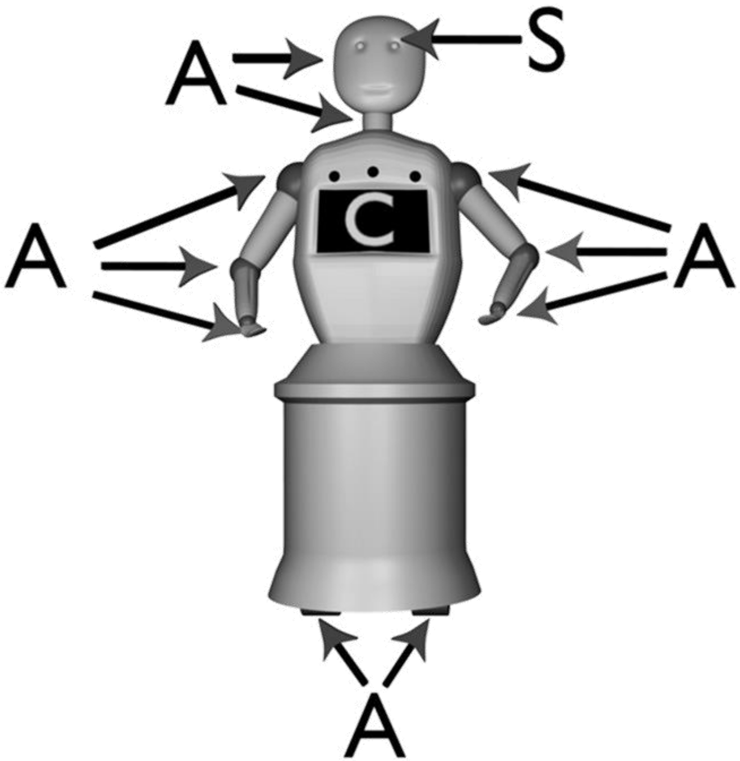
University of Pisa
Master of Science in Computer Science
Course of Robotics (ROB)
A.Y. 2019/2020



Robotics basics

Cecilia Laschi
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http://didawiki.cli.di.unipi.it/doku.php/magistraleinformatica/rob/start

Robot definition

A *robot* is an autonomous system
which exists in the physical world,
can sense its environment,
and can act on it to achieve some goals

Maja J Mataric, *The Robotics Primer*, The MIT Press, 2007

A robot is an AUTONOMOUS system

Autonomous

- An *autonomous* robot acts on the basis of its own decisions, and is not controlled by a human

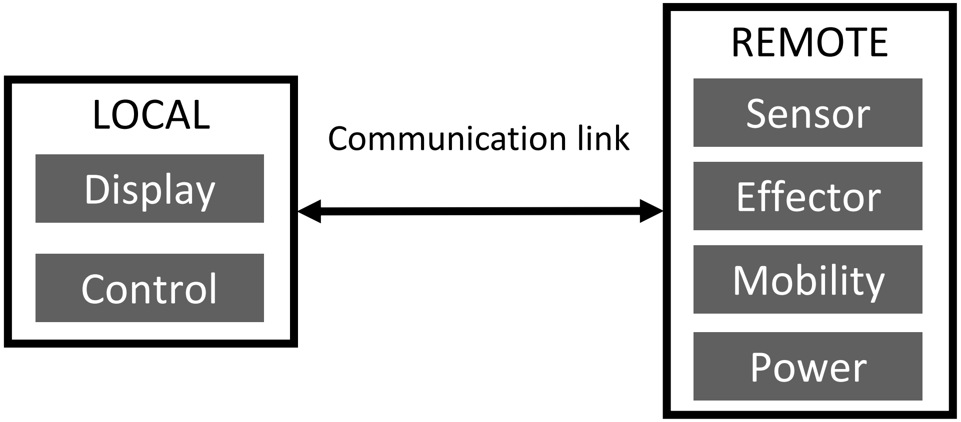
Non autonomous

- A non-autonomous robot is commanded step by step by an operator (teleoperation)

Semi-autonomous

- Control is shared between robot and user; different levels of autonomy may exist

≠ from teleoperation



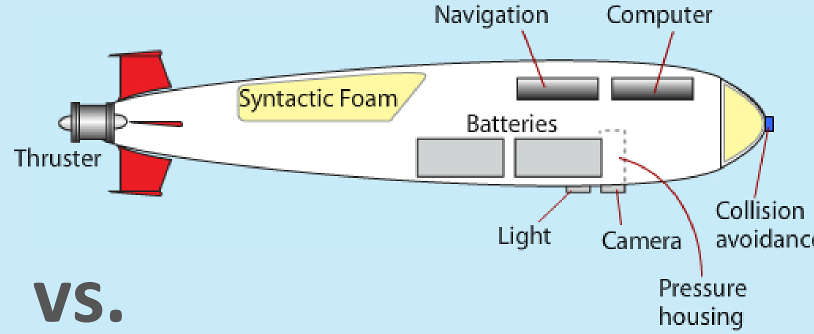
Robonaut

AUV

***A**utonomous*
***U**nderwater*
***V**ehicle*

Has:
- Thrusters
- Batteries
- Navigation
- Onboard computer
- Pressure housing

Does not have:
- Tether
- Manipulator arm
- Sample basket
- Personnel sphere



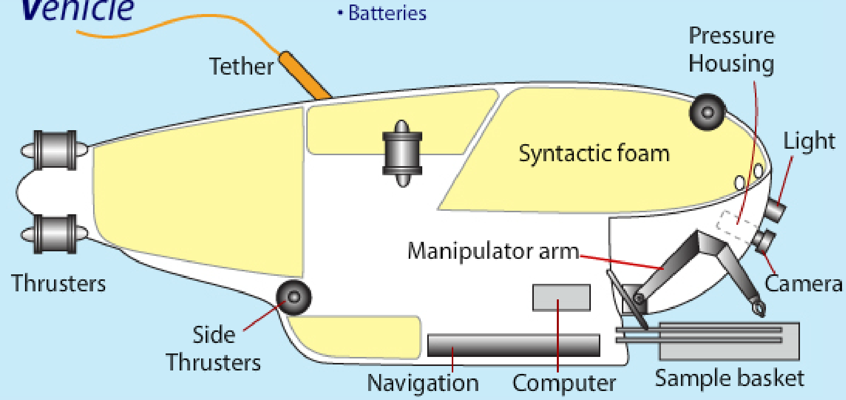
vs.

ROV

***R**emotely*
***O**perated*
***V**ehicle*

Has:
- Thrusters
- Navigation
- Sample basket
- Tether
- Manipulator arm
- Onboard computer
- Cameras

Does not have:
- Personnel sphere
- Batteries

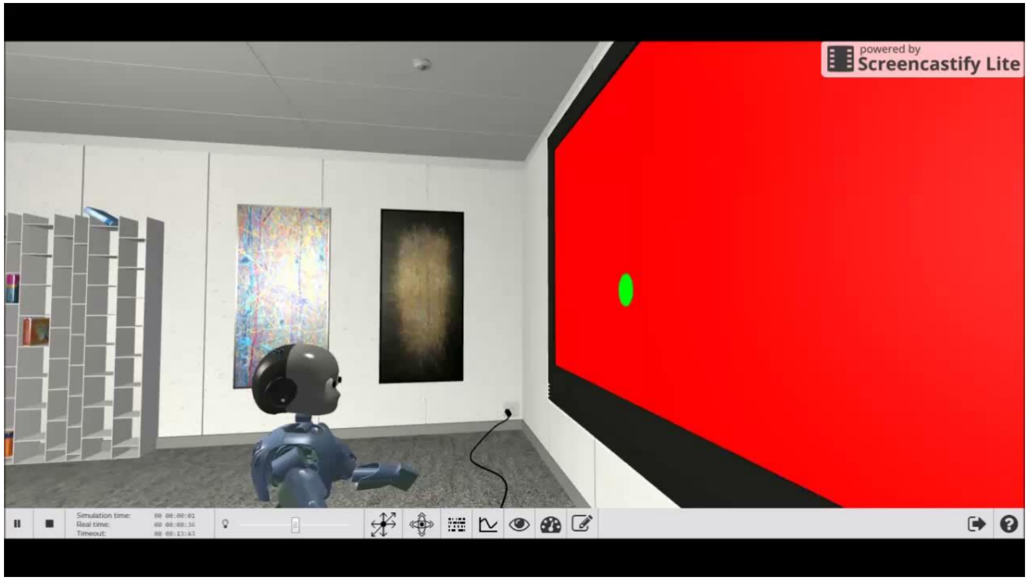


A robot is an autonomous system which exists in the PHYSICAL WORLD

- Subject to the laws of physics

≠ from simulations

The physical world, the physical laws and the interactions are simulated and somehow approximated



A robot is an autonomous system which exists in the physical world, can SENSE its environment

- the robot has *sensors*, some means of perceiving (e.g., hearing, touching, seeing, smelling, etc.) in order to get information from the world.

A robot is an autonomous system which exists in the physical world, can sense its environment, and can ACT ON IT

- the robot has *effectors* and *actuators*, for taking actions to respond to sensory inputs and to achieve what is desired

A robot is an autonomous system which exists in the physical world, can sense its environment, and can act on it to ACHIEVE SOME GOALS.

- Robot “intelligence”

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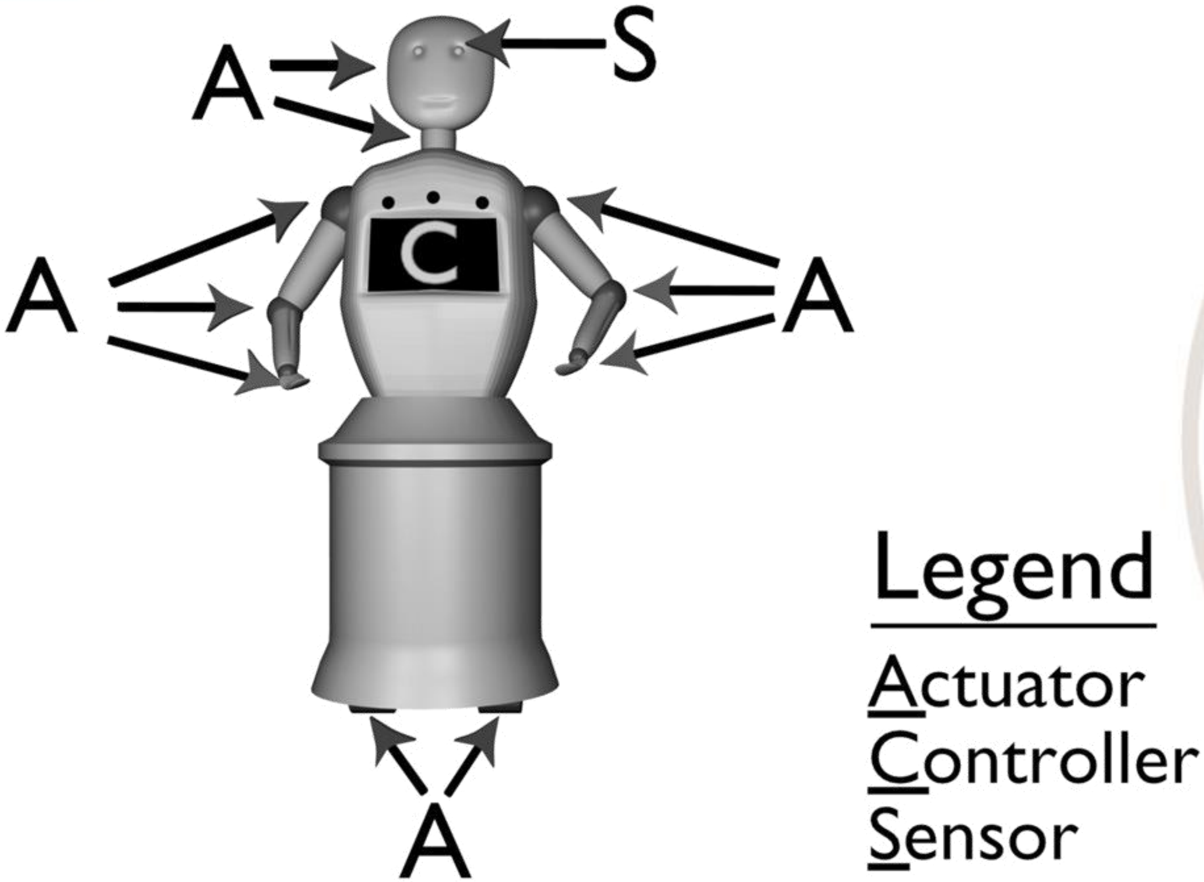
What's in a robot?

Robot components

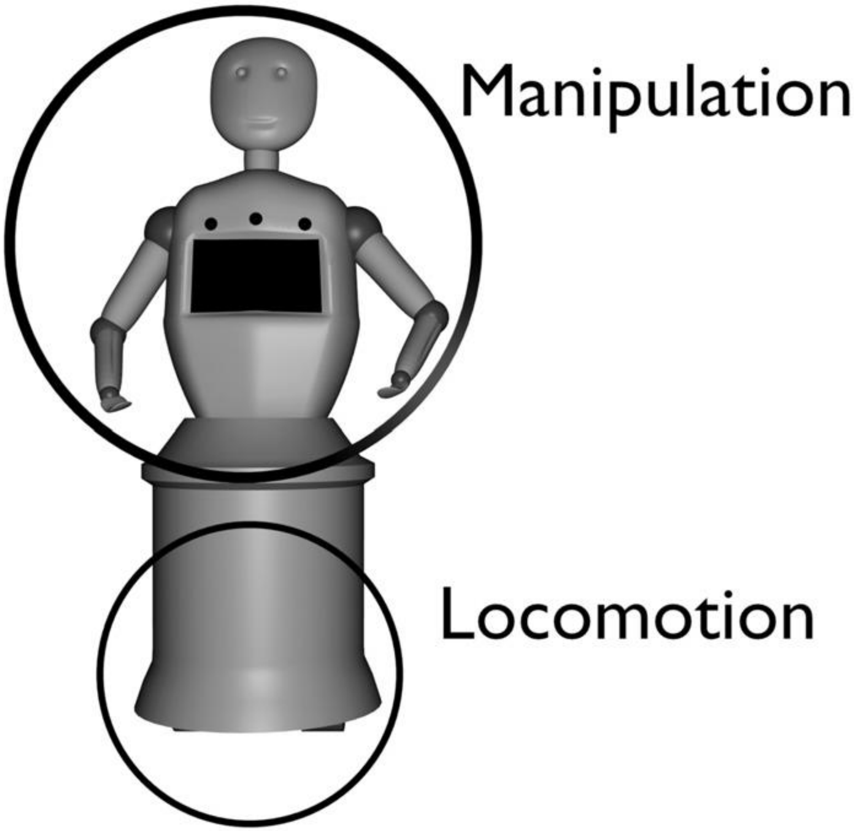
What's in a robot?
Robot components

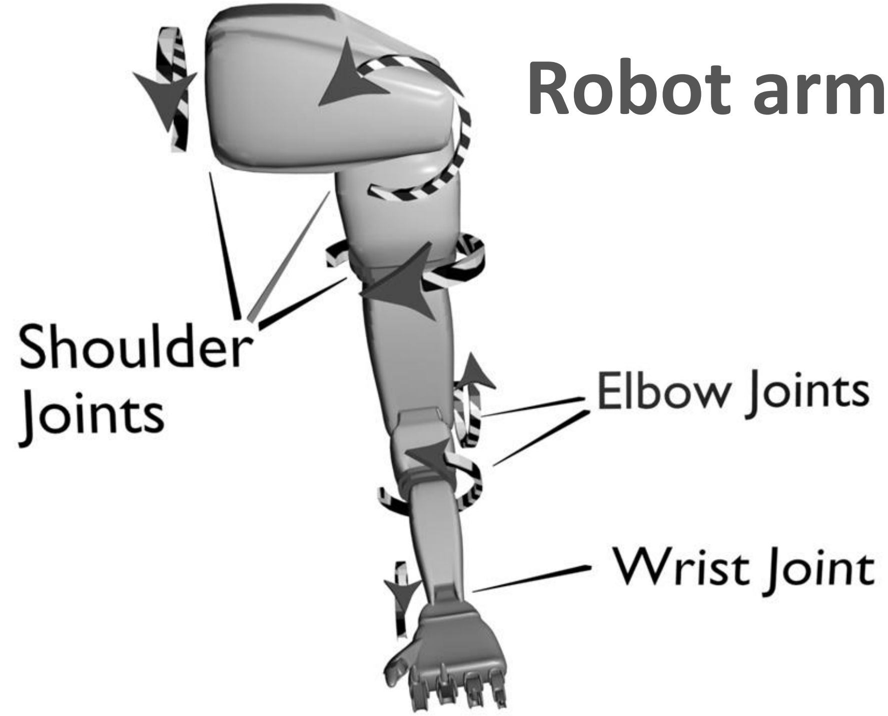


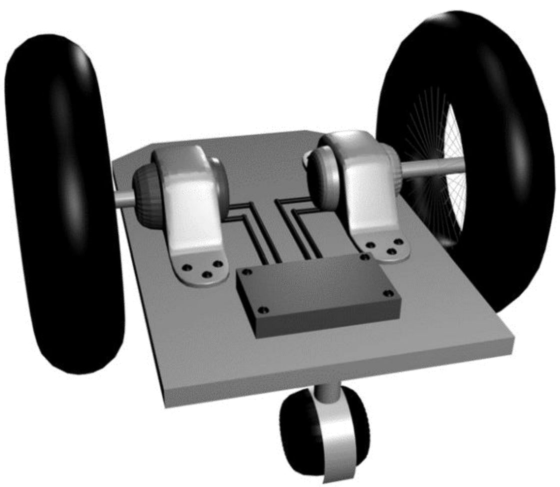
Maja J Mataric, *The Robotics Primer*, The MIT Press, 2007

Effectors

Robot arms







Robot arm

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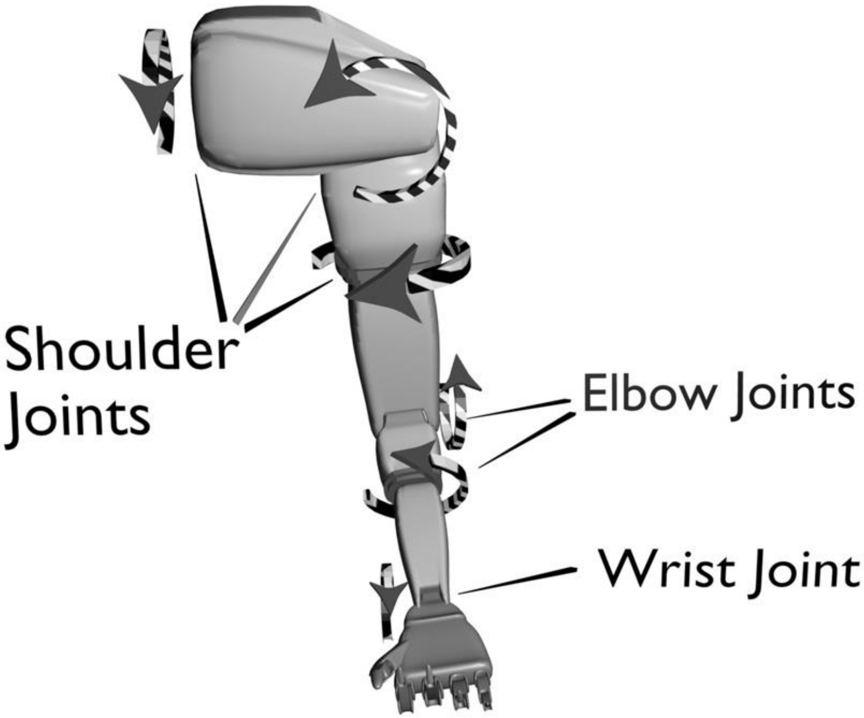
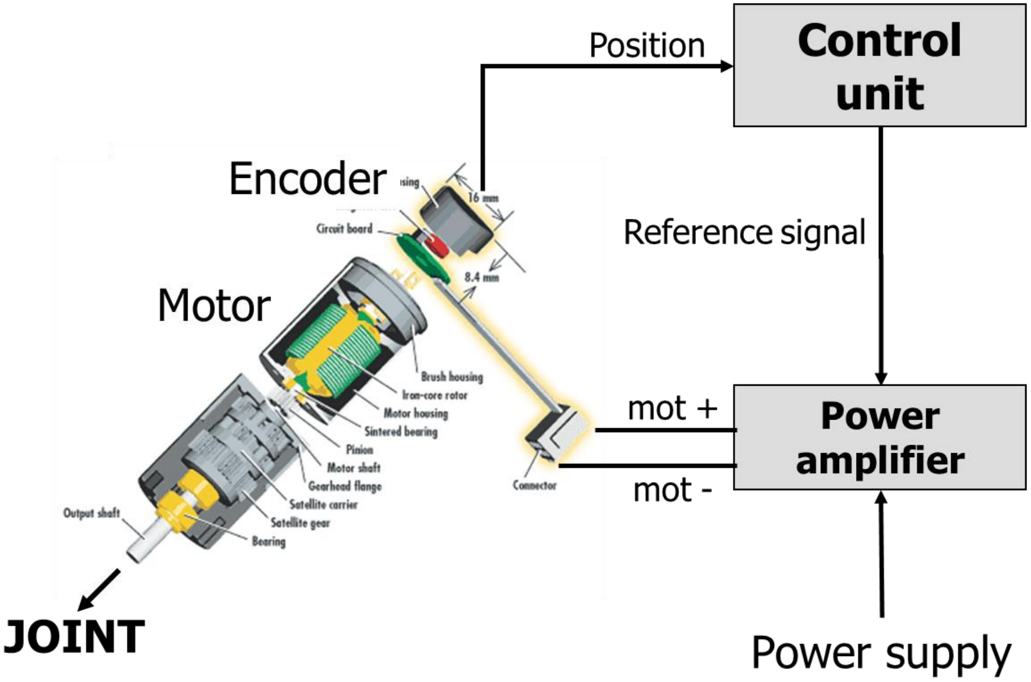


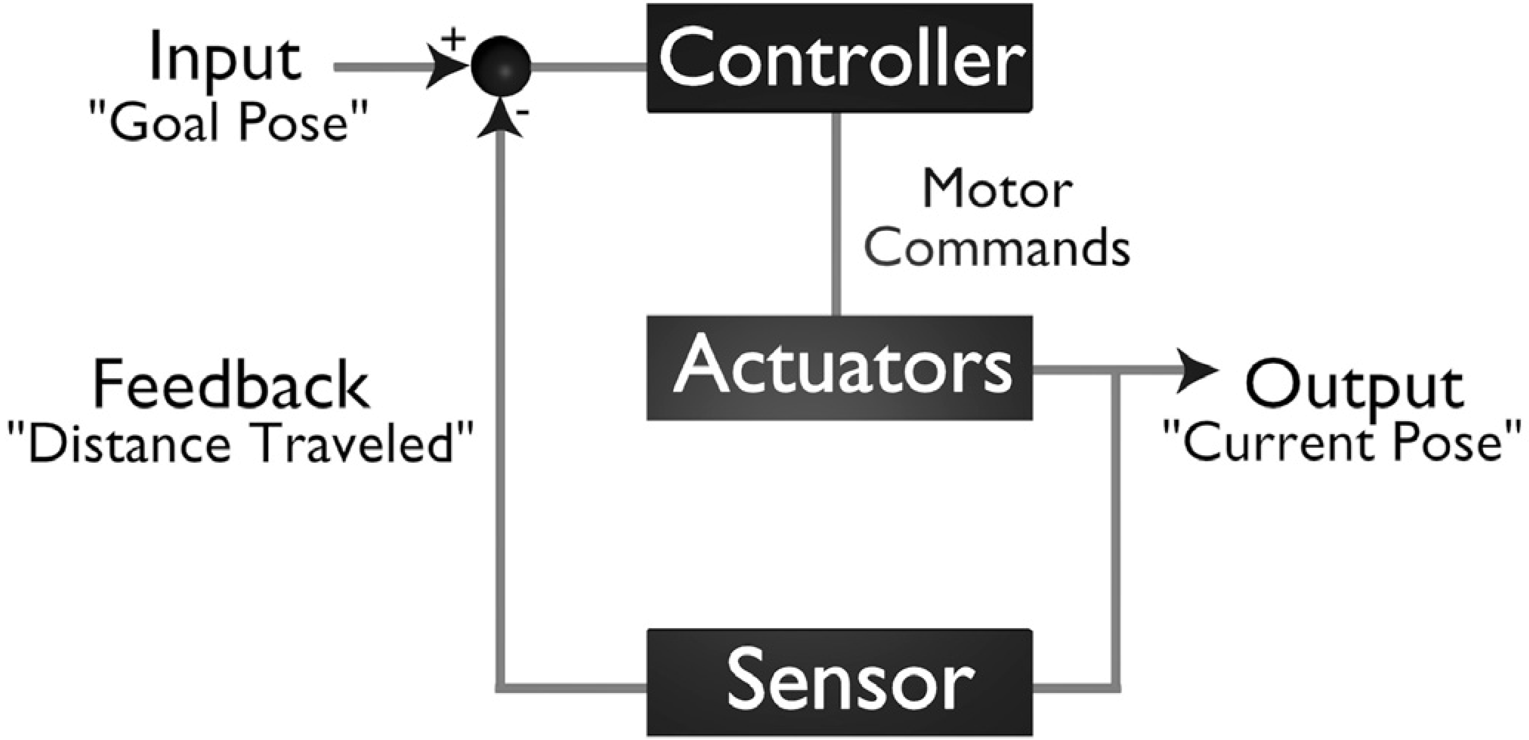
- Definition: **open kinematic chain**
- Sequence of rigid segments, or **links**, connected through revolute or translational **joints**, actuated by a **motor**
- One extremity is connected to a support **base**, the other one is free and equipped with a tool, named **end effector**

Actuators

- **Encoder**: sensor measuring joint rotations, either as an absolute or a relative value. The measurement is given in "*encoder steps*"
- **Reducer:** mechanism reducing the motor rotations with respect to the rotations of the axis mounted on the motor (ex. 1:k reduction)
- **Power amplifier:** it amplifies a reference signal into a power signal for moving the joint
- **Control unit**: unit producing the reference signal for the motor



Controllers



Industrial robots

Reliability (minimal requested values):
Mean Time Before Failure = 40,000 hrs
Efficiency η > 99.99875% *(Source: COMAU)*

Video courtesy: COMAU

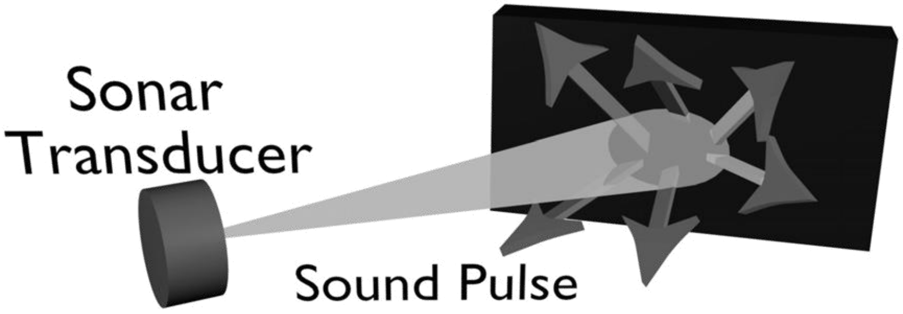
Sensors

- Sensing the **<u>external state (exteroception)</u>**: measurement of variables characterizing the working environment.
- Examples:

Physical Property	→	**Sensing Technology**
Contact	→	bump, switch
Distance	→	ultrasound, radar, infra red
Light level	→	photocells, cameras
Sound level	→	microphones
Strain	→	strain gauges
Rotation	→	encoders and potentiometers
Acceleration	→	accelerometers and gyroscopes
Magnetism	→	compasses
Smell	→	chemical sensors
Temperature	→	thermal, infra red
Inclination	→	inclinometers, gyroscopes
Pressure	→	pressure gauges
Altitude	→	altimeters

- Sensing the **<u>internal state (proprioception)</u>**: measurement of variables internal to the system that are used to control the robot.

Ultrasound sensors

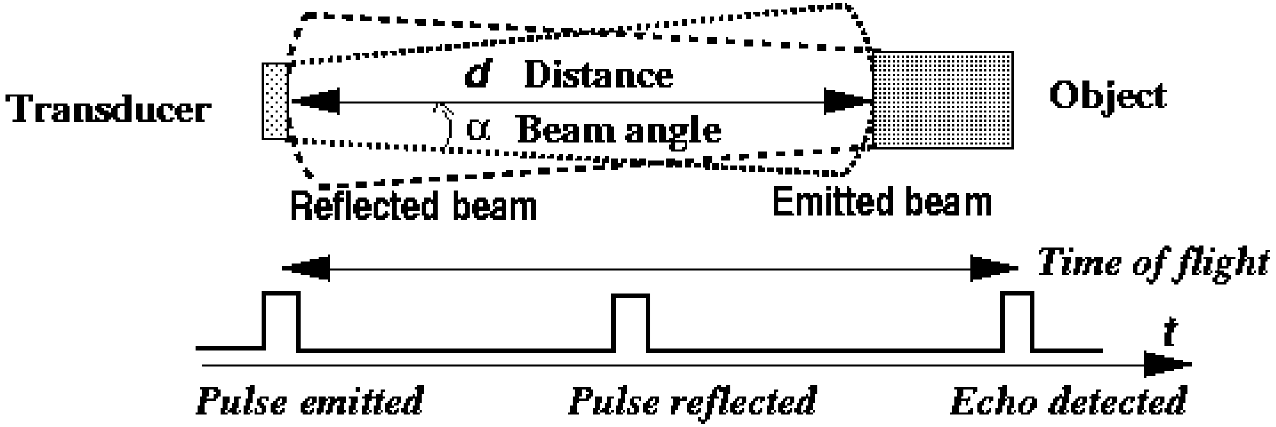


Time of flight measurement:

(example: *radar* and ultrasonic *sonar*)

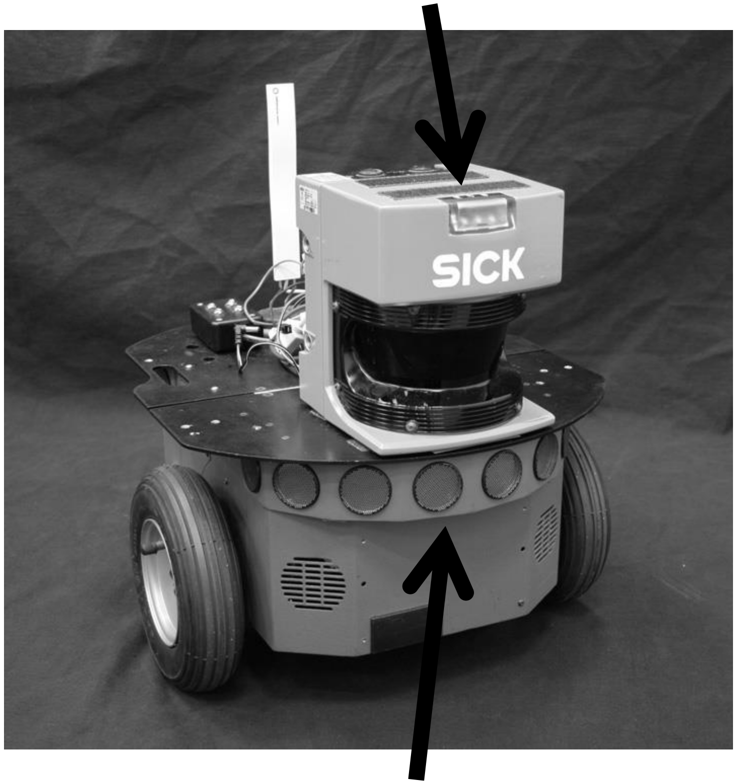
$$d = \frac{t_e}{v}$$

where v is the average speed of the signals emitted (air or water) and t_e is the time between the signal emitted and the signal echo received.

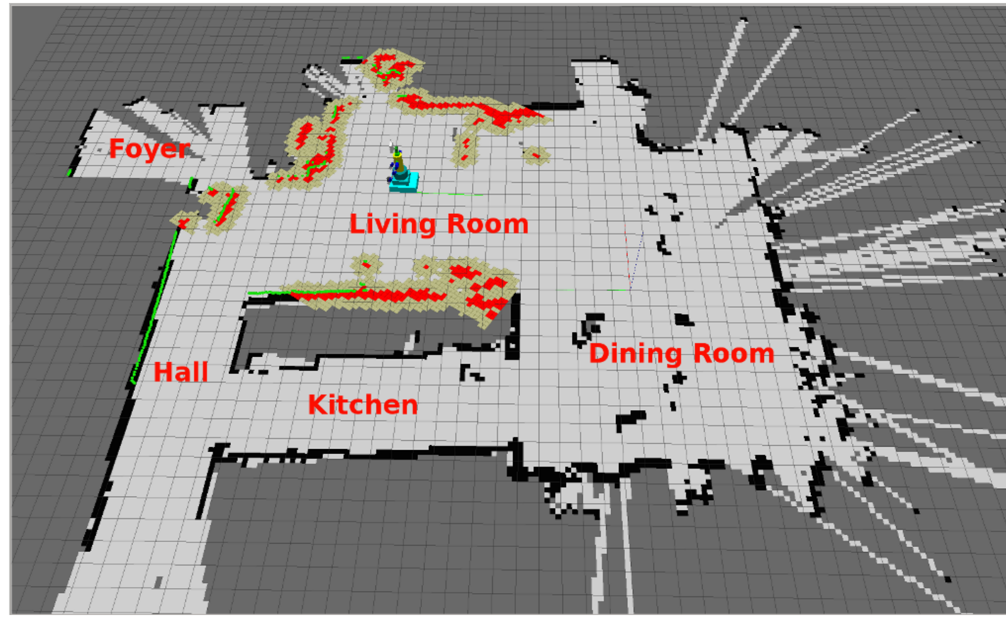


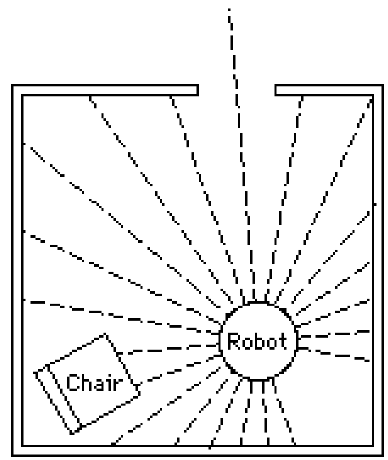
Distance sensors

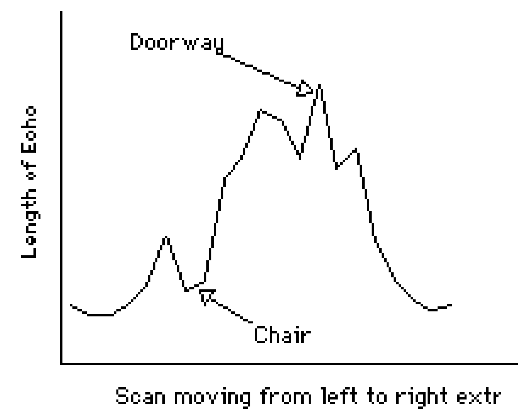
Laser scanner



US (ultrasound) sensors

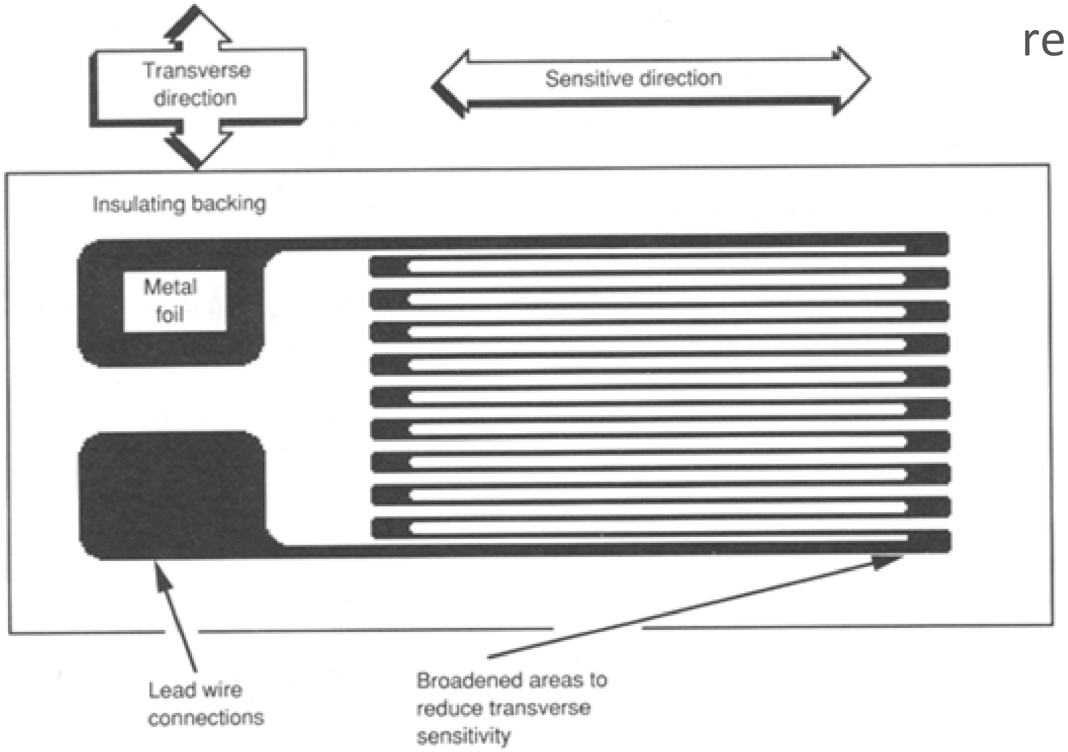






Strain gauges

Piezoresistive effect:
Every material changes its electrical resistance with strain

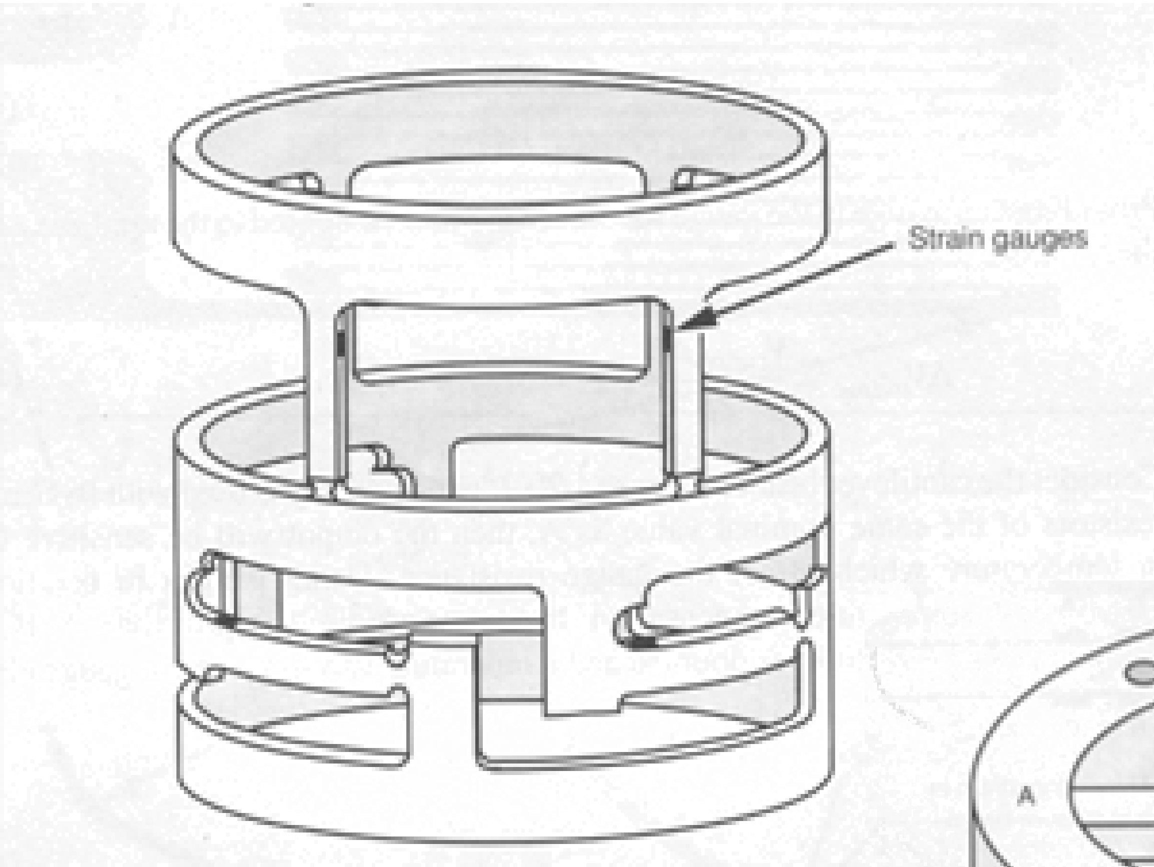


The sensor shape increases sensitivity in one direction

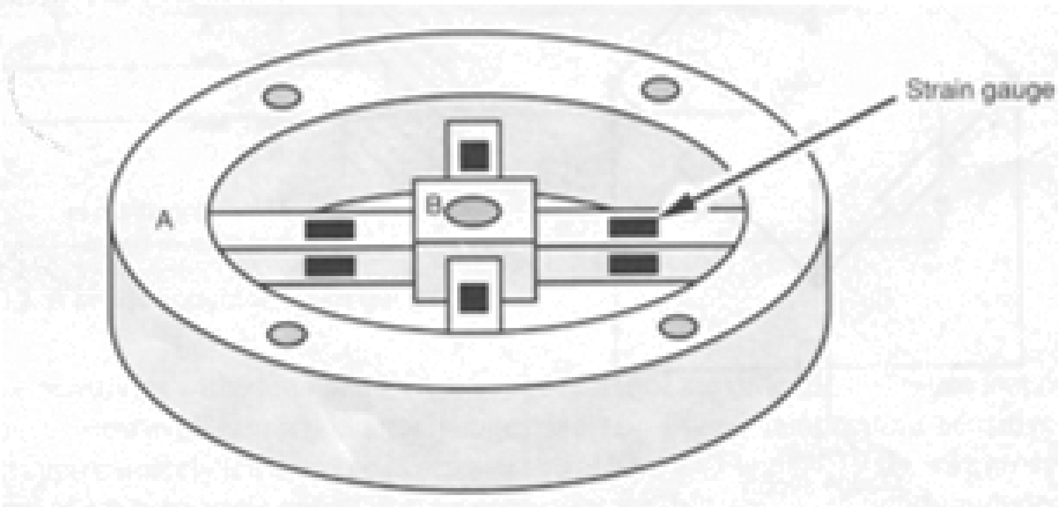
Gauge factor: $$G = \frac{\Delta R / R}{\varepsilon} = 1 + 2\nu + \frac{\Delta\rho / \rho}{\varepsilon}$$

ν = Poisson's ratio of the material

Force sensors



- Mechanical structure with preferred strain directions, along 3 axes
- Strain gauges arranged accordingly



Sensors

- Sensing the **<u>external state (exteroception)</u>**: measurement of variables characterizing the working environment.
- Examples:

Physical Property	→	Sensing Technology
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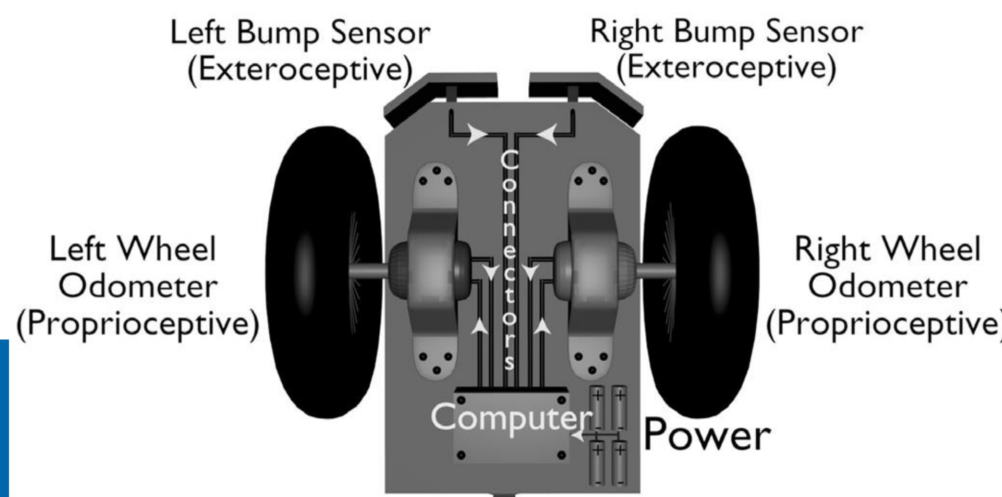
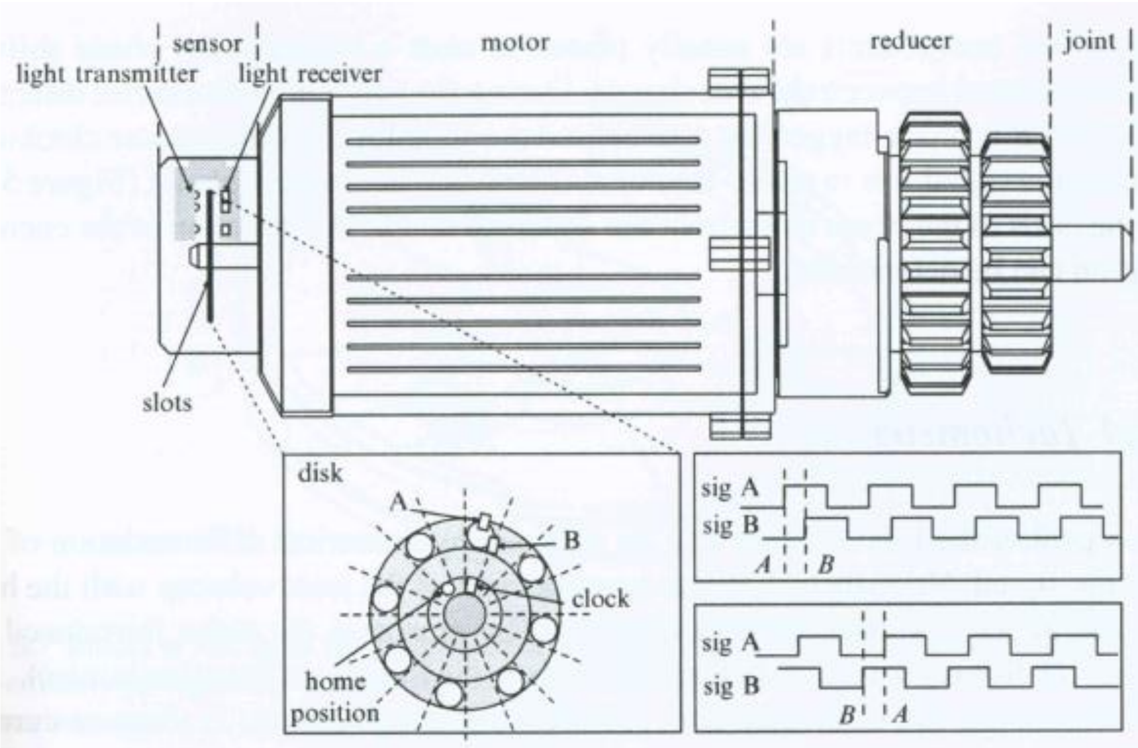
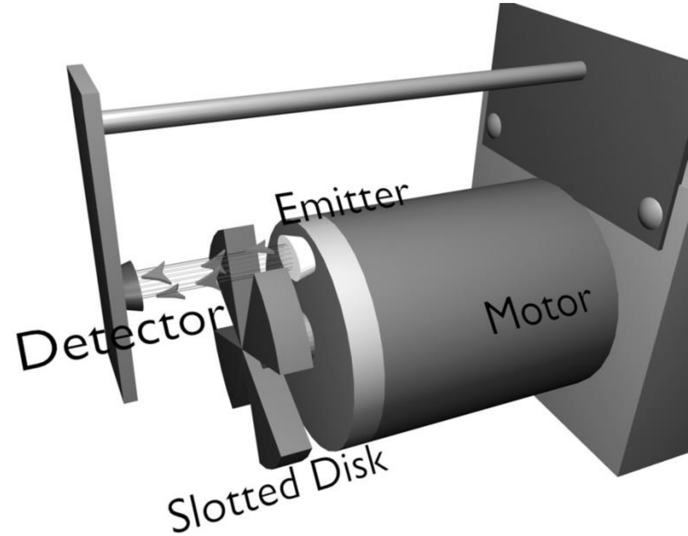
Smell	→	chemical sensors
Temperature	→	thermal, infra red
Inclination	→	inclinometers, gyroscopes
Pressure	→	pressure gauges
Altitude	→	altimeters

- Sensing the **<u>internal state (proprioception)</u>**: measurement of variables internal to the system that are used to control the robot.
- Examples:
  - Joint position / encoders
  - Battery level



Encoders





Counting the steps gives a measure of rotation

$$q = \frac{\theta \times 360°}{R \times k}$$

- q: joint angular position (in degrees)
- θ: joint position in encoder steps
- k: motor reduction ratio
- R: encoder resolution (number of steps per turn)

How does a robot work?

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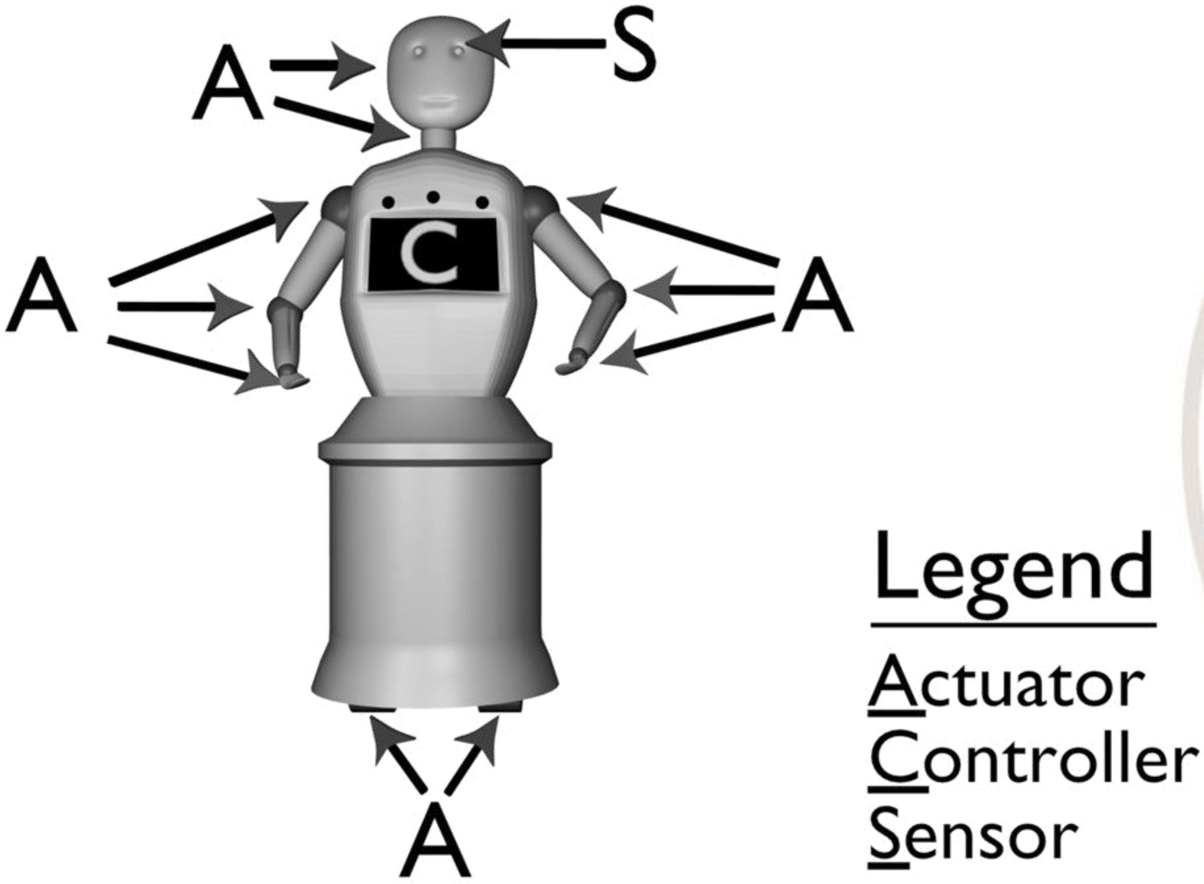
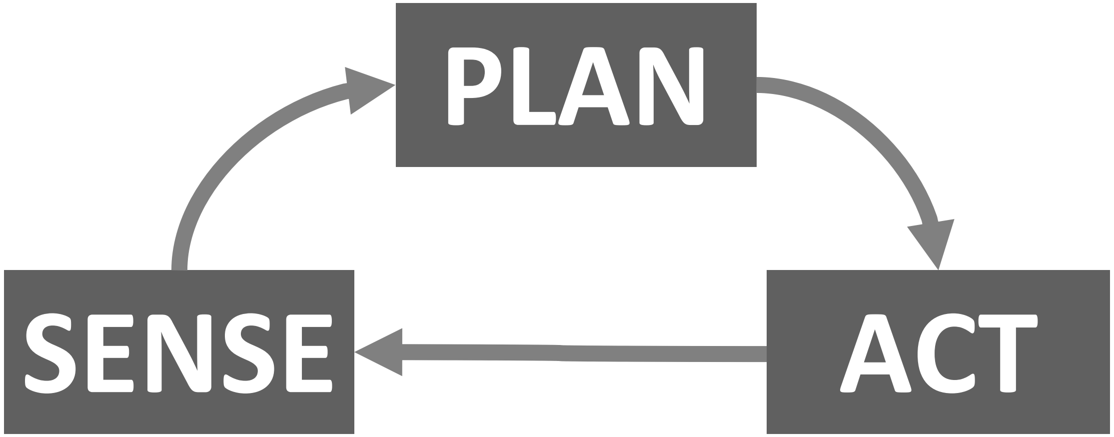


Maja J Mataric, *The Robotics Primer*, The MIT Press, 2007

Robot behaviour

Primitive functions



Hierarchical architectures

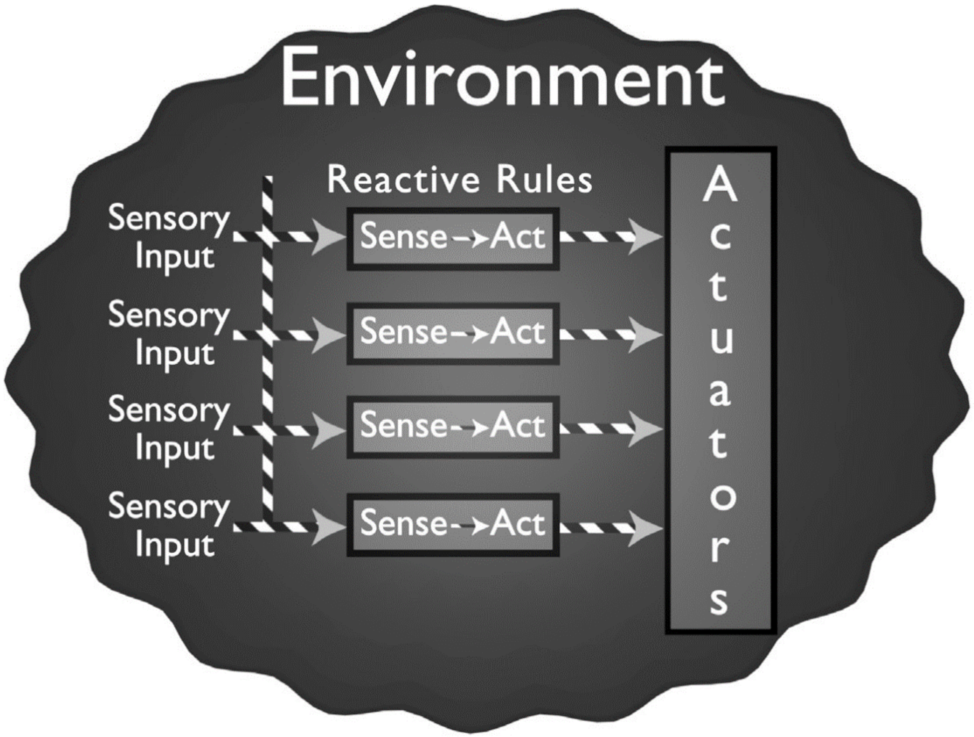
Robot behaviour

Primitive functions

Reactive architectures

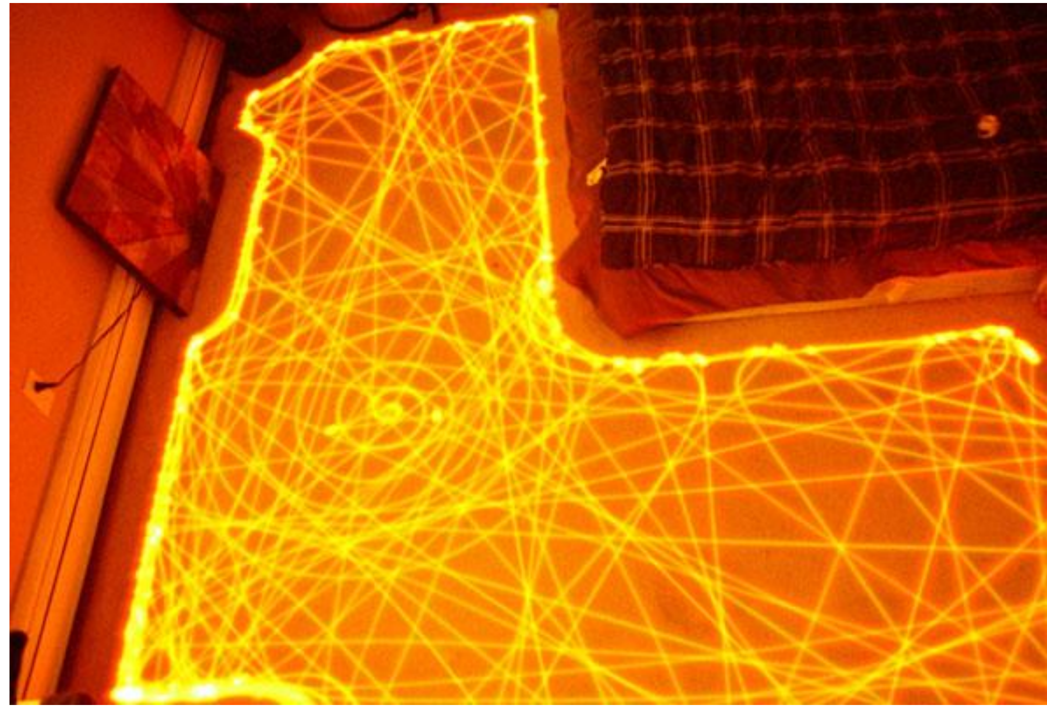
Robot behaviour

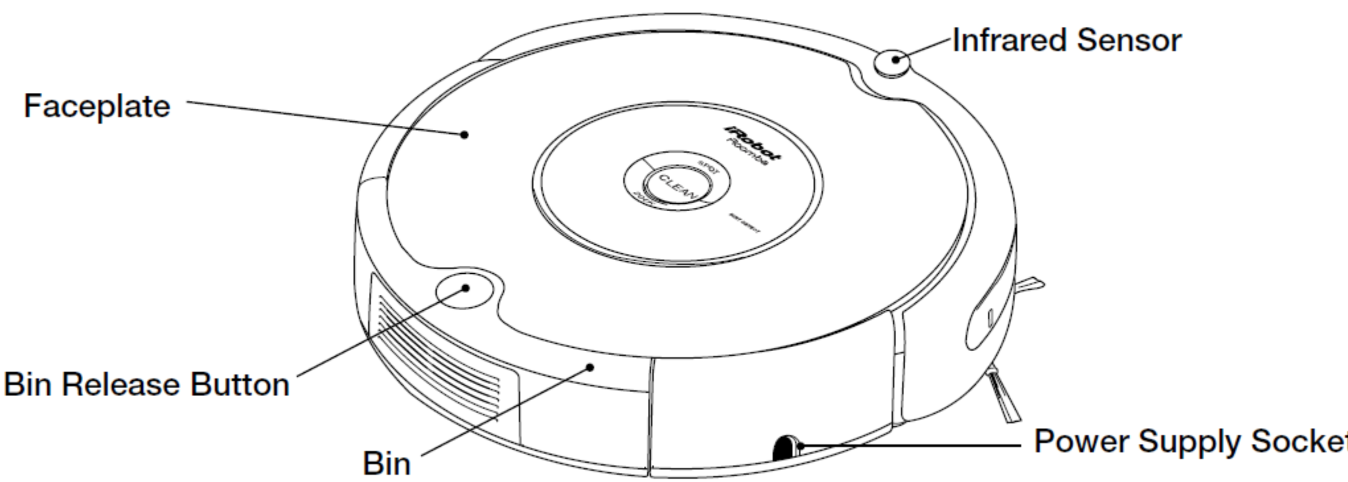
- Reactive architectures




```
If left whisker bent, turn right.
If right whisker bent, turn left.
If both whiskers bent, back up and turn to the left.
Otherwise, keep going.
```

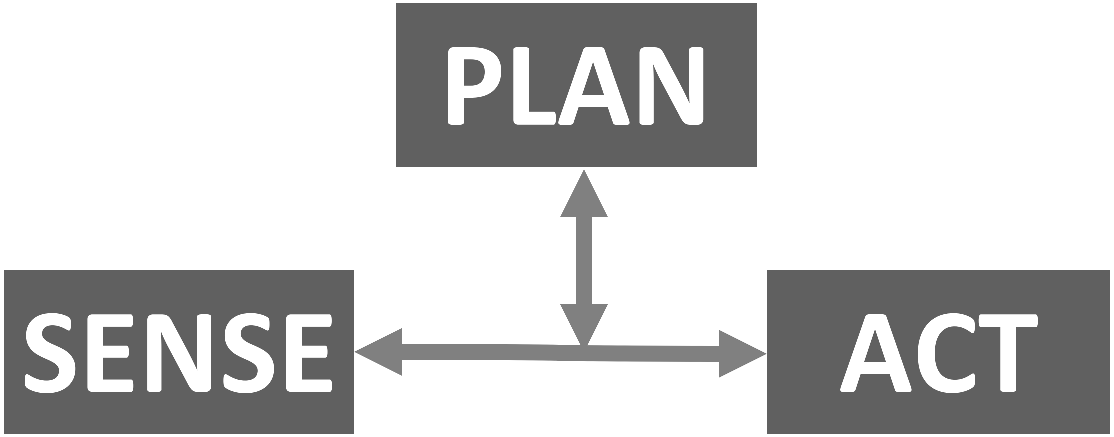

iRobot
Roomba
Vacuum Cleaning Robot
560




Infrared Sensor
Faceplate
iRobot
Roomba
SPOT
CLEAN
Bin Release Button
Bin
Power Supply Socket

Robot behaviour

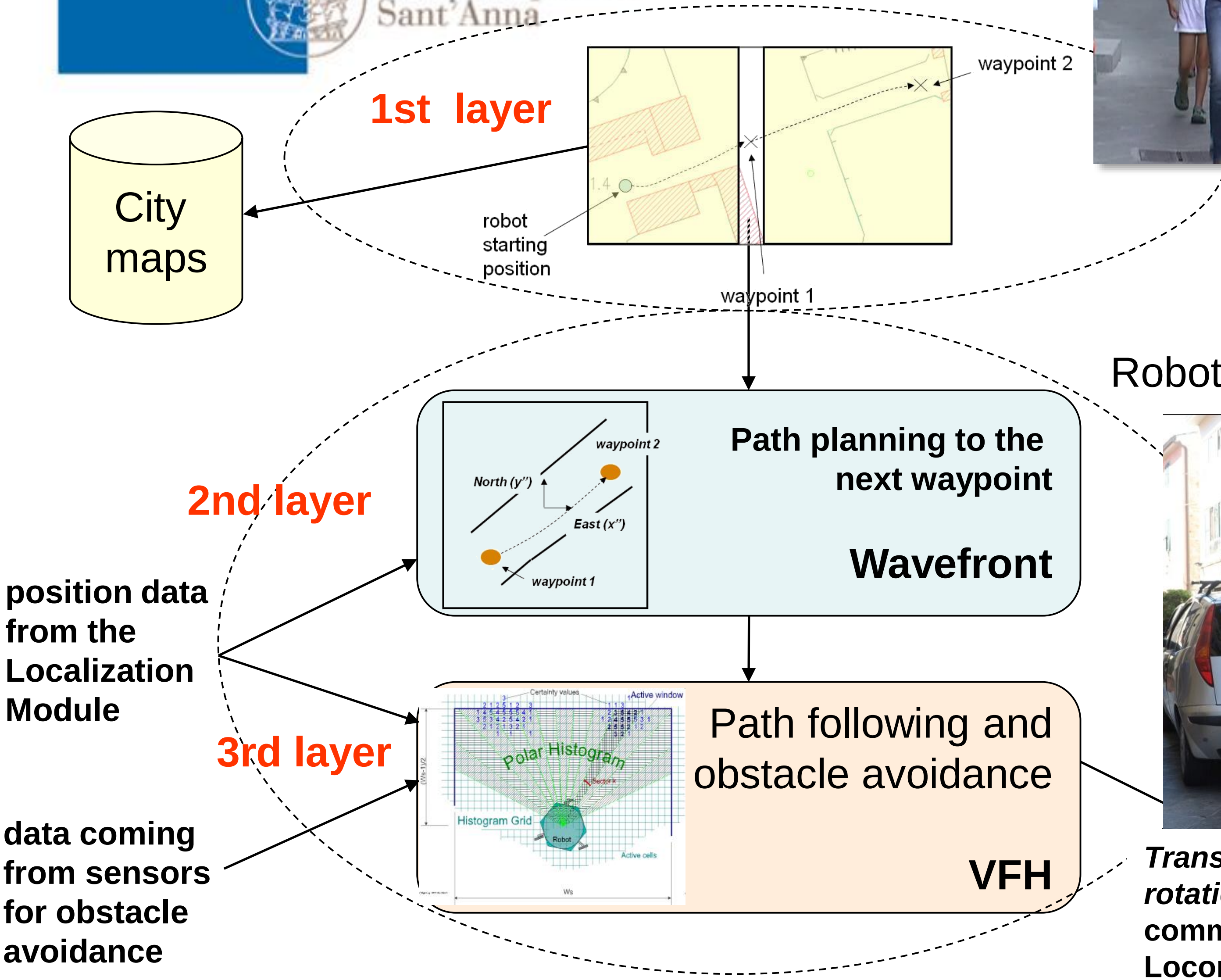
Primitive functions



Hybrid architectures

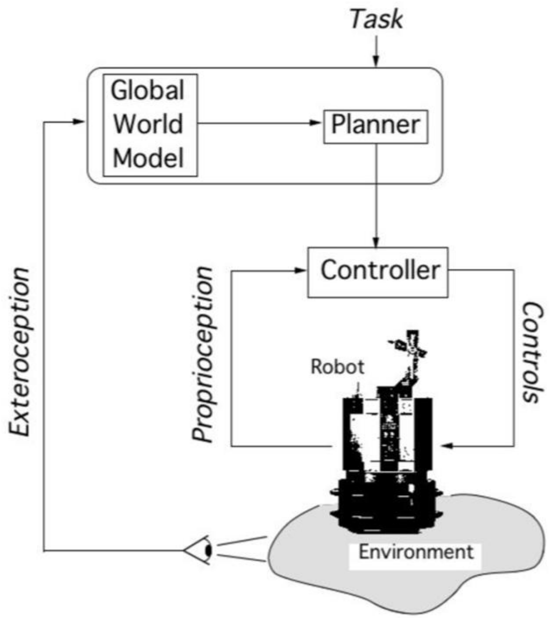
DustBot architecture

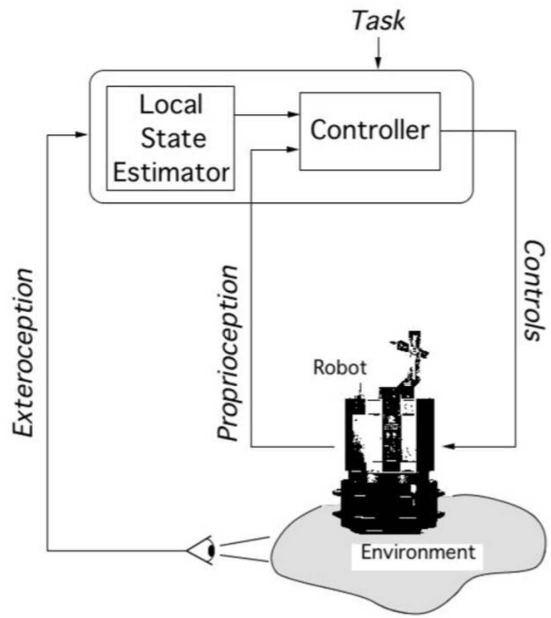
Three-layer navigation system:

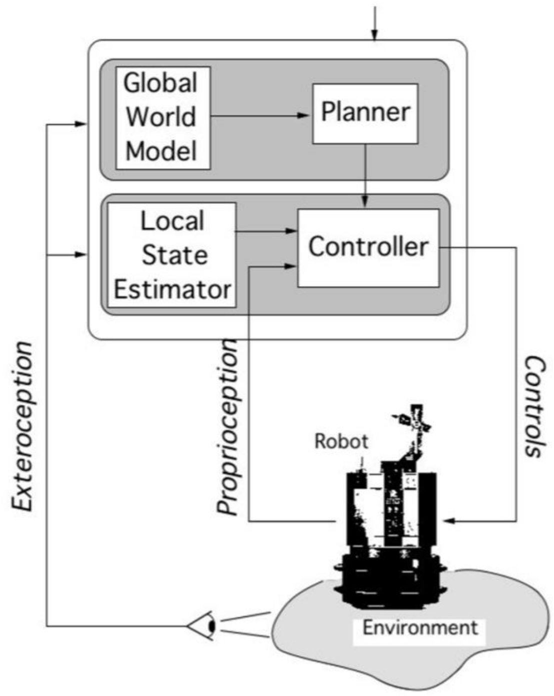


Robot

Hierarchical, reactive and hybrid architectures







Hierarchical

Reactive

Hybrid

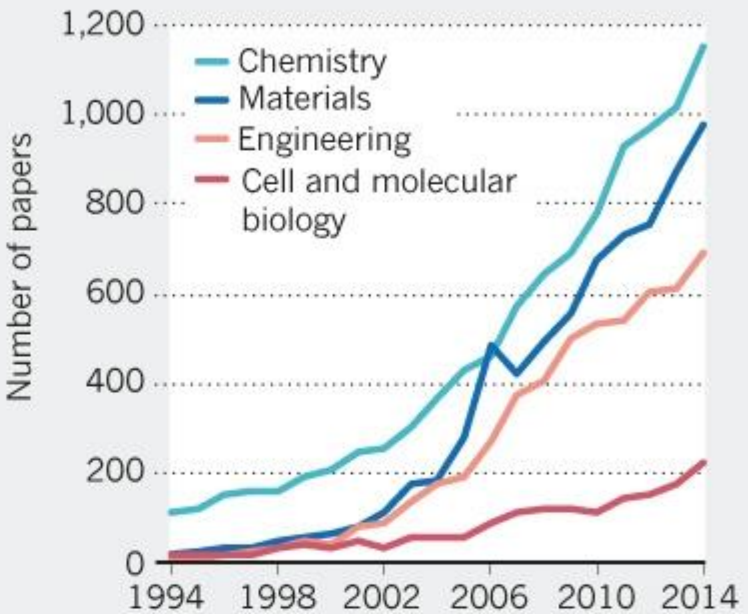
Bioinspiration and biomimetics

Interdisciplinarity:
Bring biologists into biomimetics

nature International weekly journal of science

TRENDS IN BIOMIMETICS

A search of the more than 25,000 papers in biomimicry shows the rising interest in the field over the past decade, but studies are mainly restricted to the physical sciences.



Data obtained by searching the Web of Science Core Collection with the term "biomim* or bioinspir*".

"Engineers, chemists and others taking inspiration from biological systems for human applications must team up with biologists"

"[...] **Fewer than 8%** of the nearly 300 studies on biomimetics published in the past 3 months and indexed in the Thomson Reuters Web of Science **had an author working in a biology department** — a crude proxy for 'a biologist'."

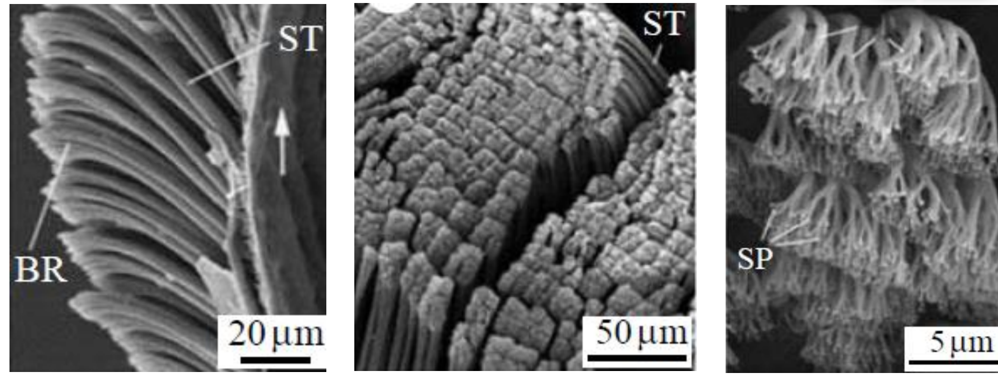
"[...] With around **1.5 million described species**, and probably some 9 million eukaryotic species in existence, researchers pursuing biomimetic approaches have barely **scratched the surface of biological inspiration**."

More biology education for engineers, in academy and in industry

Emilie Snell-Rood, "Interdisciplinarity: Bring biologists into biomimetics", *Nature* 529, 277–278 (21 January 2016) doi:10.1038/529277a

Examples of bioinspiration and biomimetics

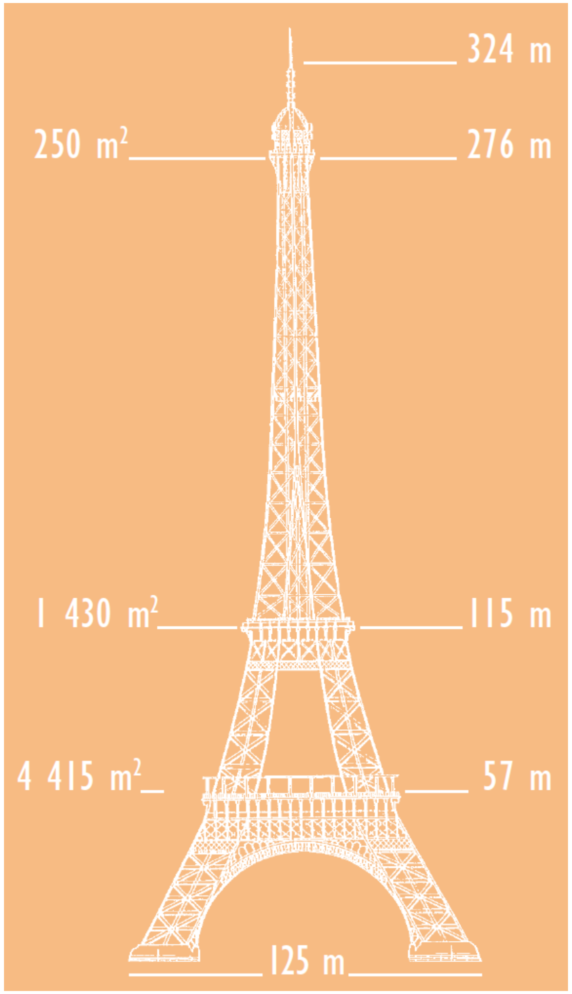
A gecko is the largest animal that can produce (dry) adhesion to support its weight. The gecko foot comprises of a complex hierarchical structure of lamellae, setae, branches, and spatula.



Velcro resulted in 1948 from a Swiss engineer, George de Mestral, seeing how the hooks of a plant burrs (*Arctium lappa*) stuck to his dog's fur.

M. R. Cutkosky, Climbing with adhesion: From bioinspiration to biounderstanding. *Interface Focus* 5, 20150015 (2015).

Examples of bioinspiration and biomimetics



The **Eiffel Tower**: the perfect structure of trabecular struts in the head of the human femur inspired a French engineer at the end of the 19th Century. He was intended to design the higher structure all the world. The name of this engineer is Gustave Eiffel. In 1889 the Tower is completed.

Bioinspiration and biomimetics

Nevertheless... …natural selection is not engineering

Organisms that are capable of surviving are not necessarily **optimal** for their performance.

They need to survive long enough to reproduce.
Models are never complete or correct: need to interpret with caution.

“**Simply copying** a biological system is either **not feasible** (even a single neuron is too complicated to be synthesized artificially in every detail) or is **of little interest** (animals have to satisfy multiple constraints that do not apply to robots, such as keeping their metabolism running and getting rid of parasites), or **the technological solution is superior** to the one found in nature (for example, the biological equivalent of the wheel has yet to be discovered).

Rather, the goal is to work out **principles** of biological systems and transfer those to robot design.” *Rolf Pfeifer*

R. Pfeifer, M. Lungarella, F. Iida, "Self-Organization, Embodiment, and Biologically Inspired Robotics", *Science* 318, 1088 (2007)

Biorobotics Science and Engineering

Biorobotics Science:
using robotics to
discover new principles...

Biorobotics Engineering:
using robotics to
invent new solutions....

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MORE FROM *SCIENCE ROBOTICS*

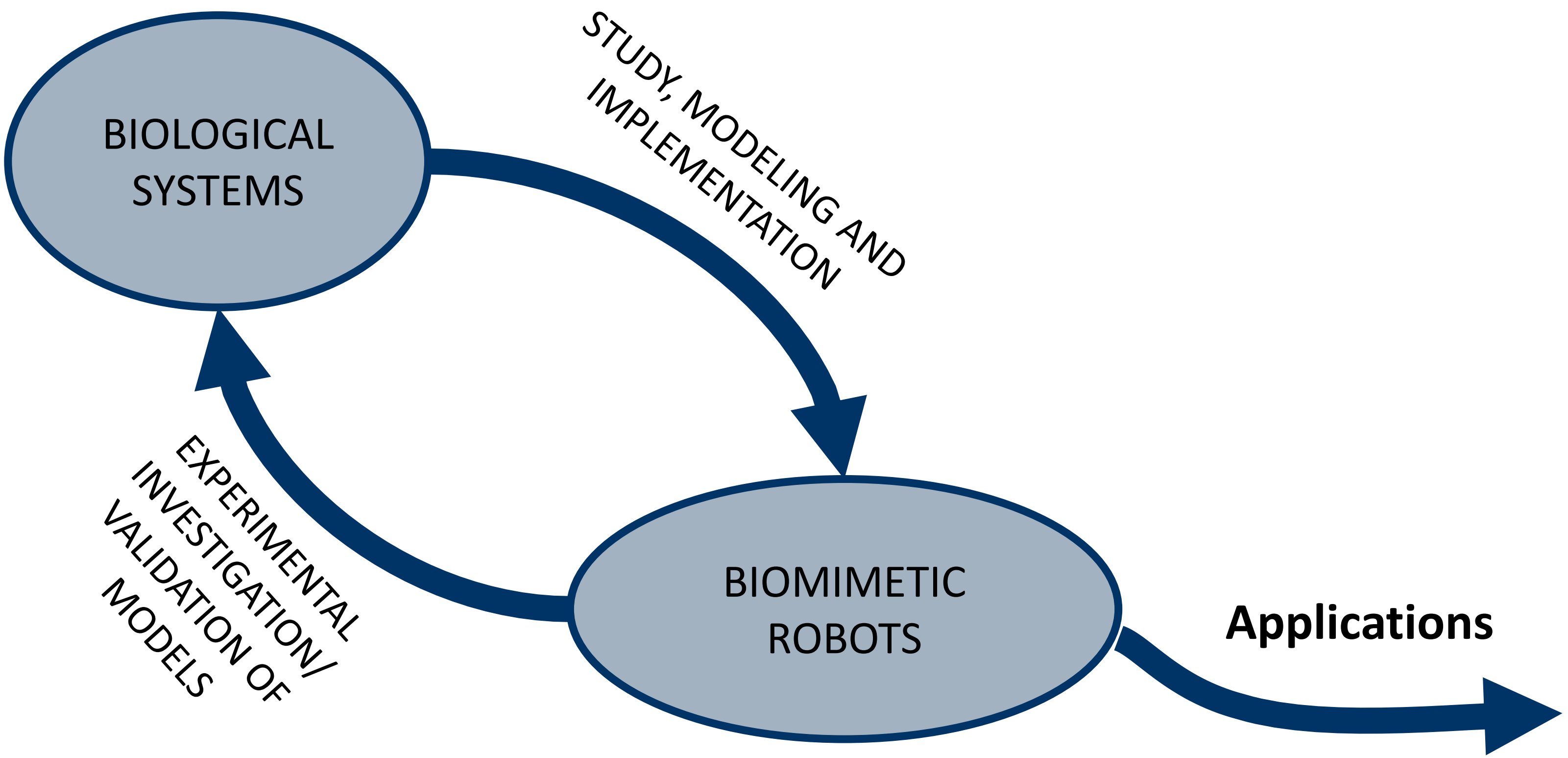
Science for Robotics and Robotics for Science

Paolo Dario, Editorial Board

Scuola Superiore Sant'Anna, Pisa, Italy

One of the ambitions of *Science Robotics* is to root robotics research deeply into science. Biorobotics represents such an ambition: It keeps the living world (and thus life sciences) at its core and investigates different applications of bioinspired machines and robots, as well as validates scientific hypotheses. The power of the latter is somewhat underestimated, but in fact it may represent what really makes robotics worthy of constituting a scientific and not only a technological or engineering pursuit. Robotics science can be pursued in two different ways: the first, according to the model of synthetic science, in which engineers create new knowledge (and thus science) by addressing and solving a series of problems; the second, by using robots to unveil natural principles. The latter approach has been pursued explicitly by some seminal papers in robotics that have appeared in the past 15 years.

The two-fold relation between robotics and biology



Biomimetic robotics:

- developing robots for real-world applications
- studying biological systems by robotic platforms

Unified approach to the study of living organisms and robots

Biorobotics epistemology

Proto-Cybernetics (J. Loeb 1905, 1912; H. S. Jennings 1906)

Mechanicism vs. Functionalism for studying the behavior of living organisms

If a machine is implemented on the basis of a theory of behavior and ***it behaves according to what this theory allows to predict***, this test reinforces the theory

Cybernetics (Rosenblueth, Wiener, Bigelow 1943)

Unified approach to the study of living organisms and machines

Purposive adaptive behaviors (in animals and humans) are produced by *feedback machines (teleology)*

Machines as 'material models' useful for testing scientific hypotheses

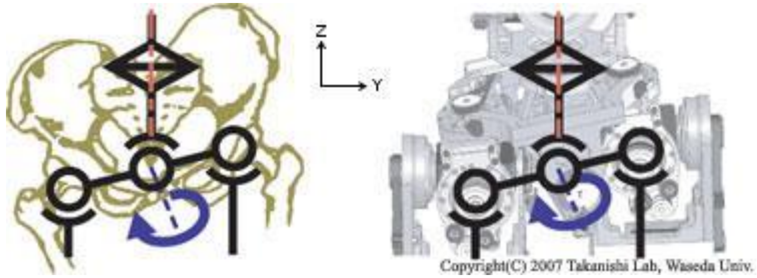
Machines are used for SCIENCE

Barbara Webb, *Biorobotics*, MIT Press, 2001
Datteri, E., Tamburrini, G., "Bio-robotic experiments and scientific method", in Magnani, L., Dossena, R. (eds), *Computing, Philosophy and Cognition*, College Publications, London, 2005.

The WABIAN humanoid robot as a Robotic Human Simulator

Wabian humanoid robot,
Waseda University, Tokyo, Japan

Anthropomorphic kinematic model



2-DOF model for the waist mechanism allowing knee stretch walking

Height mm	1500
Weight kg	64 (with batteries)
Degrees of Freedom (DOF)	
Leg	6×2
Foot	1×2 (passive)
Waist	2
Trunk	2
Arm	7×2
Hand	3×2
Neck	3
Total	41

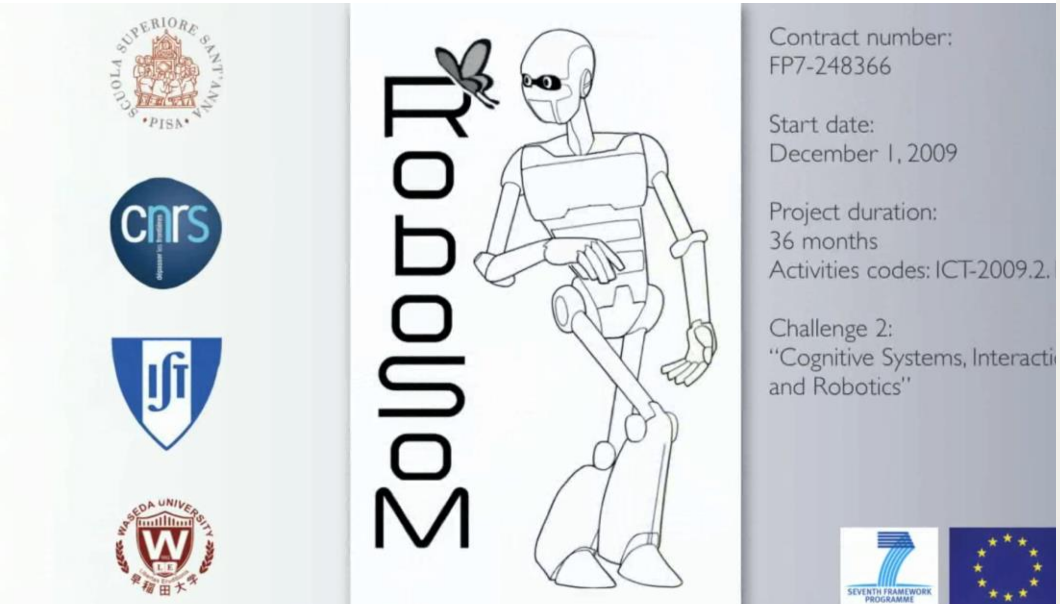
WABIAN testing the Walking Aid Robot for Elderly developed by HITACHI (WABOT-HOUSE Project, Gifu Prefecture)

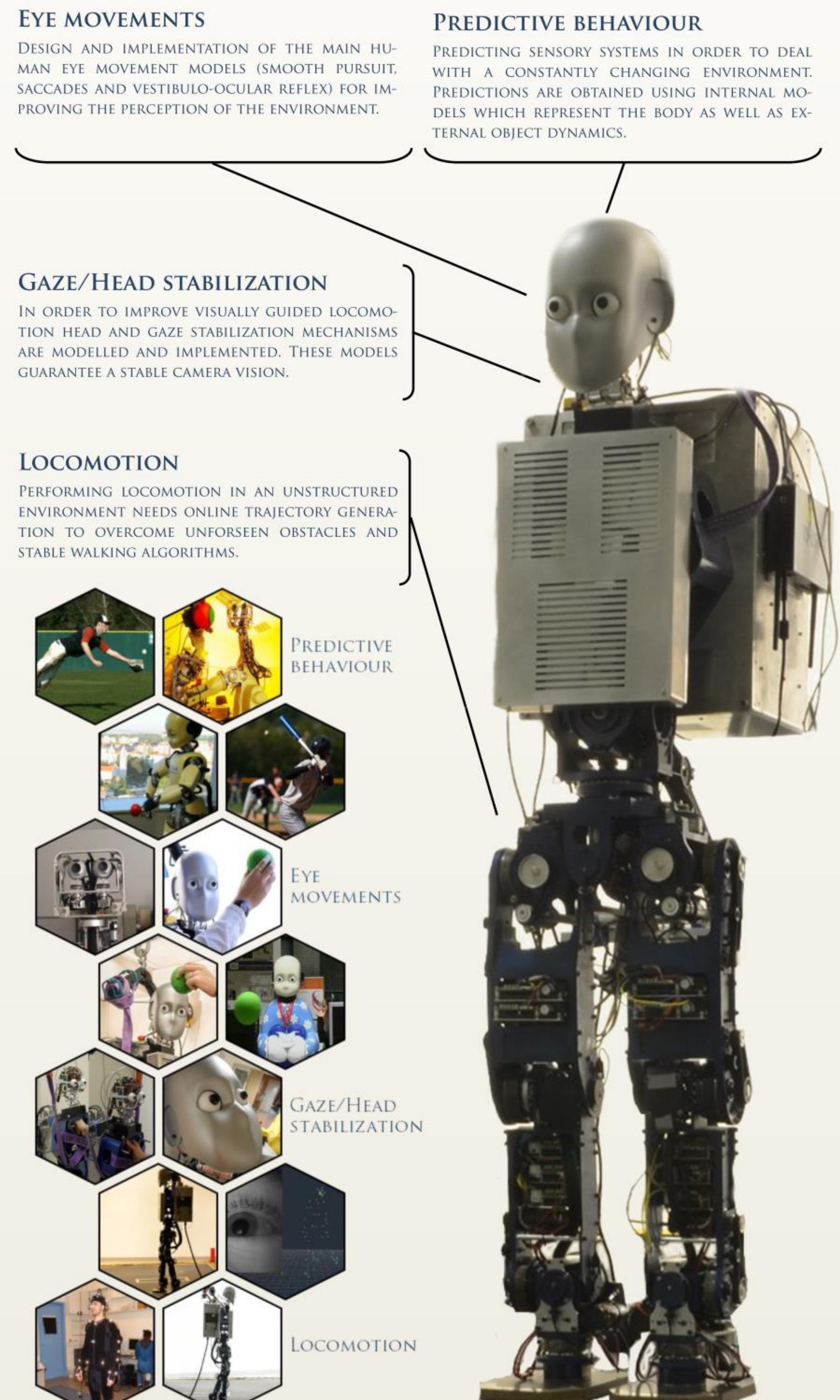
WABIAN simulating the pathological walking of post-stroke patients

Humanoid robotics

A Robotic Sense of Movement
RoboSoM 2009-2013

Objective: to implement on humanoid robots the principles of the human ‘**sense of movement**’, i.e. unified reference system, expected perception, and coordinated eye/head/leg movements in following a moving visual target





NATURE|Vol 460|27 August 2009

The bot that plays ball

He looks like a child and plays like a child. But can the iCub robot reveal how a child learns and thinks? **Nicola Nosengo** reports.

Giulio Sandini cannot help smiling as his child reaches out a hand and tries to grasp the red ball that Sandini keeps waving before his eyes. "He is getting really good at it," he says, with the proud tone of any father. True, most fathers would expect more from their three-year-old than the ability to grasp a ball. But Sandini is indulgent: although the object of his affection has the wide eyes and rounded cheeks of a little boy, he is, in fact, a robot.

His name is iCub or, as the team calls him, iCub Number 1. Together with his brothers now in laboratories around the world, this little robot may help researchers to understand how humans learn and think. Grasping a ball is only a first step, says Sandini, director of the robotics and cognitive-sciences department at the Italian Institute of Technology (IIT) in Genova, and head of the child-robot project since it started in 2004. Sandini is confident that iCub will learn more and more tricks — until, in the end, he is even able to communicate with humans.

"We wanted to create a robot with sufficient movement capabilities to replicate the learning process a real child goes through" as it develops from a dependent, speechless newborn into a walking, talking being, Sandini says. So he and his colleagues have not only given iCub the hands, limbs and height of a toddler, they have also tried to give him the brain of one — a computer that runs algorithms allowing iCub to learn and develop as he interacts with his surroundings.

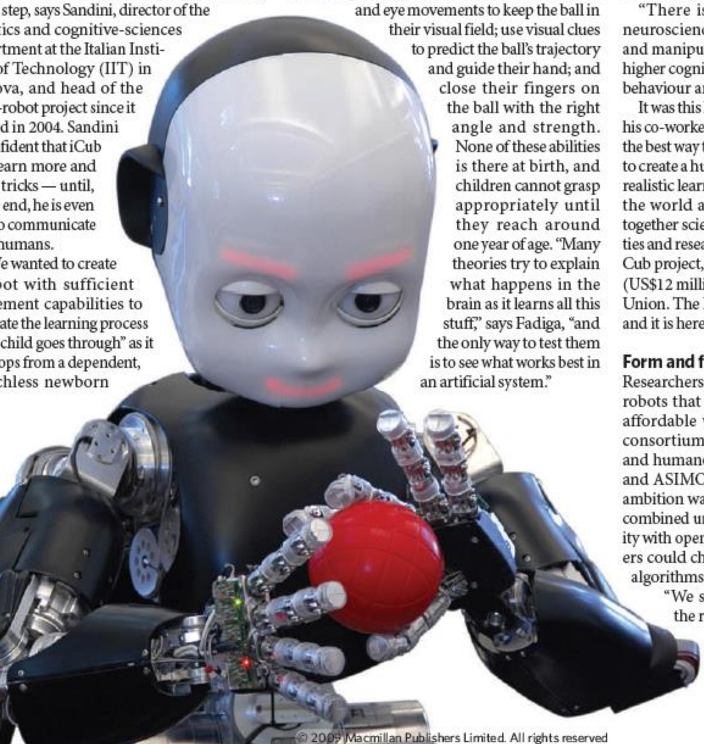
In a child, says Luciano Fadiga, a neurophysiologist at Italy's University of Ferrara who is part of the team that developed iCub, those interactions are essential for shaping the rapidly growing brain. Before children can grasp a moving ball, for example, they must learn to coordinate head and eye movements to keep the ball in their visual field; use visual clues to predict the ball's trajectory and guide their hand; and close their fingers on the ball with the right angle and strength. None of these abilities is there at birth, and children cannot grasp appropriately until they reach around one year of age. "Many theories try to explain what happens in the brain as it learns all this stuff," says Fadiga, "and the only way to test them is to see what works best in an artificial system."

> "This is not a car you just buy and start to drive around; we're in totally new ground."
> — Paul Verschure

Such testing is certainly not new. Cognitive scientists have been using computer models to simulate mental processes since the 1950s, including algorithms that mimic learning. But many of these simulations have focused on the high-level, conscious reasoning used to solve logical puzzles, play chess or make medical diagnoses. And many others — notably 'neural network' models — have simulated neurons. But Sandini and Fadiga are among the many researchers who have come to think that both types of simulations leave out something essential: the body.

"There is ever-growing evidence from neuroscience that visuo–motor processing, and manipulation in particular, are crucial for higher cognitive development, including social behaviour and language," Sandini says.

It was this line of thinking that led Sandini and his co-workers to their central hypothesis — that the best way to model the human mind would be to create a humanoid robot that is controlled by realistic learning algorithms, then let it explore the world as a child would. They gathered together scientists from 11 European universities and research institutions to form the RobotCub project, and began work with €8.5 million (US$12 million) in funding from the European Union. The IIT is the project's leading partner, and it is here that iCubs are born.



L. NATALE

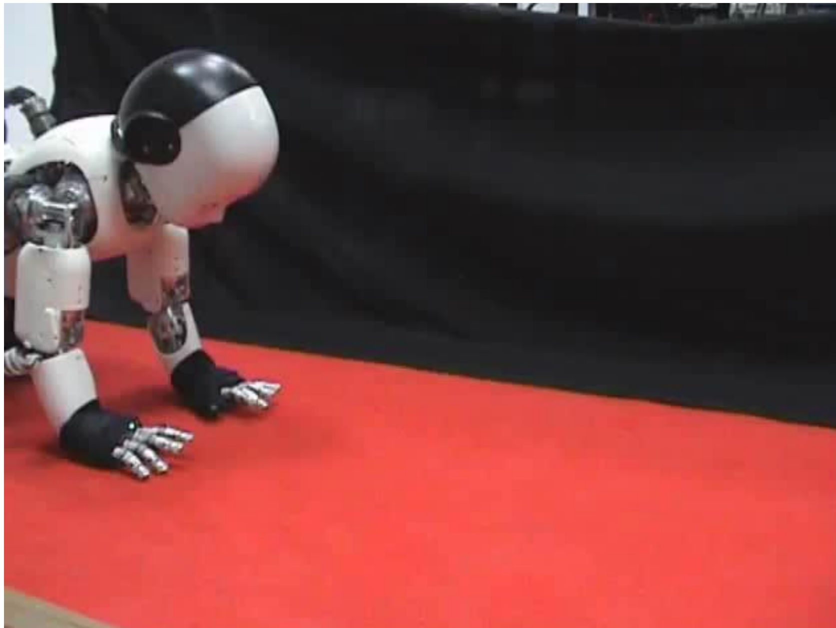
Form and function

Researchers can already choose from a list of robots that includes Khepera, a simple and affordable wheeled robot built by a Swiss consortium and used to study locomotion, and humanoid robots such as HRP-2, PINO and ASIMO, all built in Japan. But Sandini's ambition was to create a humanoid robot that combined unprecedented mechanical versatility with open-source software, so that researchers could change both the hardware and the algorithms as needed.

"We started from the hand, and built the rest of the robot around it," Sandini says. With seven degrees of freedom in the arm and nine in the hand, and its mechanical shoulders, elbows, wrists and fingers

more uses than just
he robot look good
tional pictures, says
In the future, some
lan to try iCub with
who are autistic, testing
ions to his expressions
ments".
Number 1 was never
be an only son. After
robot became opera-
consortium issued an
or proposals to conduct
nts. The six winners,
an independent panel
by the consortium and the European
ave received their own iCub for free.
ne else can order one for the cost of
g it, some €180,000–200,000. "It was
e deal with the European Union that
provide a number of robots to inter-
ips," Sandini says. This way, the team
reate a de facto standard in robotics,
g data exchange. "There is a desper-

Giulio Sandini (left) and Giorgio Metta gradually pieced together a robot with an unprecedented level of dexterity and coordination.



Assignment

Search the internet for a good example of a robot <u>responding to our definition</u>

- Present your robot
- Explain how it responds to the definition
- Show its main components
- If bioinspired, explain why/how/where

A *robot* is an autonomous system
which exists in the physical world,
can sense its environment,
and can act on it to achieve some goals