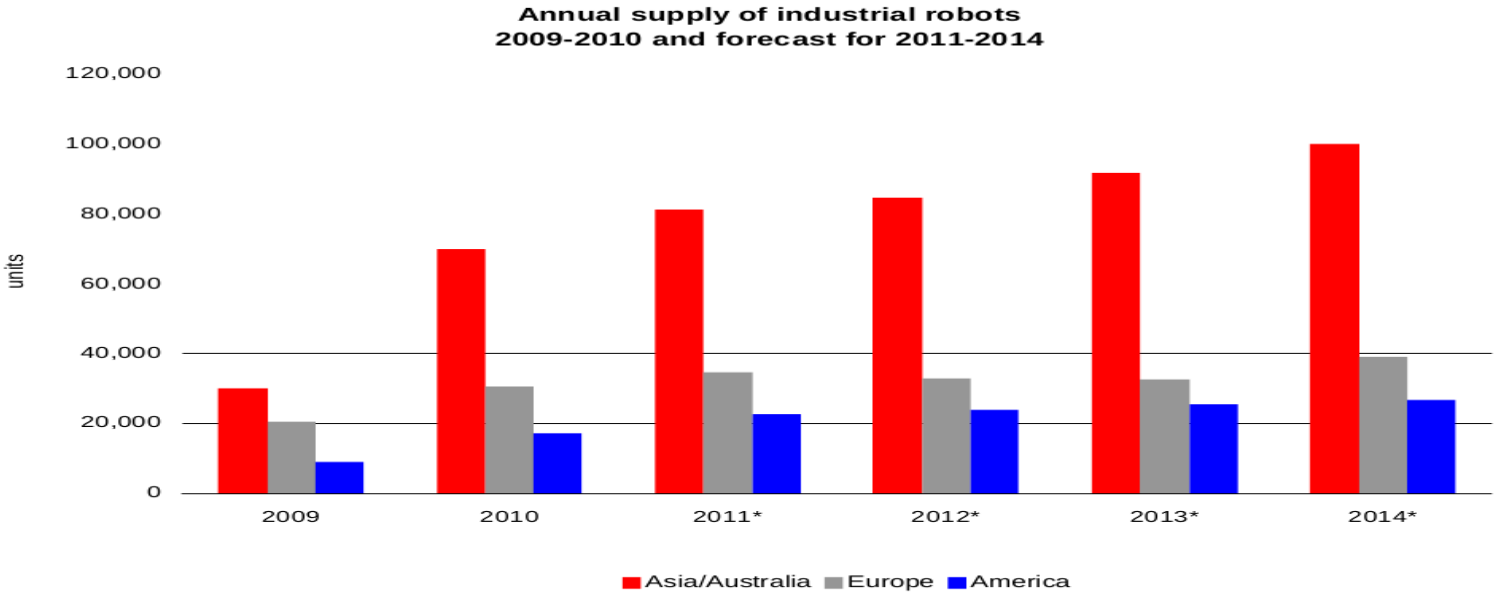

IFR statistics : Equipment by country (1/2)

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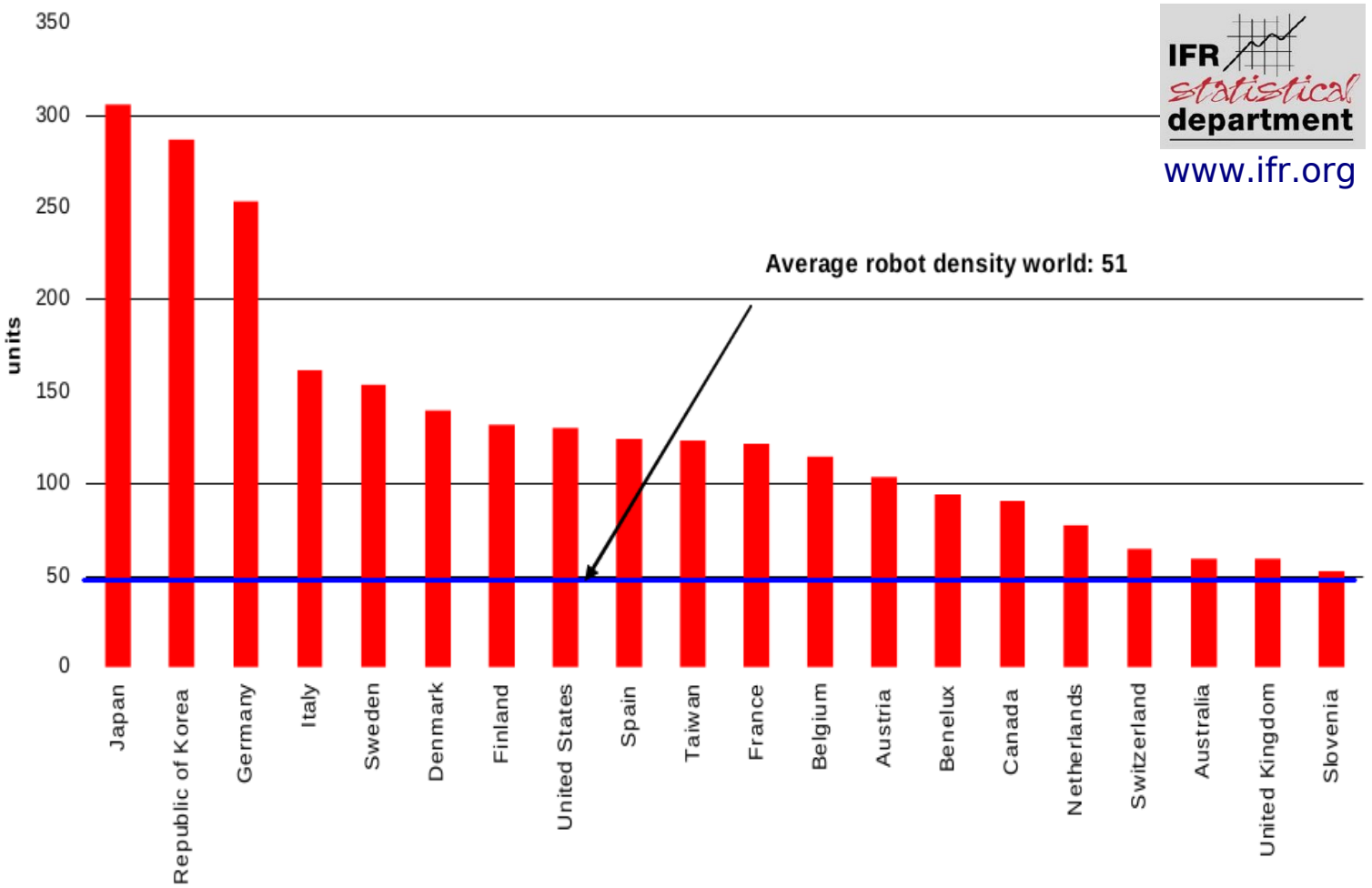
Number of multipurpose industrial robots (all types)
per 10,000 employees in the manufacturing industry (ISIC rev.4: C) 2010



IFR statistics : Equipment by country (2/2)

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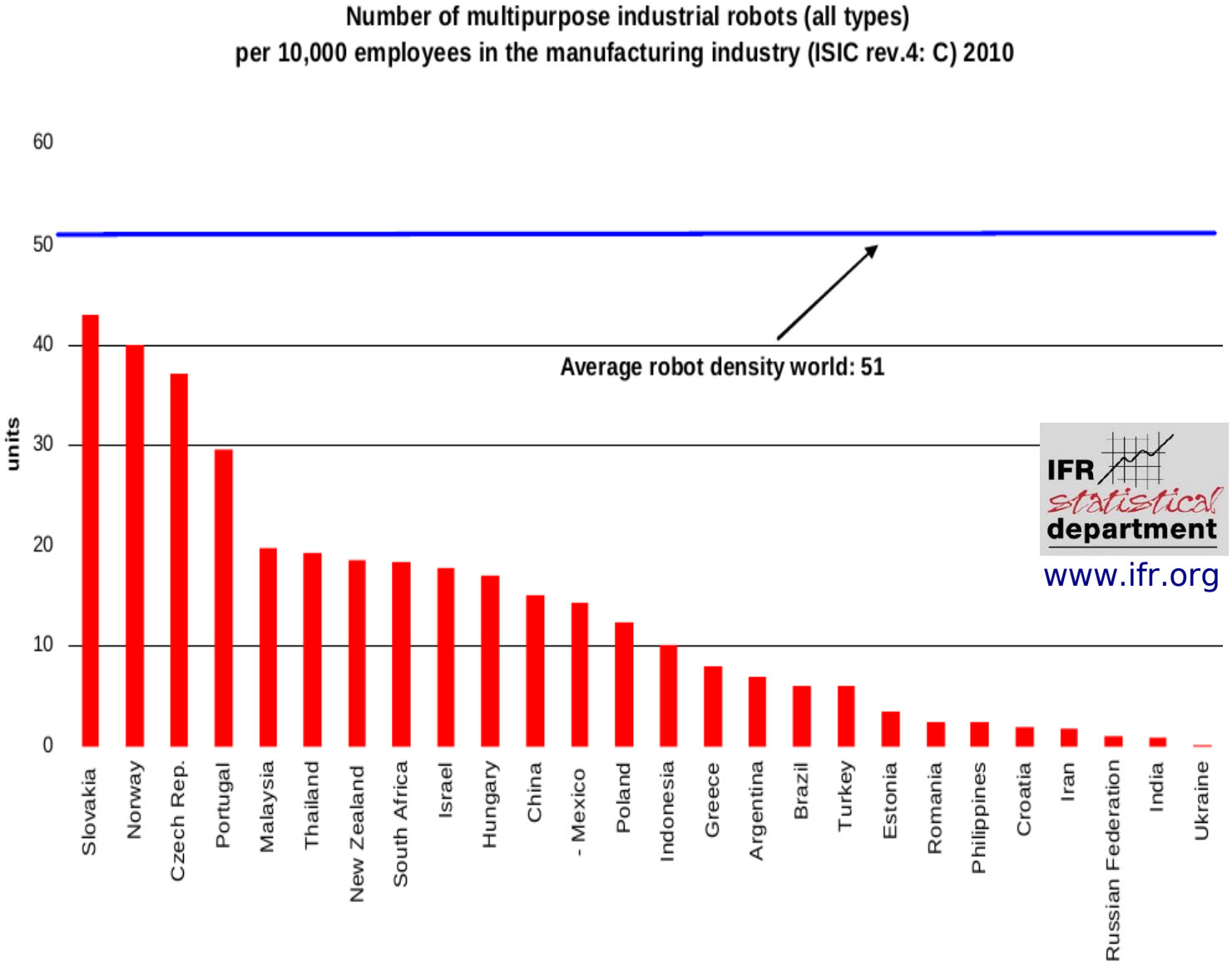

IFR statistics : Supply by sector

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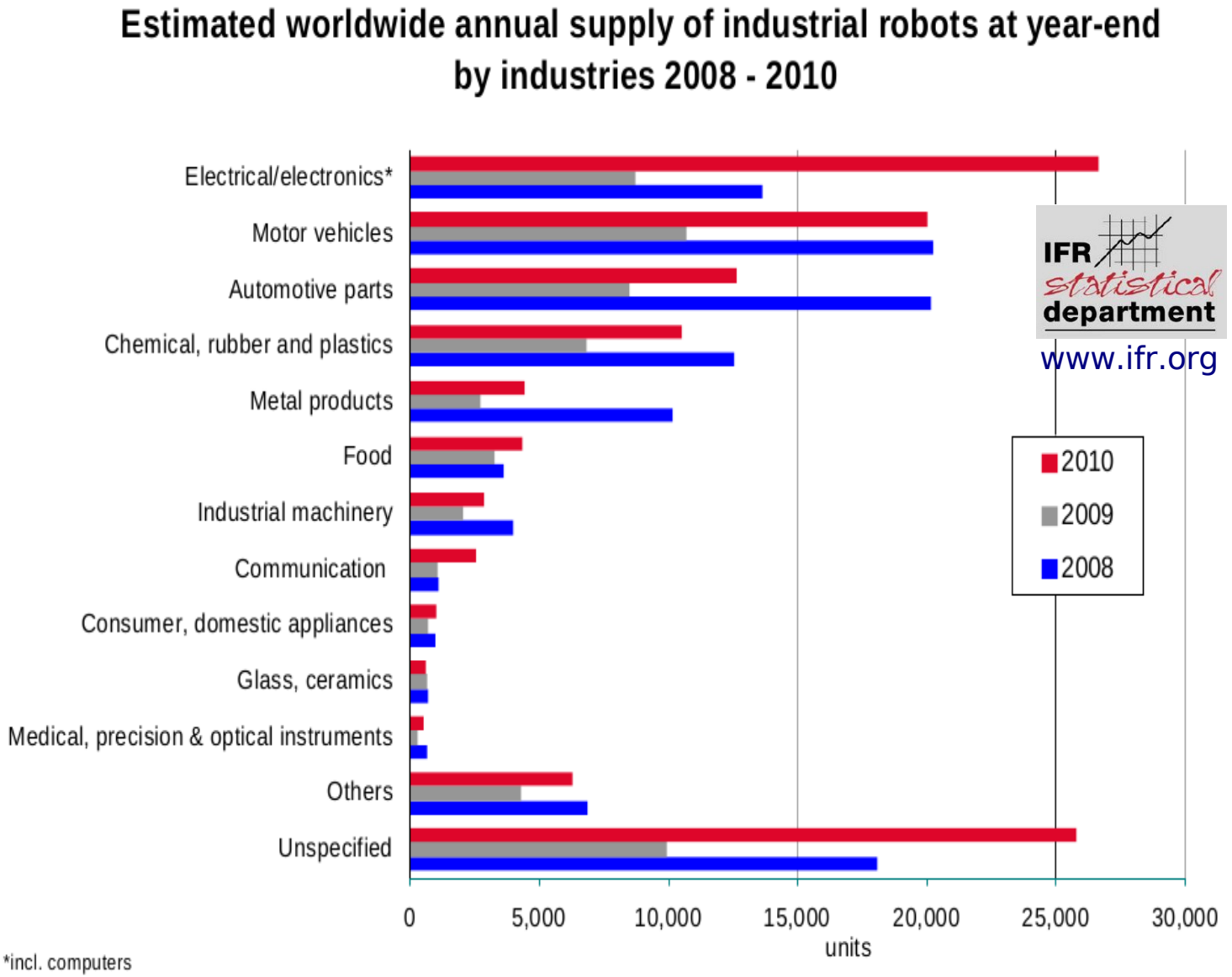

*incl. computers

Industrial robot applications

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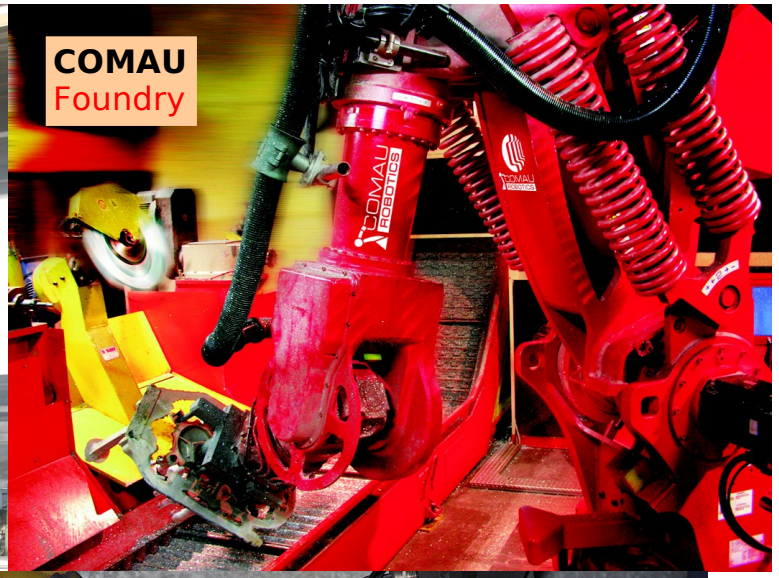
ABB
Die casting



COMAU
Foundry

FANUC
Removing a hot preformed forging from a furnace

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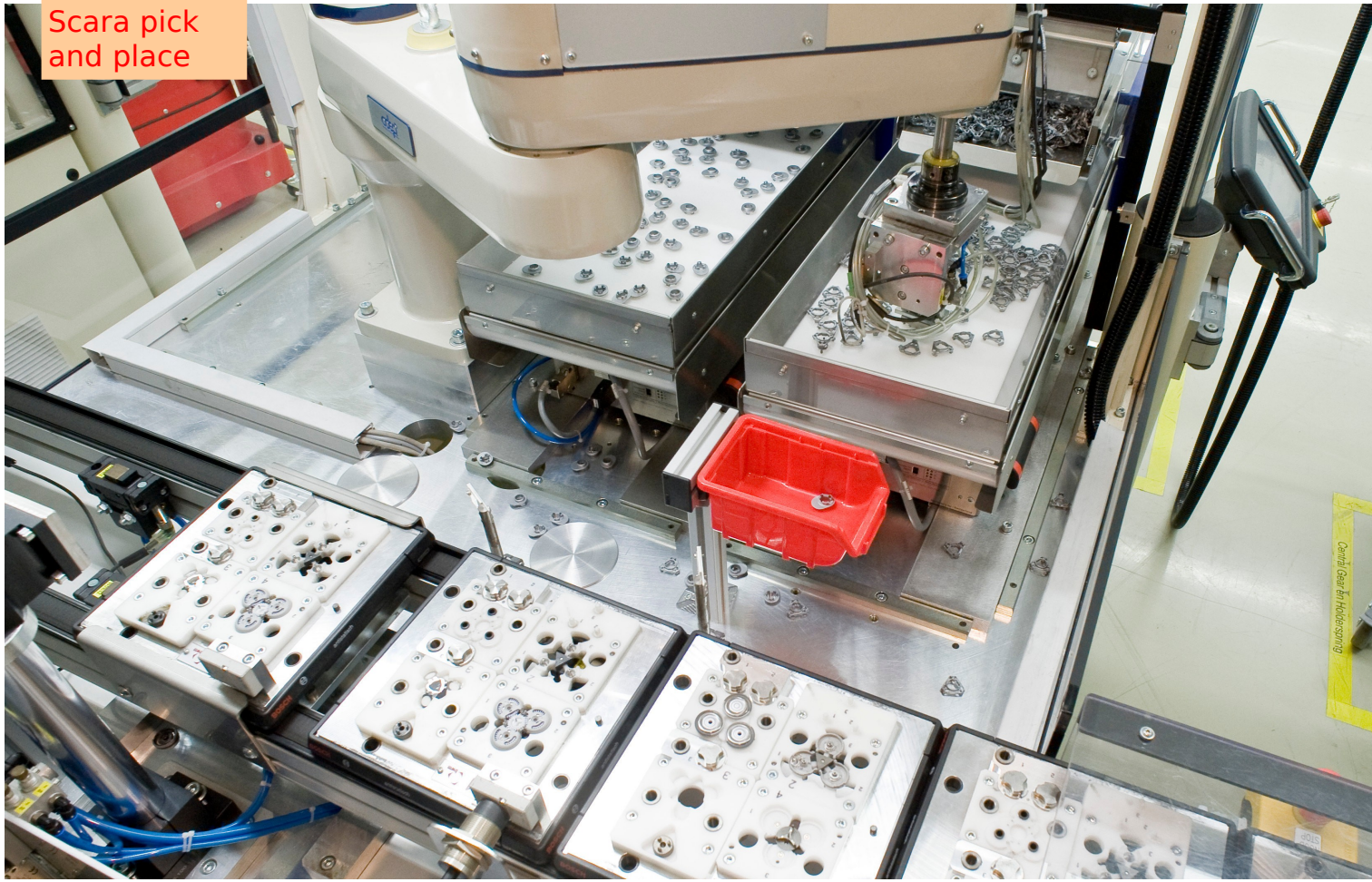
ADEPT
Scara pick and place



Industrial robot applications

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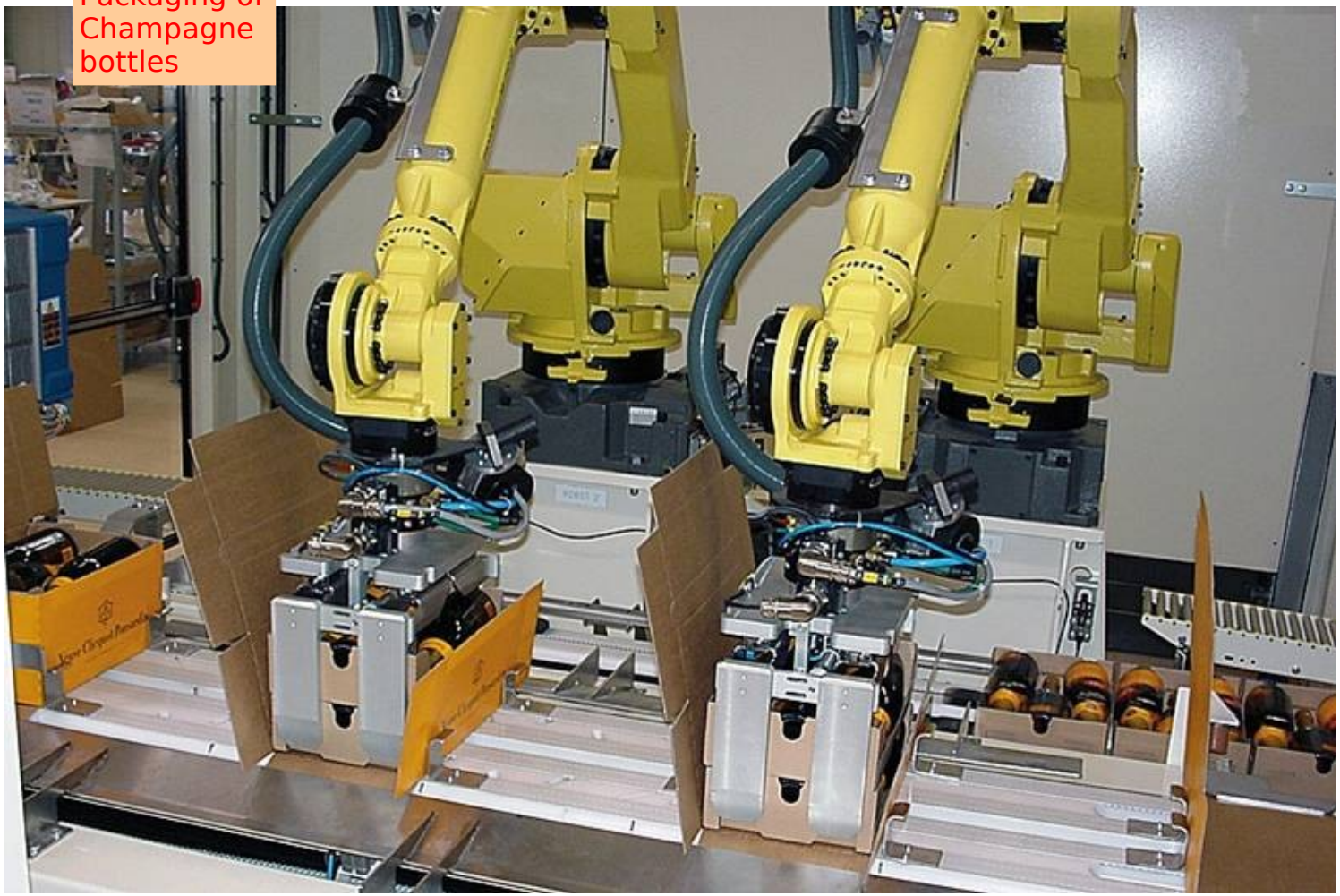
FANUC
Packaging of Champagne bottles



Industrial robot applications

KUKA
A robot collects pallets for stacking after nailing

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YASKAWA MOTOMAN
Automating plastic injection moulding

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REIS
Man collaborating with robot for soldering

Structure of manipulators

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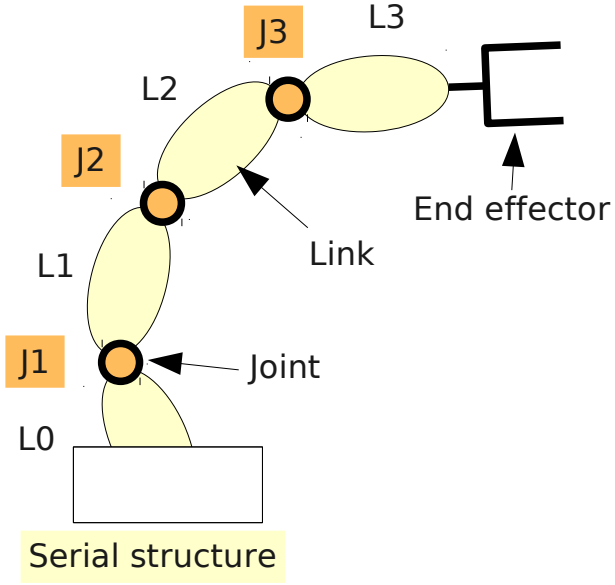
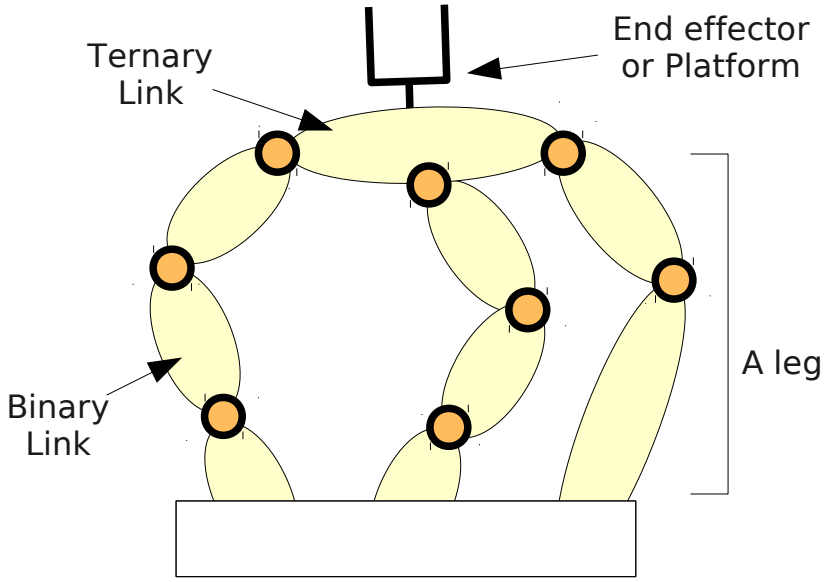


Serial structure

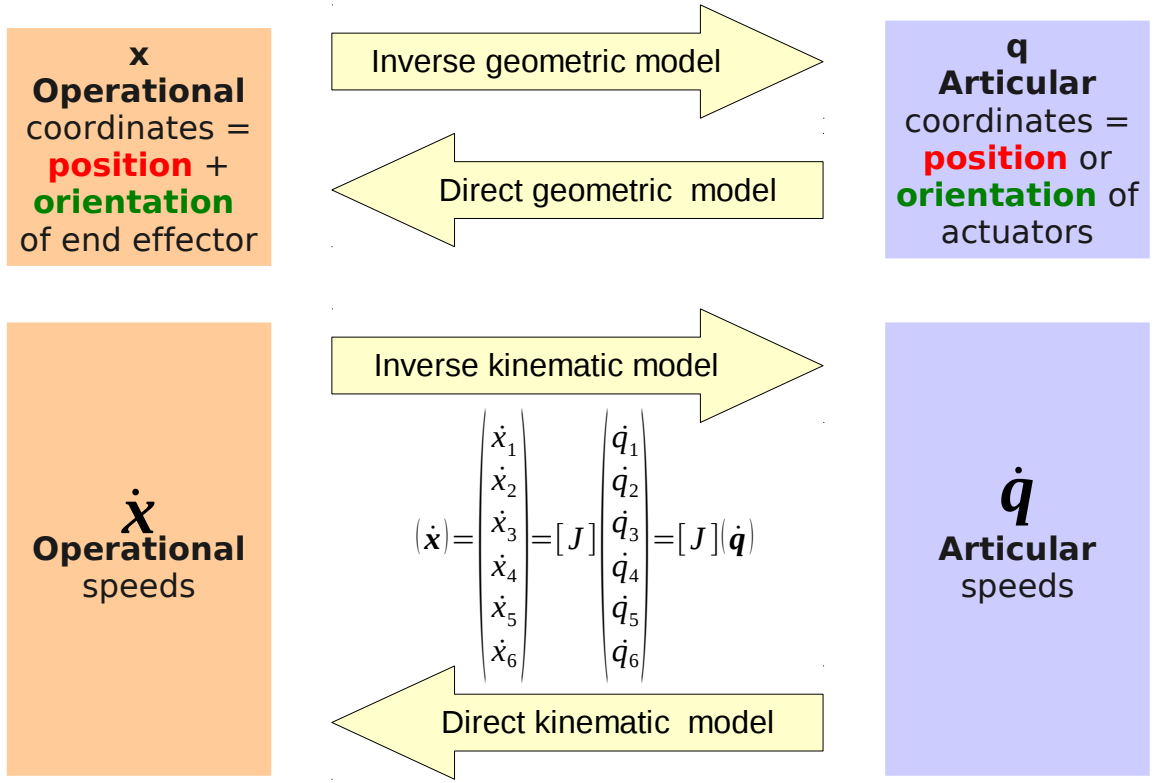


Parallel structure

- ✔ Serial / Parallel / Hybrid structures
- ✔ Kinematical graph
- ✔ Models for representation of motions : Denavit-Hartenberg, TCS...

Modelling manipulators

- Model



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- Properties of robots:
  - ✔ Workspace
  - ✔ Singularities (come from conditioning of Jacobian J matrix)
  - ✔ Stiffness and precision
- Can be used for synthesis

Serial Manipulators

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Kuka KR1000 Titan 6R
(L1000kg / R3.2m / r0.2mm)
www.kuka.com

Staubli RS80 Scara 2RPR
(L8kg / R0.8m / r0.01mm)
www.staubli.com

ABB IRB660 4R
(L250kg / R3.1m / r0.05mm)
www.abb.com

- ✔ Specifications :
- ✔ Load L (up to 1000kg)
- ✔ Reach R (up to 3m)
- ✔ Repeatability r (up to 0.01mm)

Serial arms

- ✔ **Virtual Reality** applications
- ✔ Use robot **geometrical model**

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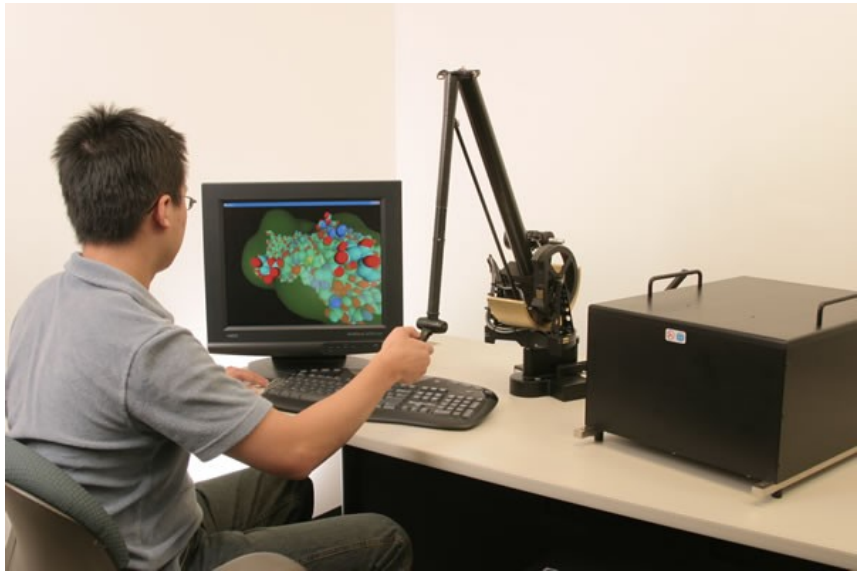
Sigma Measuring Arm
6kg, up to 5m range
Accuracy +/- 25 µm
www.romer.com



Phantom 3.0
6 DOF, Accuracy 20 µm
Haptic rendering on 3 translations
20 N max, 3N nominal)
www.sensable.com

Parallel Manipulators

- ✔ Direct (reverse) geometric model is hard (easy) to solve
- ✔ Recent gain of popularity in industry

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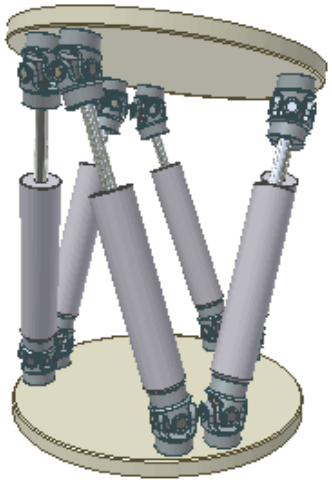
ABB IRB360 Delta 3 DOF
(L3kg / R0.4m / r0.1mm)
www.abb.com



Hexapod Gough-Stewart platform
Used for simulators / milling machines

Falcon joystick
3 leg parallel mechanis
www.novint.com

- ✔ Industrial applications are recent (simulator, positioning device, pick and place, milling machine)
- ✔ Small workspace but good precision
- ✔ Actuators on the frame → High accelerations (100g)
- ✔ High precision
- ✔ New structures are synthesized each year
- ✔ Resource on parallel machines: www.parallemic.org

Isoglide 4 T3R1
A Decoupled Parallel Manipulator

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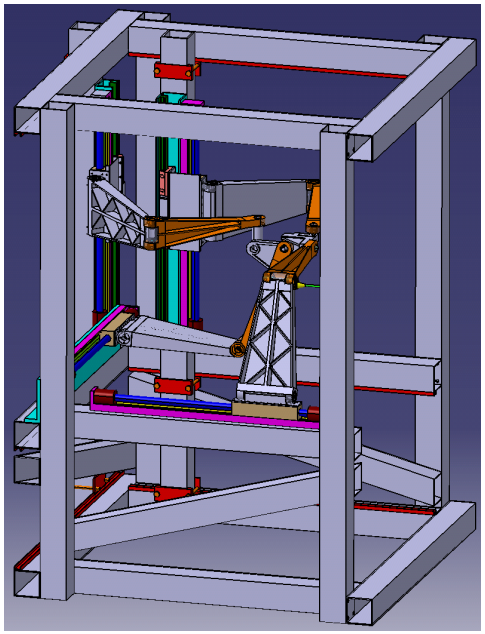
- ✔ Original idea of G. Gogu
- ✔ Isoglide family of robots
- ✔ Isoglide 4 T3R1 decoupled in translation
- ✔ Unitary Jacobian



IFMA INSTITUT FRANÇAIS DE MECANIQUE AVANCEE — LaMI

Isoglide 4 T3R1
www.ifma.fr/lami

Surgery Manipulators

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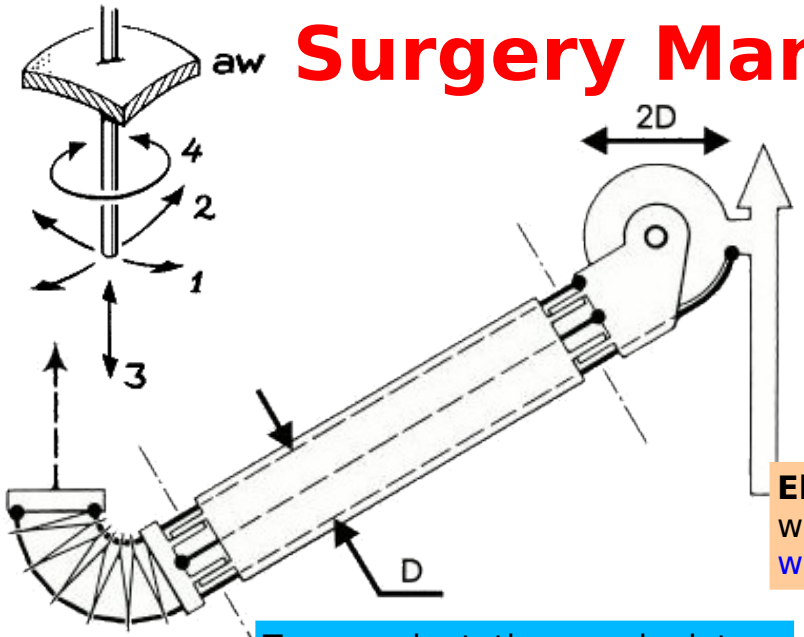
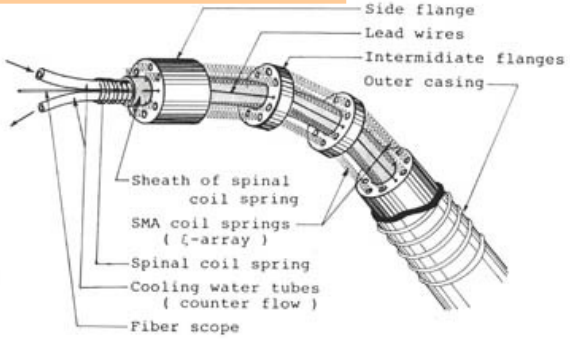
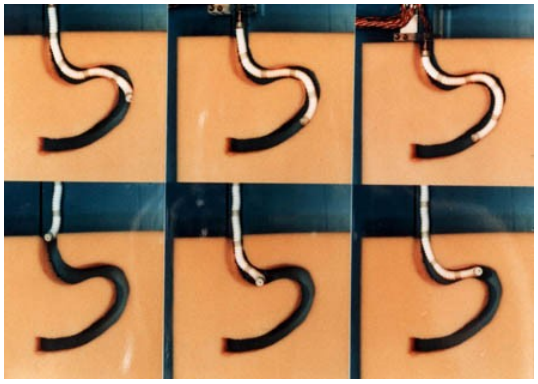


Trump orientating manipulator
for laparoscopy
www-robot.mes.titech.ac.jp

Elastor endoscope
with SMA actuators
www-robot.mes.titech.ac.jp





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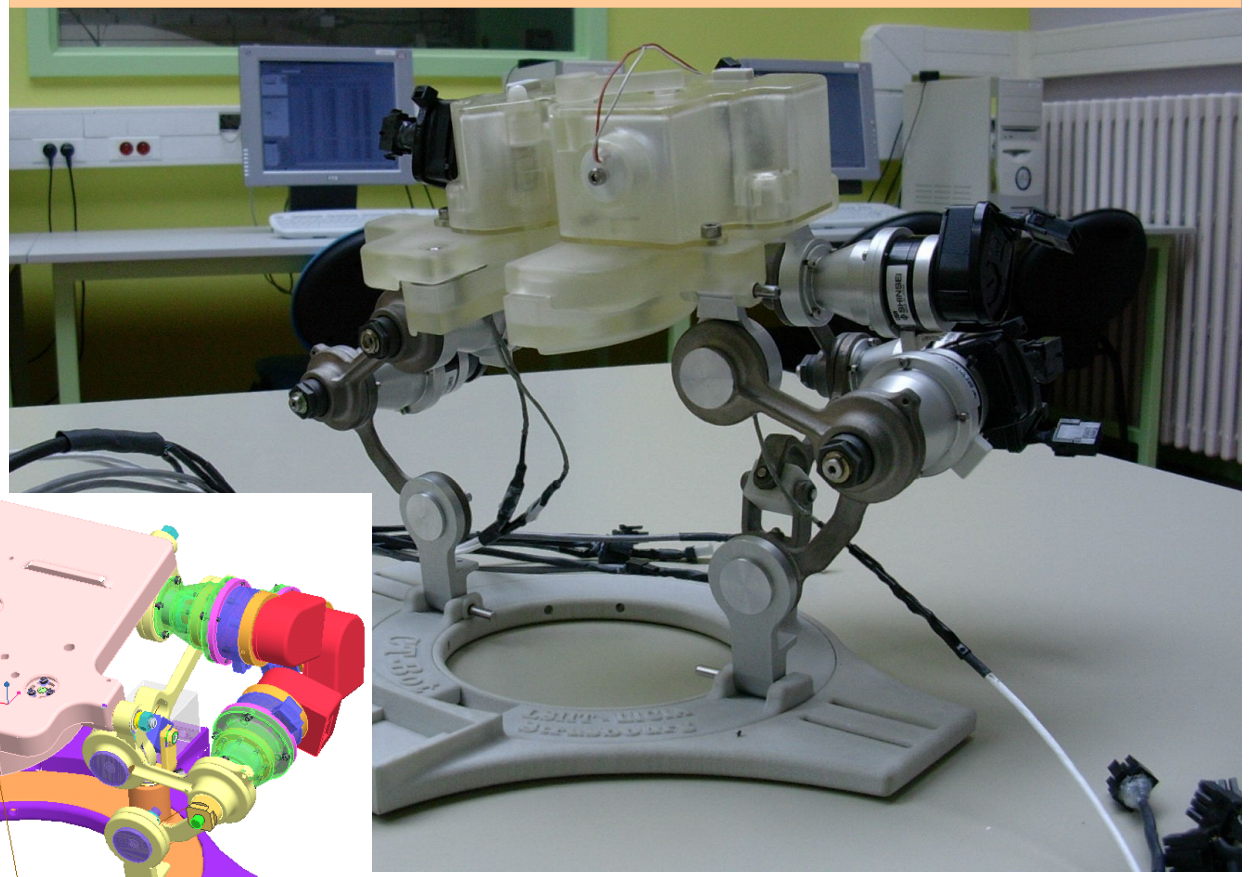
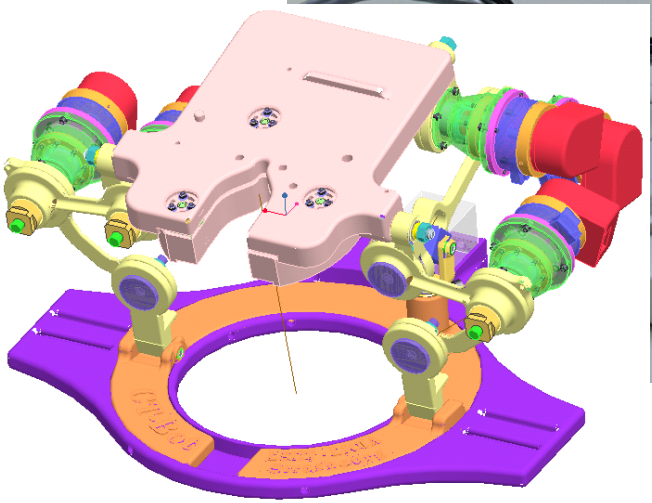
Surgery Manipulators

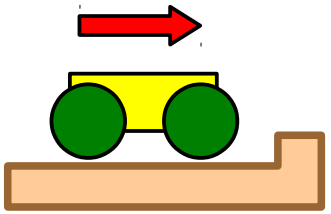
CT-Bot
5DOF parallel robot for needle insertion guided by **C**omputer **T**omography (the surgeon avoids to work among X-Rays)
lsiit.u-strasbg.fr





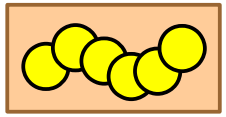
Mobile robots

Terrestrial vehicles

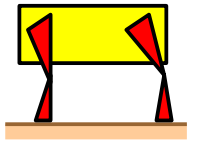


- ✔ **Wheeled** vehicles prevail (energetic efficiency ?)
- ✔ Blocked on **slope discontinuities** of the ground
- ✔ Legs / Tracks regain interest for **climbing**

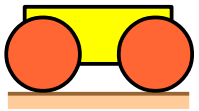
Interface with the ground



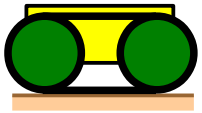
- ✔ **Crawler**
  + multiples contacts, can cross obstacles & rough terrain
  - require high energy, moderate speed, complex control



- ✔ **Leg**
  + can cross obstacles and go fast on rough terrain
  - contact discontinuity, energy cost, stability control



- ✔ **Wheel**
  + fast on smooth surface, energy efficient
  - cannot climb obstacles or run on rough terrain



- ✔ **Track**
  + permanent stability, high traction
  - high friction energy loss, particularly during steering

Steering

- ✔ Most of the vehicles have **non holonomic behaviour**

  E.g. a car cannot **go sideways** without a **manoeuvre**
  Going sideways is **non controlable**, although **possible**

- ✔ Holonomy is brought by **omnidirectional** propulsion

Crawling mobile robots

- ✔ Several **modes** (slide-pushing, peristaltism...)
- ✔ Suitable for inspection tasks (pipes...)
- ✔ **Solid ground** / **water**

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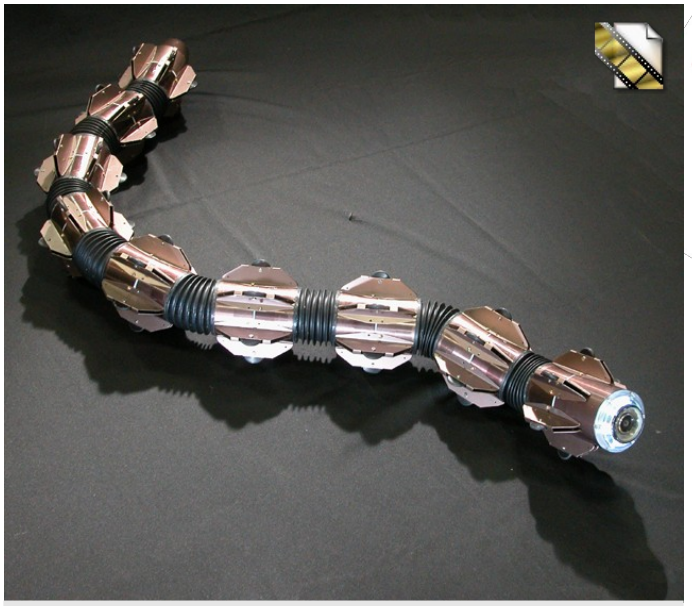

Active Cord Mechanism ACM-R5
7.5kg, 1.7m long, 80mm diameter
Snake propulsion on ground and water
www-robot.mes.titech.ac.jp

Aiko
7kg, 1.5m long, 20 DOF, 2.5 Nm
Obstacle-aided locomotion, slidewinding
www.sintef.no

Mobile robots based on legs

- ✔ Bi / Quadri / Hexa / Octo
- ✔ Gait study based on nature
- ✔ Gait self-teaching

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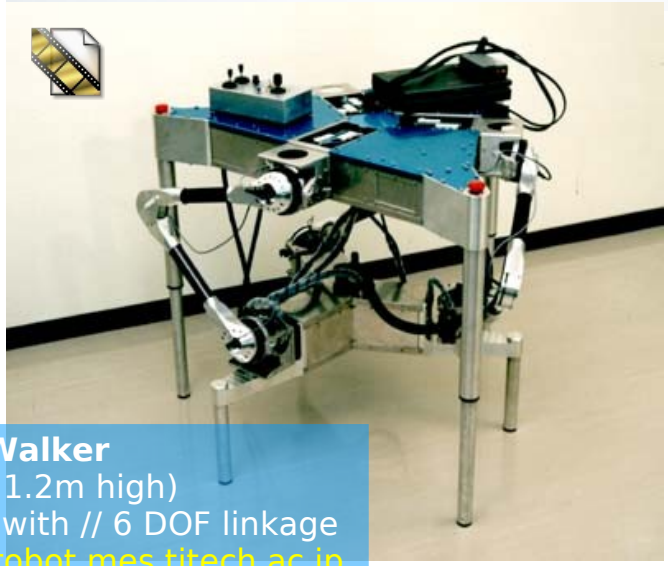
Big Dog (75kg, 1m long, 6km/h, 35° slopes, 150kg payload)
www.bostondynamics.com

Resilient walker
Gait self-teaching
Functional damage compensation
ccsl.mae.cornell.edu



ParaWalker
(50kg,1.2m high)
Biped with // 6 DOF linkage
www-robot.mes.titech.ac.jp

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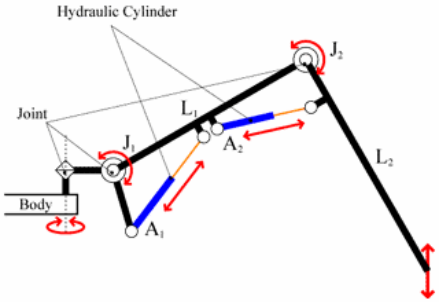
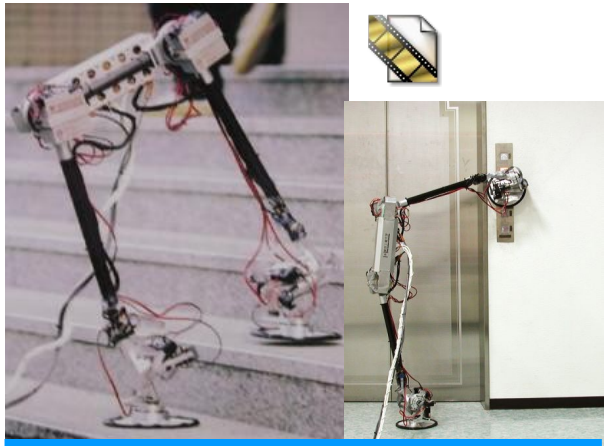
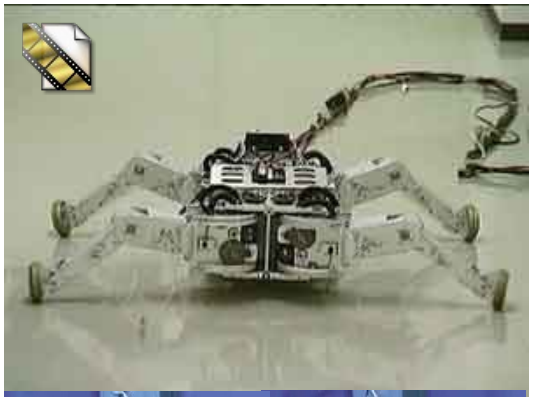
Mobile robots based on legs

Titan XI
(7000kg, leg 3.7m)
Climbing&heavy drilling
www-robot.mes.titech.ac.jp





Yanboo III
(13kg,0.7m high)
Biped with suction/rolling effectors
Legs are manipulators
www-robot.mes.titech.ac.jp



Roller-Walker (24kg, 0.5m long) Convertible wheels
Dual locomotion mode: walking / roller-skating
www-robot.mes.titech.ac.jp

Wheeled & tracked robots

- ✔ Wheel: energy efficient even when steering
- ✔ Only exception : **skid steering**

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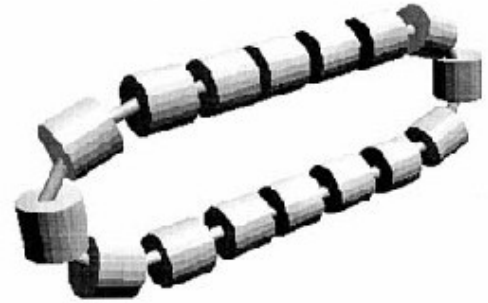
Pioneer P3-AT
Skid steering simple robot
www.mobilerobots.com

Nomad
Dual Ackermann steering strategy
www.frc.ri.cmu.edu/projects/lorax

Wheeled & tracked robots

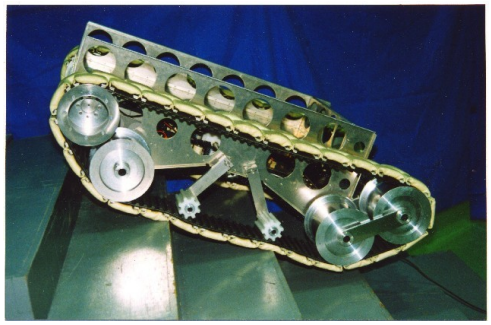
- Tracks: good traction but steering generates wear

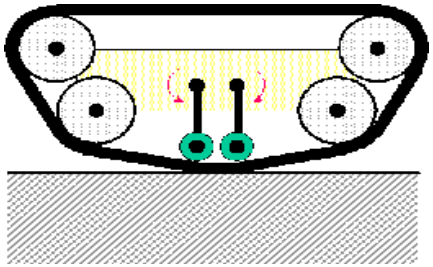


Packbot
Tracked robot
with auxilliary climbing tracks
www.irobot.com

Vuton
4 Omnidirectional tracks
Holonomic vehicle
www-robot.mes.titech.ac.jp

Xevius
Tracked robot
with reconfigurable polygon
www-robot.mes.titech.ac.jp





Robotics
State of the art 2012

- Robots
- Manipulators
- Mobile
  - Crawler
  - Leg
  - Wheel-Track
  - Hybrid
  - Special
- Humanoids
- Modular

Adaptative Wheeled Robots

- ✔ **Minimally actuated frame**, energy efficiency
- ✔ Simple control

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Rocky 7
Adaptative rocker-bogie structure
www-robotics.jpl.nasa.gov

Micro5
Climbing abilities via 5 wheels
www.mit.edu/~ykuroda

Adaptative Wheeled Robots

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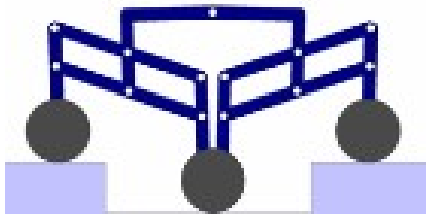
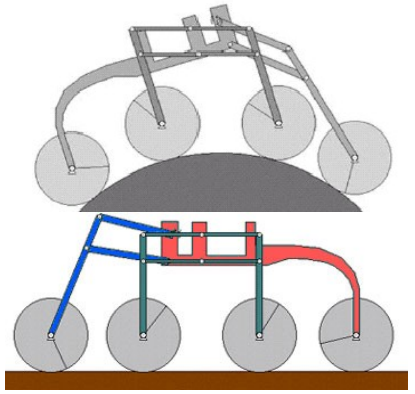
Crab I
Adaptative parallel bogies
Obstacle climbing abilities
www.asl.ethz.ch



Shrimp
6 wheels on 2 // bogies
and 1 front linkage
www.asl.ethz.ch



Hybrid multi-mode robots

- Highly **actuated** frame
- **Orientable tracks** for special modes of displacement

Robotics
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Azimut
4 orientable tracks
www.gel.usherbrooke.ca/laborius

Helios VII
2 articulated tracks + 1 manipulating arm with hybrid grip/wheel end effector
www-robot.mes.titech.ac.jp

Hybrid multi-mode robots

- ✔ **Highly actuated** frame
- ✔ Displacement modes: **peristaltic** crossing, obstacle **climbing**

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State of the art 2012

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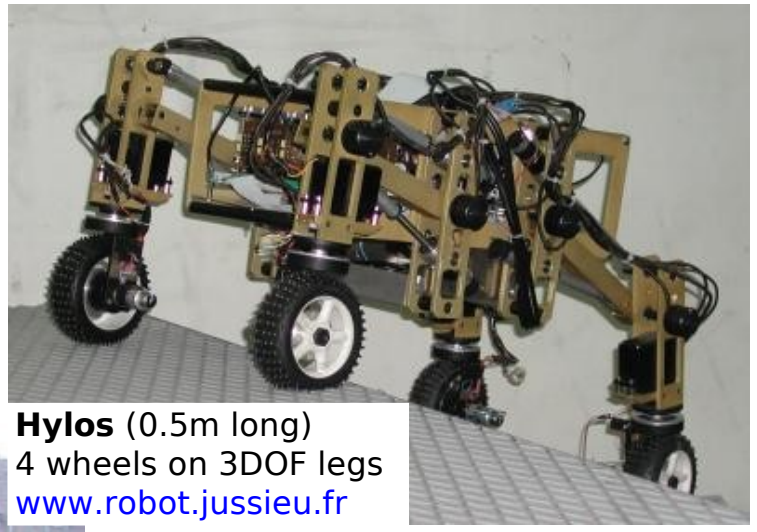
RobuROC 6 (150 kg, 1.5m long)
3 tiltable axles with passive warping
Able to turn on itself
Can climb obstacles
www.robosoft.fr



Hylos (0.5m long)
4 wheels on 3DOF legs
www.robot.jussieu.fr

Lama
Peristaltic crossing
of sandy areas
www.laas.fr

A Hybrid multi-mode robot OpenWHEEL i3R

- ✔ OpenWHEEL **i3R** robot
- ✔ **Stable** obstacle climbing with **only 4** wheels
- ✔ Only one supplemental **central actuator**

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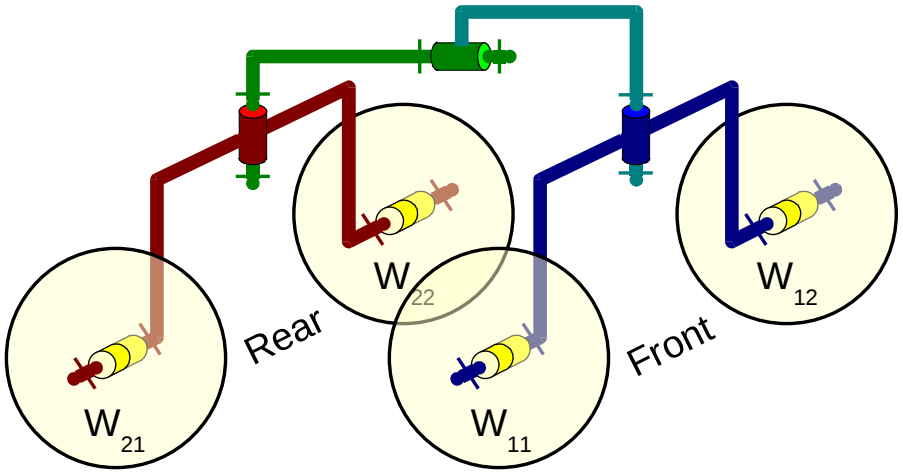
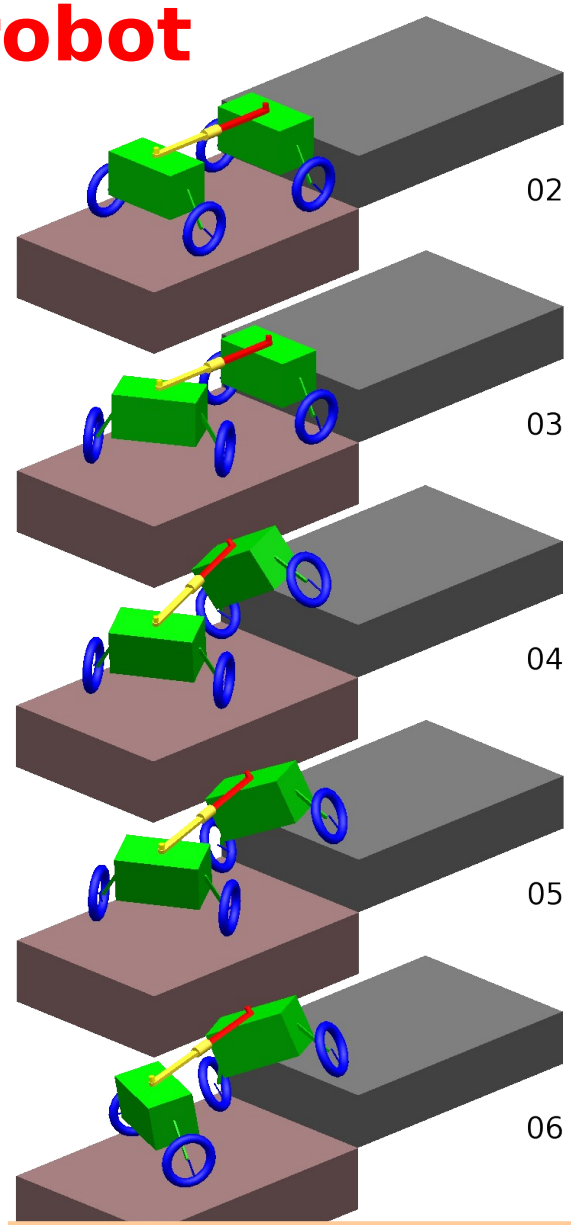
OpenWHEEL i3R
A big central actuator for warping





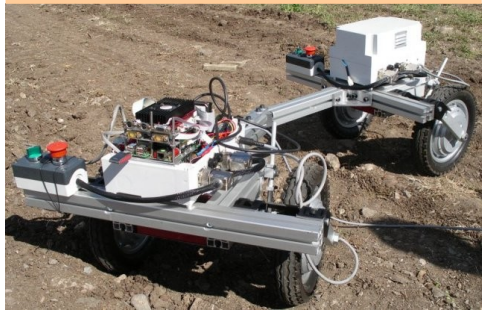
OpenWHEEL i3R
jc.fauroux.free.fr
www.ifma.fr/lami

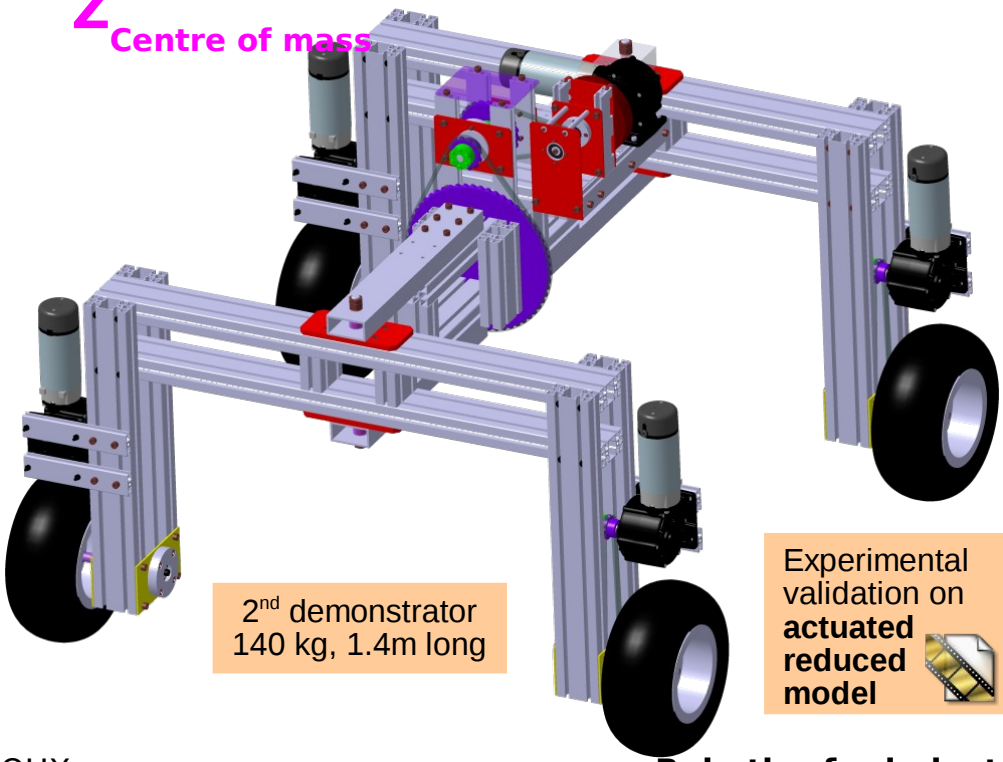
A stable **climbing process**
Multibody validation (Adams)

A Hybrid multi-mode robot OpenWHEEL i3R

- Climbing process in **19 stages**
- Climbs obstacles as high as **66%** of $Z_{\text{Centre of mass}}$

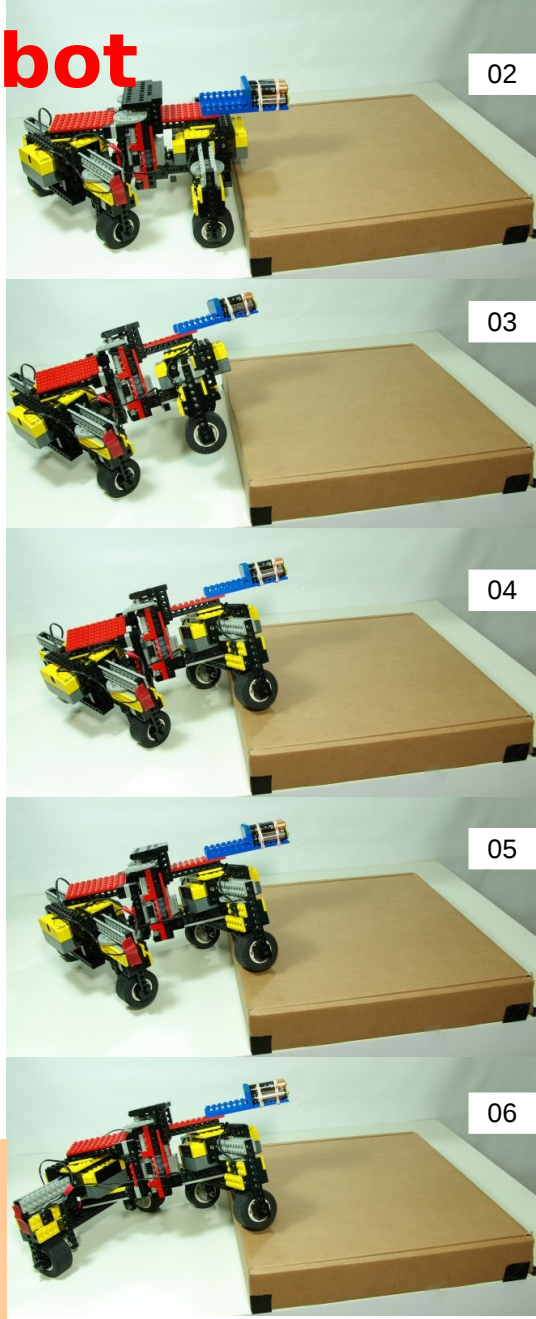
First demonstrator at scale 1:1





2nd demonstrator
140 kg, 1.4m long

Experimental validation on **actuated reduced model**



Robotics
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Special robots

- ✔ Flying **drones** become popular
- ✔ Aero-terrestrial **cooperation**
- ✔ **Underwater** drones

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Dragonfly Nanodrone
120mg, 6cm wide, 80mW
SMA actuators on the wings
www.silmach.com

Minidrone
www.bertin.fr

Alistar 3000
5m long, 2800kg
Depth 3000m
www.eca.fr

Seaglider
1.8m long, 52kg
Range 1000km
Depth 1000m
www.irobot.com

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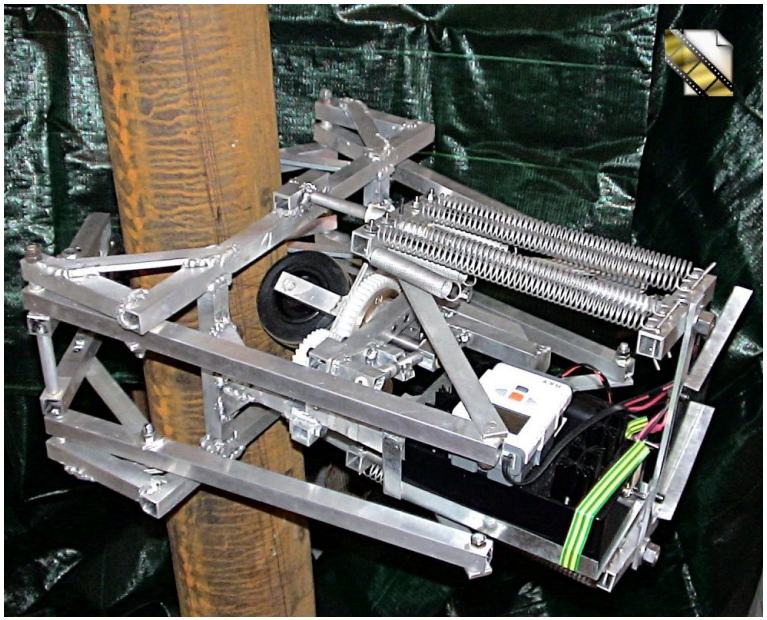
Special robots

✔ Pole climbing



Pobot V2
Pole climbing robot
Cannot fall, can turn around the pole
jc.fauroux.free.fr
www.ifma.fr/lami

✔ Pipe exploring

MagneBike
2 magnetic wheels with
anti-locking rollers
www.asl.ethz.ch

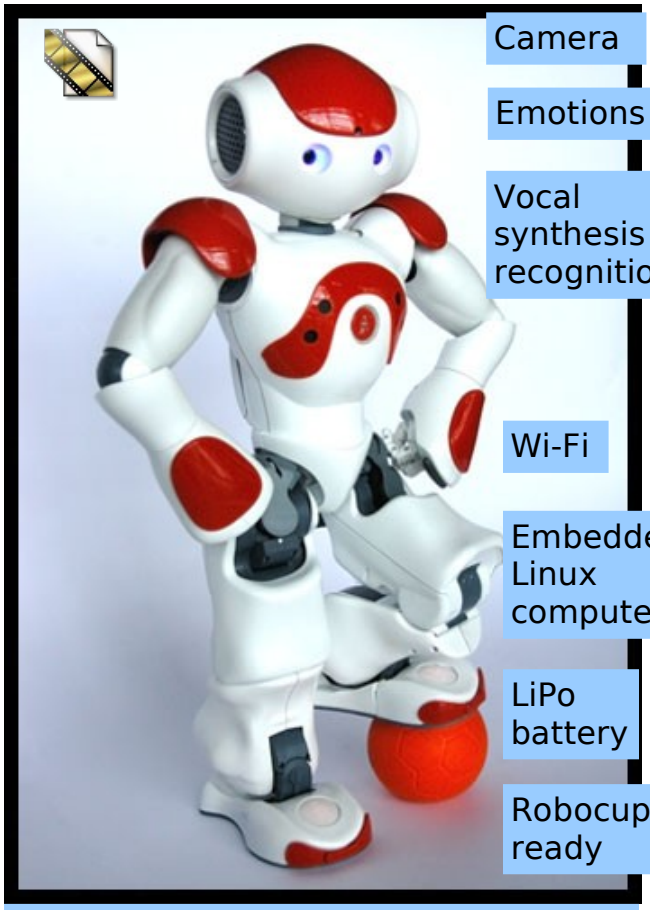
Robotics
State of the art 2012

- Robots
- Manipulators
- Mobile
- Humanoids
  - Human-like
  - Exo-skeletons
- Modular
- Conclusion

Human-like robots

- ✔ Humanoid = 1 **walking** robot + 2 **manipulators**
- ✔ New applications : **companion** robots

Asimo
24 DOF, 52 kg, 1.2m high
world.honda.com/ASIMO

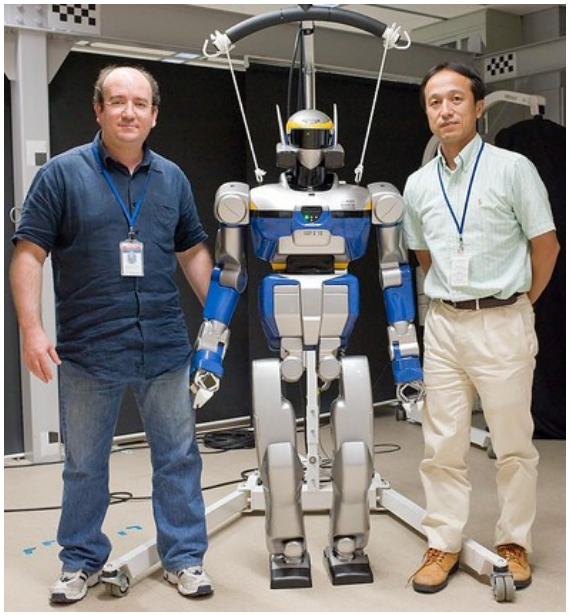


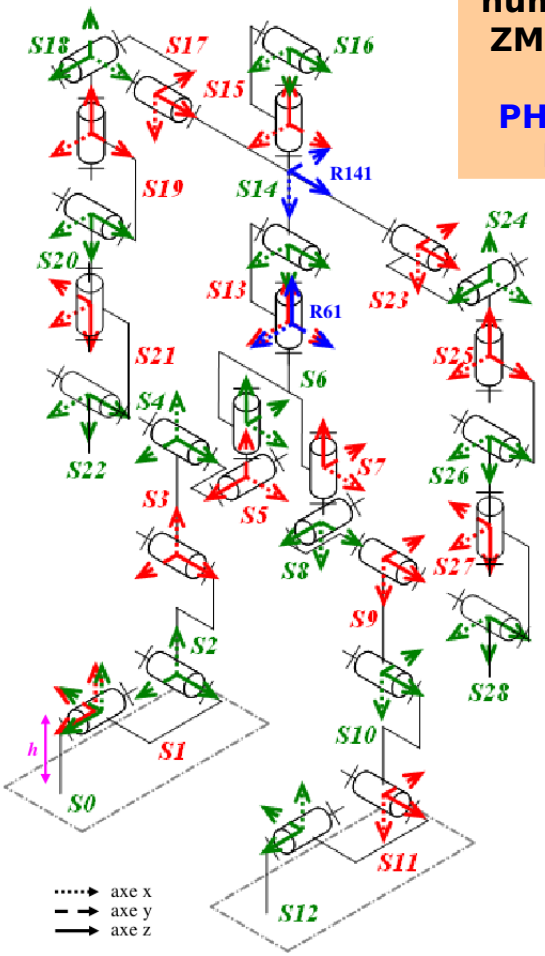
Nao
25 DOF, 0.58m high, 3k€
www.aldebaran-robotics.com

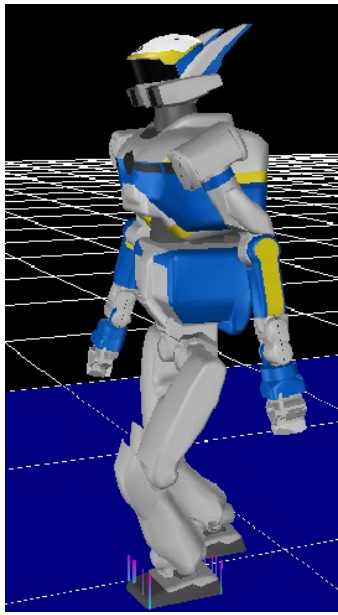
Human-like robots

- **HRP-2** (Humanoïd Robotics Project)
- Japon : AIST, Kawada Industry
- Collaboration LAAS CNRS (2006+)
  - 28DDL =
  - 2x6 legs
  - + 2x6 arms
  - + 2 torso
  - + 2 head
  - 1,54m 58 kg

Dynamic control of humanoïd robots by ZMP (Zero Moment Point)
PHD Antoine EON, Poitiers 2009







Robotics
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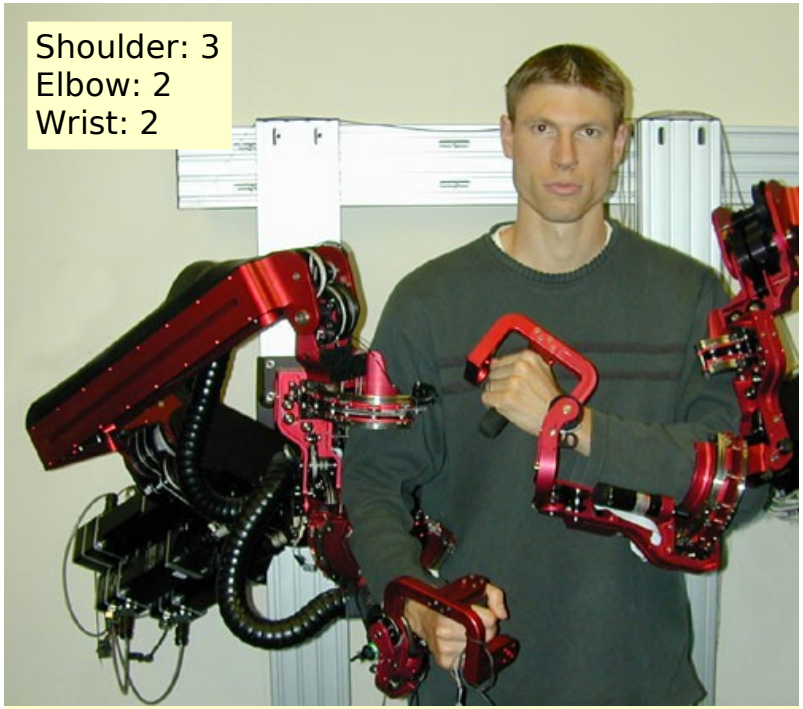
Exo-skeletons

- ✔ Bio-compatible
- ✔ **Haptic** device + Force **amplifier**
- ✔ Specialized on a limb (arm/leg)



Wearable robotics - Exoskeleton
7DOF, Neural control
brl.ee.washington.edu

ReWalk robotic suit
For walking / lifting from seat
www.argomedtec.com

Exo-skeletons

- ✔ Military applications (Raytheon Sarcos)
- ✔ **Force feedback** for delicate tasks

Complete exo-skeleton XOS2
Lower and upper limbs
www.raytheon.com

Dual manipulatorBigArm
2x100kg at a distance of 2m
www.raytheon.com

Modular Robotics Kits

- ✔ From toys to industry
- ✔ Cost-effective / maintainability

Mindstorms NXT
Control box, Bluetooth,
3 actuators 2W 50Ncm
Sensors (contact / sound / US / light / ...)
mindstorms.lego.com

Ranked 1st and 2nd in France 2007. Source : www.robopolis.com

Bioloid
Servomotors AX12 150 Ncm
Sensors (distance / light / heat / ...)
www.robotis.com

Robotics
State of the art 2012

- Robots
- Manipulators
- Mobile
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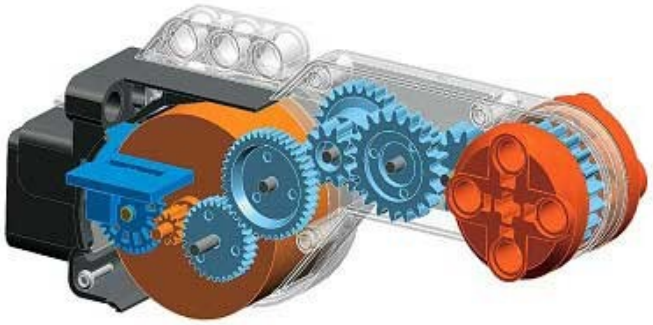
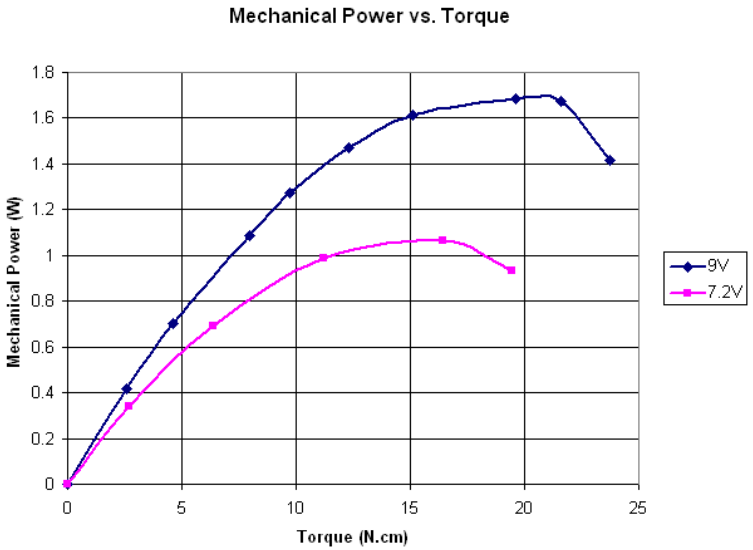
  - Kit approach
  - Self-reconfig.
- Conclusion

Mindstorms : case study

- An open and expandable architecture
  - Atmel **32-bit ARM** processor at 48MHz, 256 Kb flash
  - **Bluetooth** / USB2
  - 3 motors outputs / 4 sensor inputs / multiplexers with daisy chain
  - Only **one controller** required
  - Closed loop control with access to PID parameters
  - **Powerful** 9V actuators (5W)
  - Many **sensors** : contact, angular, distance (US), 3D accelerometer to measure tilting
- A dynamic community
  - Experimental actuator characterization
  - **www.philohome.com**





Mindstorms : Sensors (1/2)

Robotics
State of the art 2012

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Angle incremental coder (1°)
www.hitechnic.com

Flex sensor (1° acc.)
Dexterindustries.com

Camera 88x144@30Hz
www.mindsensors.com

WIFI remote (digital/analog)
www.mindsensors.com

Sensor type	lego.com	codatex.com	dexterindustries.com	hitechnic.com	humarobotics.com	mindsensors.com	vernier.com
Locating							
Contact	X					X	
Distance US	X						
Distance IR						X	
Accelerometer				X		X	X
Angle				X			
Flexion			X				X
Gyrometer				X			
IMU			X				
GPS			X				
Magnetic compass			X	X			X
Force							X
Vision						X	
Communication							
RFID		X					
USB HID						X	
Wifi			X		X		
Zigbee			X				
Remote control						X	

Mindstorms : Sensors (2/2)

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Sensor multiplexer
www.hitechnic.com

Motor multiplexer
www.hitechnic.com

Dswitch
Dexterindustries.com

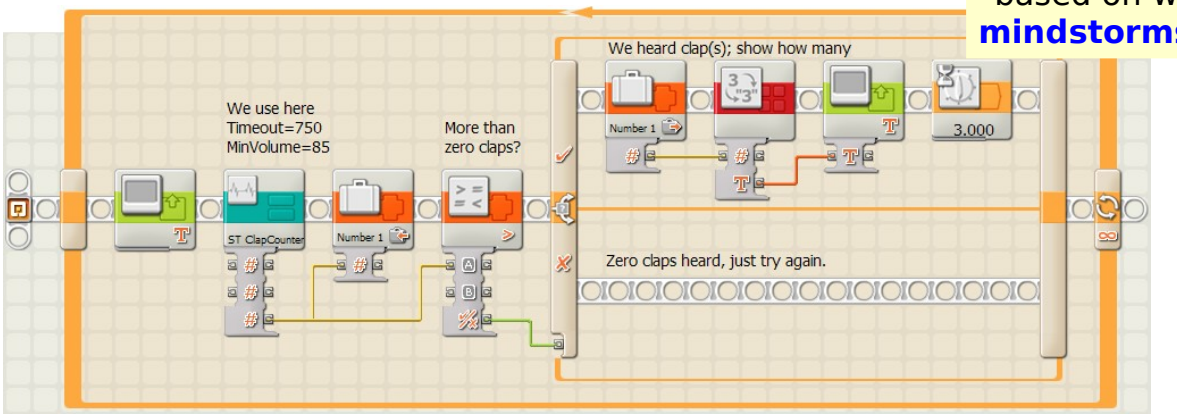
NXT adapter
www.vernier.com

Sensor type	lego.com	codatex.com	dexterindustries.com	hitechnic.com	humarobotics.com	mindsensors.com	vernier.com
Infrastructure							
Clock						X	
Sensor multiplexer				X		X	
Actuator multiplexer						X	
Servomotor control						X	
AC control			X				
Solar power	X		X				
Various sensors							
Current							X
Power						X	
Anemometer							X
Barometer				X			X
Color	X			X		X	X
Sound	X						X
Temperature			X				X
Moisture							X
Turbidity							X
Flow							X
Pressure			X			X	X
Dissolved oxygen							X
pH							X

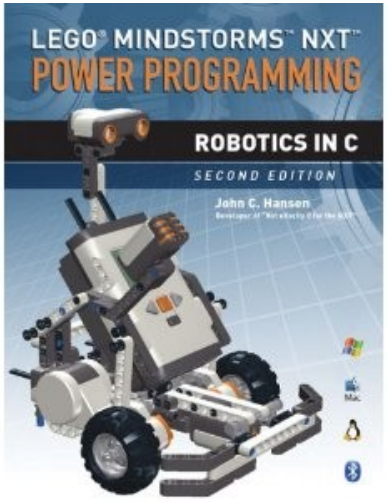
Mindstorms : native OSes

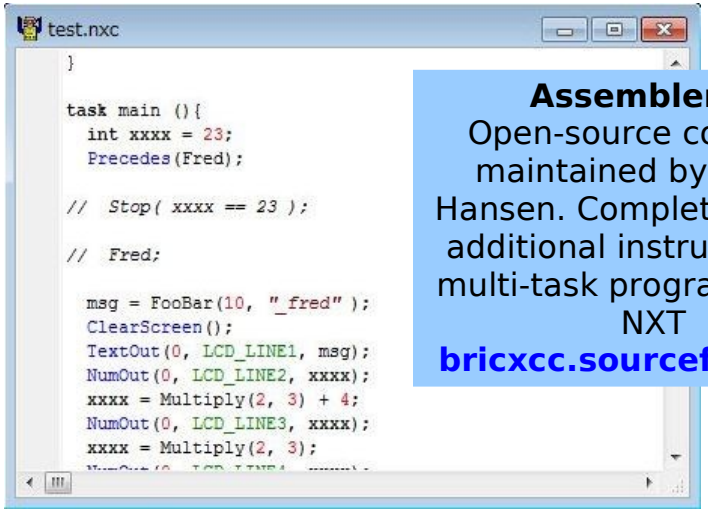
- NXT-G Labview like language

Graphical language based on wired blocks
mindstorms.lego.com



- NBC / NXC Assembler and C compilers





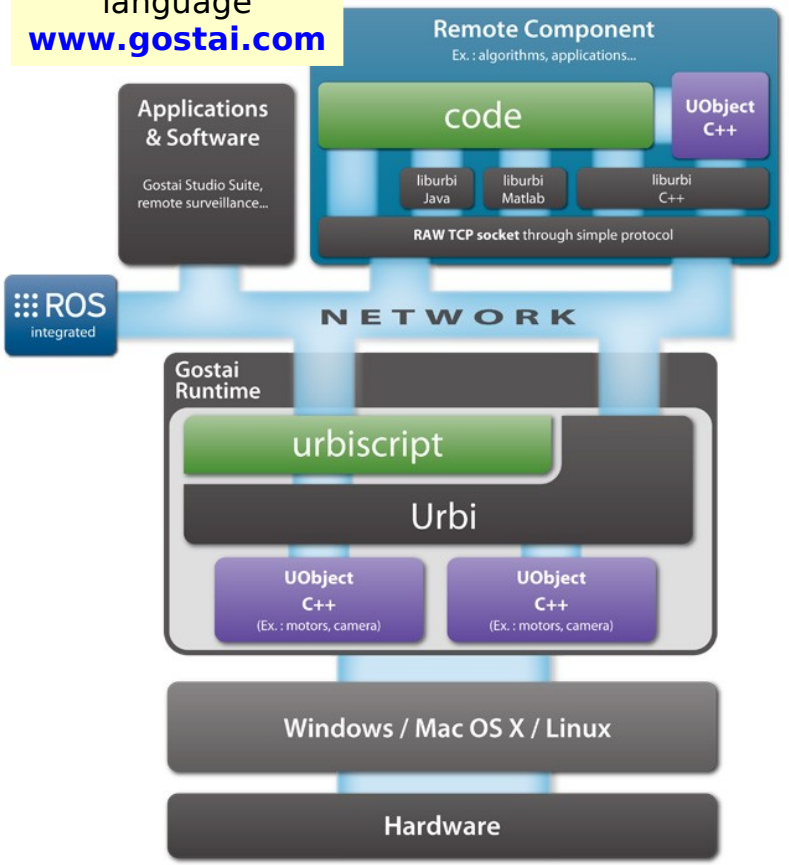
Assembler / C
Open-source compilers maintained by John C. Hansen. Complete API with additional instructions for multi-task programming of NXT
bricxcc.sourceforge.net

- Others: RobotC, LejOS (Java)...

Mindstorms : neutral OSes

- ✔ Principle : one program for several hardware architectures → maintainability
- ✔ GOSTAI Urbi :
  - **Open Source**
  - **Multi-OS**: Linux / Mac OS / Windows
  - **Multi-hardware** : NXT / Bioloid / Spykee / Aibo / Nao / Segway / ...
  - Event **orchestration script** Urbiscript with graphical programming
  - **C++ component** UObject
  - **Network** connection
  - **Abstraction level**: "jumping" means different control laws for Aibo & Nao but is represented by the same Urbi function

Open source Urbi language
www.gostai.com



- ✔ ROS (Robot Operating System) www.ros.org
- ✔ Microsoft Robotics studio (closed source)

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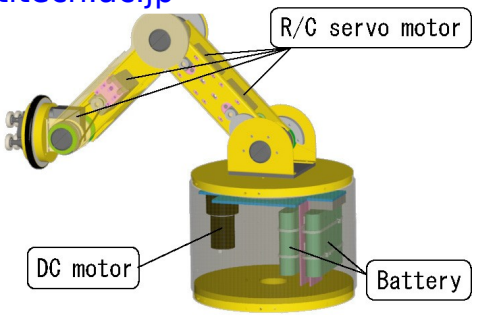
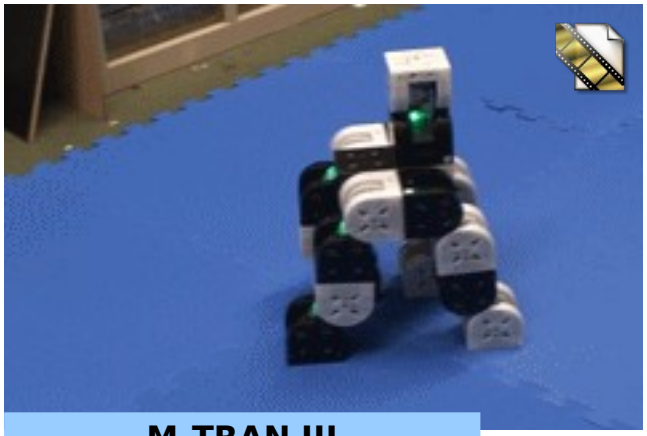
Self-reconfigurable robots

- ✔ Robot with detachable limbs

SMC Rover and **UniRover**
6 wheels on detachable legs
www-robot.mes.titech.ac.jp

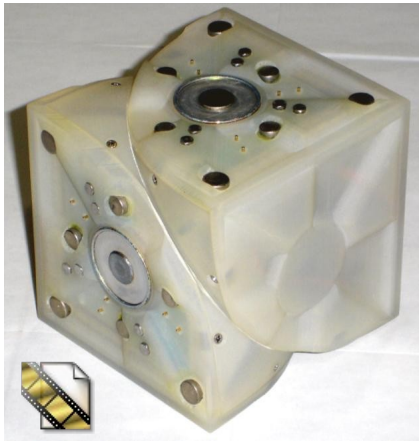


- ✔ Self-attaching modules
- ✔ Towards auto-replication / cloning



M-TRAN III
Self reconfigurable robot
Locomotion and Adaptation
unit.aist.go.jp/is

The next step:
robot **breeding**



Molecube
Auto-cloning
ccsl.mae.cornell.edu

Conclusion

- Manipulators
  - ✔ **Serial** manipulators reached industrial **maturity**
  - ✔ **Parallel and hybrid** architectures may improve **dynamics** and **precision**
- Mobile robots
  - ✔ No locomotion mode is perfect
  - ✔ Improved architectures: engines **distributed** on the wheels, **wheels on legs**
  - ✔ Innovative architectures already exist (e.g. for **spatial** robots)
- Humanoids
  - ✔ **Realism** and **energetic autonomy**
  - ✔ Companion robots with improved **interaction** and **expressivity**
- Modular robots
  - ✔ Modularity for **reliable** and **cost-effective** building of **anything**
  - ✔ Control via portable software development kits, limb and behavior libraries