I615 Robotics

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December 2009

Robotics crosses

traditional engineering boundaries –

mechanical engineering,
electrical engineering,
systems and industrial engineering,
computer science,
economics,
mathematics,
manufacturing engineering,
applications engineering,
knowledge engineering

Text

- Introduction to Robotics: Mechanics and Control 3rd Edition, John J. Craig, Prentice Hall, 2004
- Handouts
- Robotics Toolbox for MATLAB (Release 7.1)

  http://www.ict.csiro.au/downloads/robotics/
- Lecture notes are available online

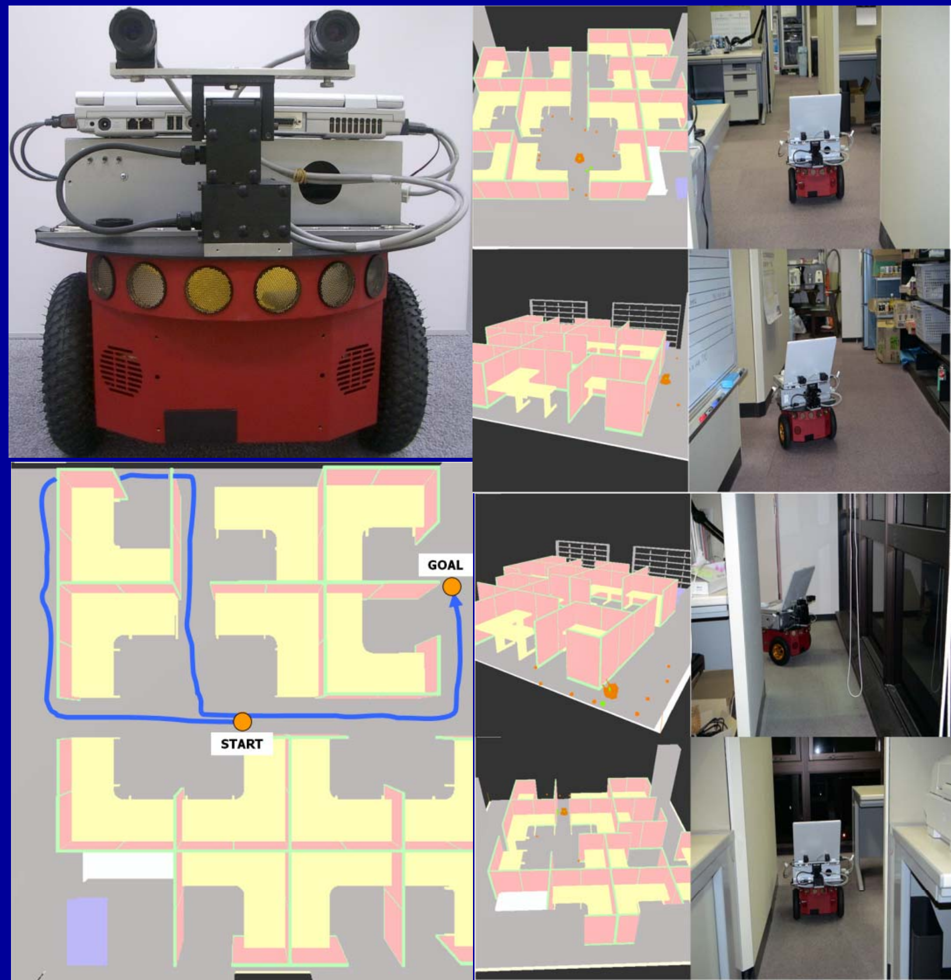
  http://www.jaist.ac.jp/robot/

Office Hours

- 15:10-16:40 Monday
- TA Dr. Geunho Lee I-35/36, I-34B

Office Hours: Robot Programming Exercise

- Form a team of 2 people and work as a team
- Sonar-based navigation of Pioneer 3-DX
- Final demo schedule: TBA



Grading

- Homeworks/Quizzes 20%
- Labs with real robot 20%
- Simulations using Matlab/Simulink 20%
- Midterm 15% (open book, open notes)
- Final 25% (open book, open notes)

Contents

Contents (will be modified to accommodate the progress and interests of the participants)

- Trajectory Generation
- Linear Control of Manipulators
- Nonlinear Control of Manipulators
- Force Control of Manipulators
- Teleoperation
- Knowledge Distributed Control Framework
- Final Exam on Feb 10

Robotics Journals

- IEEE Transactions on Robotics
- IEEE Robotics and Automation Magazine
- International Journal of Robotics Research
- Autonomous Robots
- Robotics and Autonomous Systems
- Journal of Field Robotics
- Journal of Intelligent and Robotic Systems
- Advanced Robotics

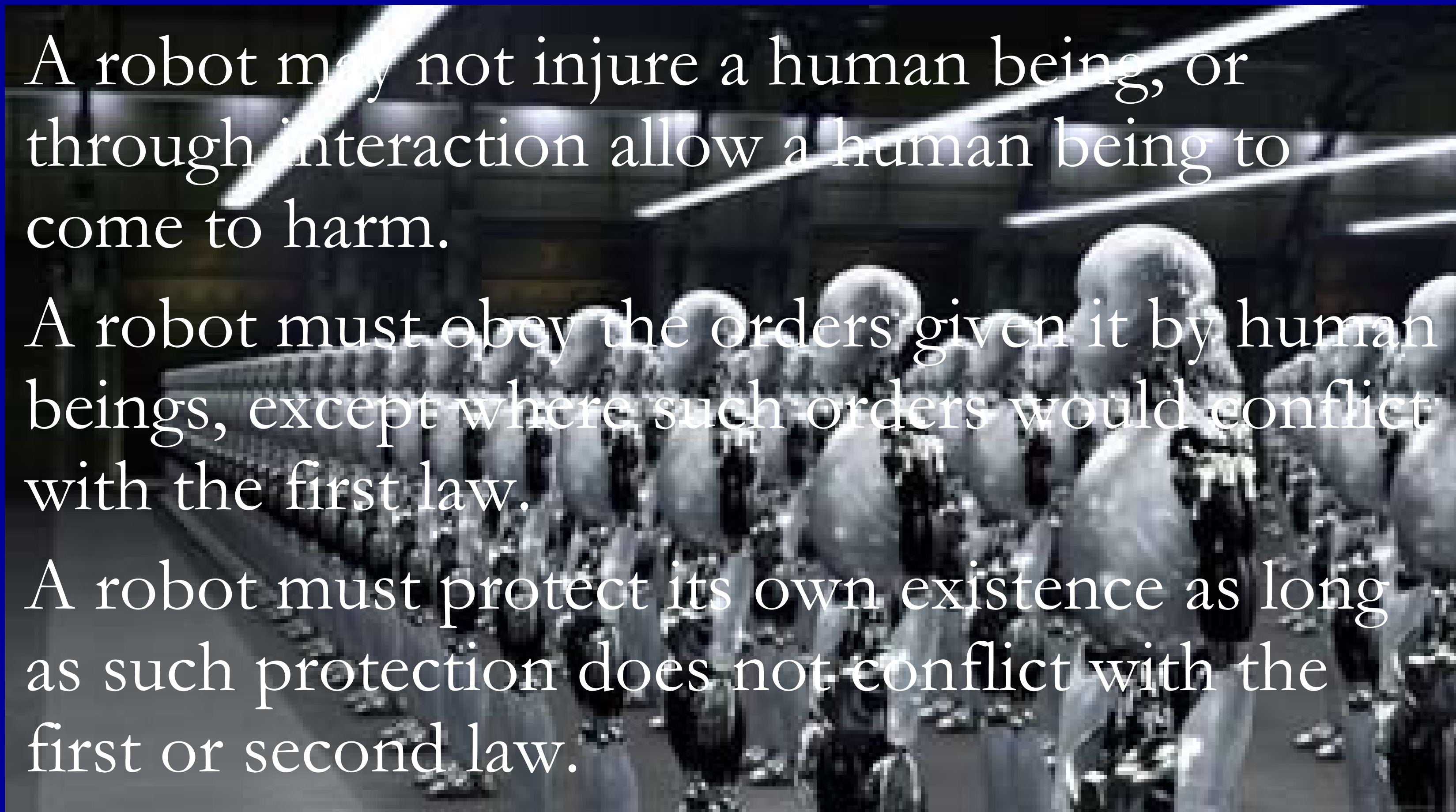
Robotics Conferences

- ICRA IEEE International Conference on Robotics and Automation
- IROS IEEE/RSJ International Conference on Intelligent Robots and Systems
- CASE IEEE Conference on Automation Science and Engineering
- ICAR International Conference on Advanced Robotics
- RO-MAN IEEE International Symposium on Human and Robot Interactive Communication

Robot…

- The slavic language that means worker, compulsory work, or drudgery
- A word for intelligent machines by the Czechoslovakian playwright Karel Kapek in Rossum’s Universal Robot (1921)

Laws of Robotics (Isaac Asimov in I, Robot 1950)



- A robot may not injure a human being, or through interaction allow a human being to come to harm.
- A robot must obey the orders given it by human beings, except where such orders would conflict with the first law.
- A robot must protect its own existence as long as such protection does not conflict with the first or second law.

An official definition

Robot Institute of America (RIA)

- A robot is a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

An official definition

Japan Robot Association (JARA)

- Devices capable of moving in a flexible manner analogous to the moving parts of living organisms, with or without intelligent functions, allowing operations in response to human commands

Classification of Robots

- Use- Industrial, Non-industrial
- Mobility- Fixed, Mobile
- Power source- Electrically, hydraulically, pneumatically powered
- Method of control- Non-servo control, Servo-controlled robots
- Capability- 1st, 2nd, 3rd generation robots
- Kinematic configuration (geometry)- RRR, RRP, RPP, PPP

Classification of Robots

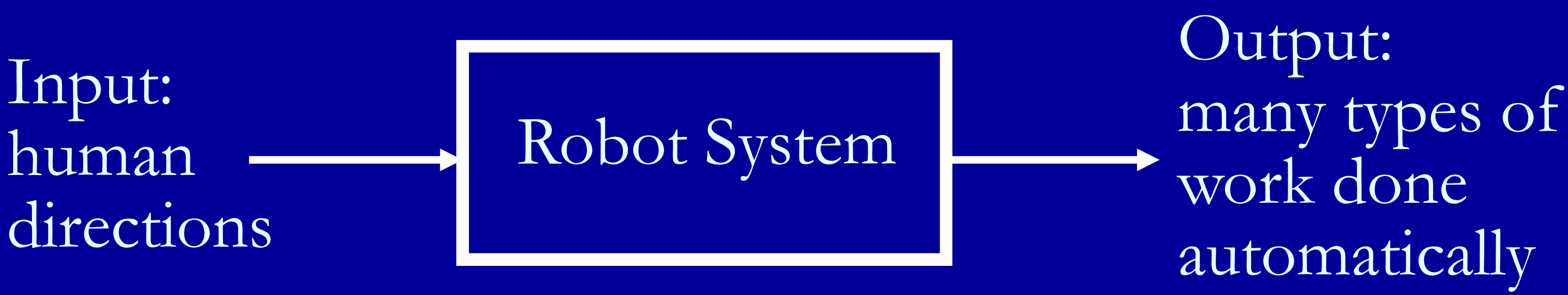
- First generation- reprogrammable, arm-type, manipulative devices, only capable of memorizing repetitive movements, internal sensors
- Second generation (1980's)- external sensors, feedback, make limited decisions and respond to the working environment
- Third generation (late 90's and beyond)- employ artificial intelligence, able to recognize, learn, and think, able to adapt to new situations

What Is a Robot?

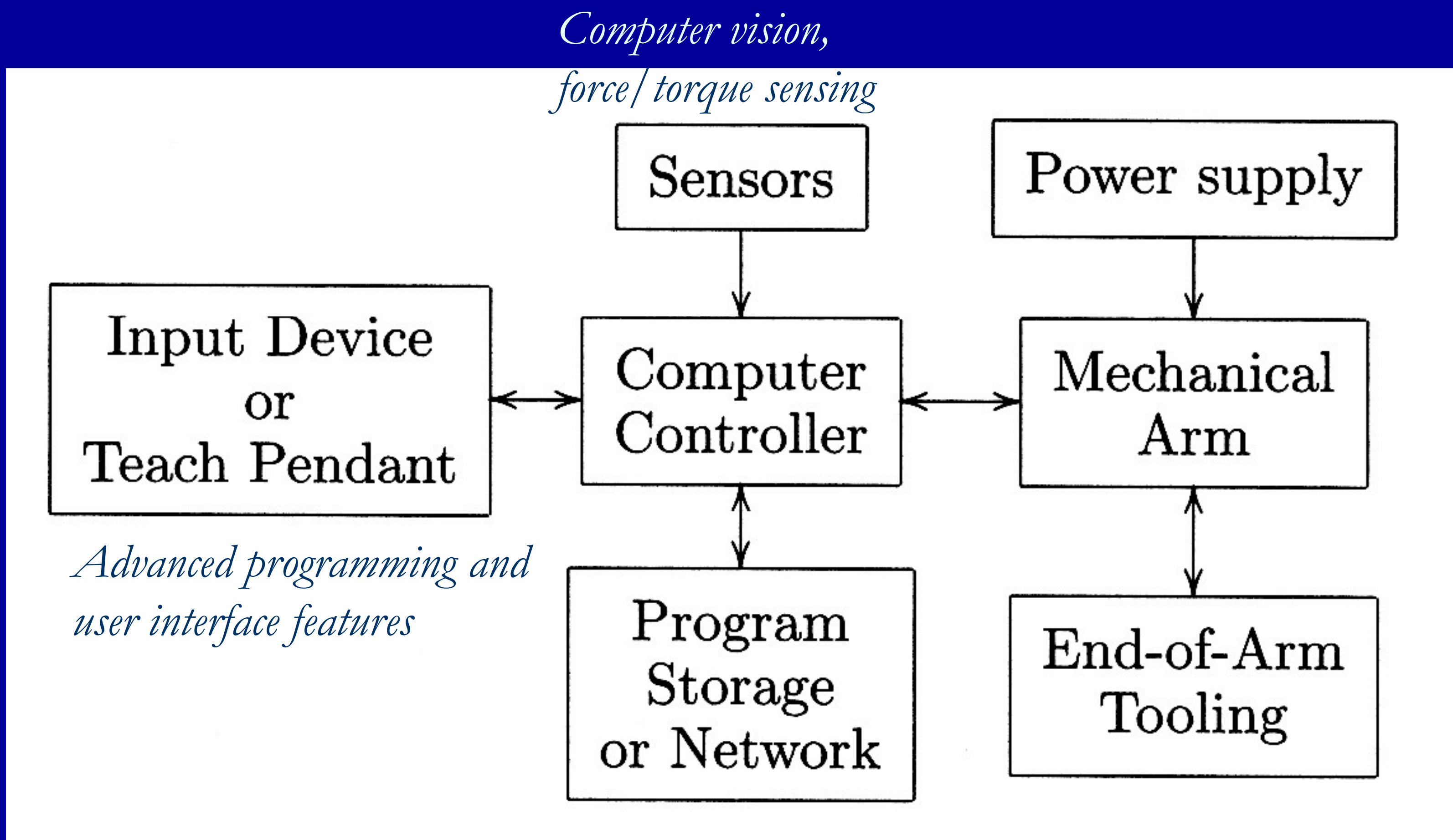
- A machine that senses, thinks, and acts
- Must have sensors, processing ability that emulates some aspects of cognition, and actuators

In artificial intelligence, such systems are known as "agents."

Robot System as a Black Box

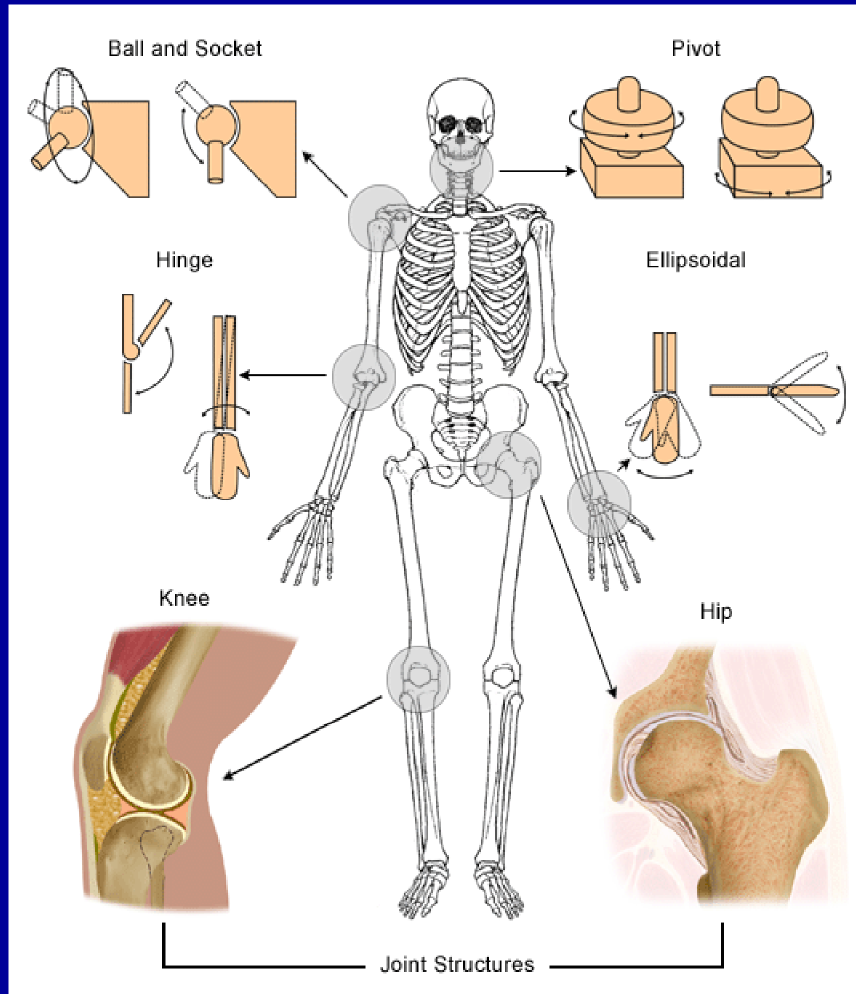


A Robotic System



Want to build a robot?

- Links: rigid bodies
- Actuators: connect and move links
- Sensors: perceiving the world
- Others: end-effectors, communication, etc.
- Controllers



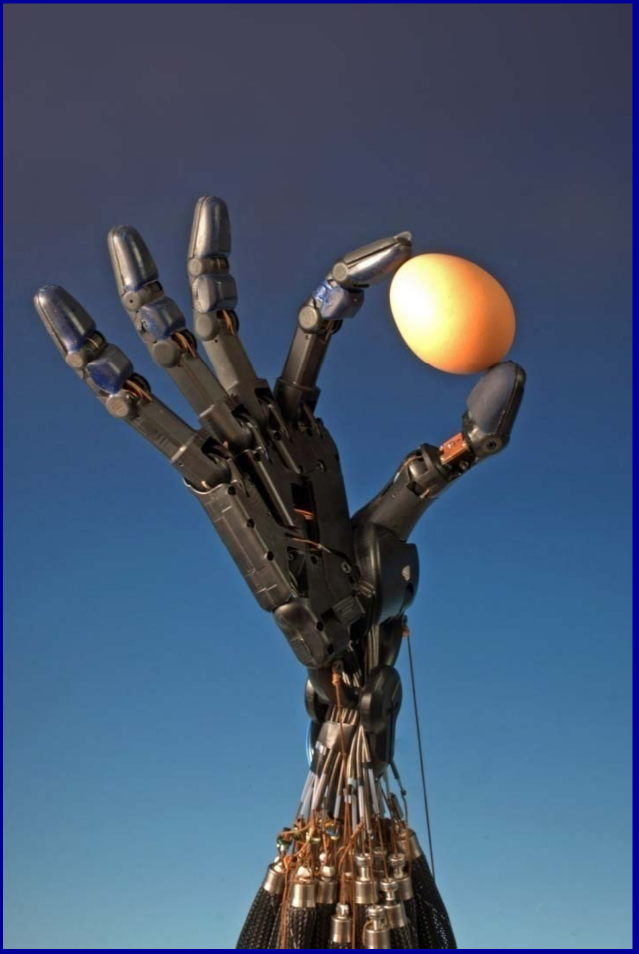
Constructing physical robots can be complicated

- Physical limitations
  - sensor technology
  - actuator technology
  - power consumption
- Design issues
  - general structure: mobile, underwater, aerial, full-body, torso, single arm
  - interaction modality: facial expression, end-effector
  - level of articulation

Controllers try to push the limits!

Major Areas of Robotics

- Mechanical manipulation
- Locomotion
- Computer vision
- Artificial intelligence



Shadow Robot

Manipulation

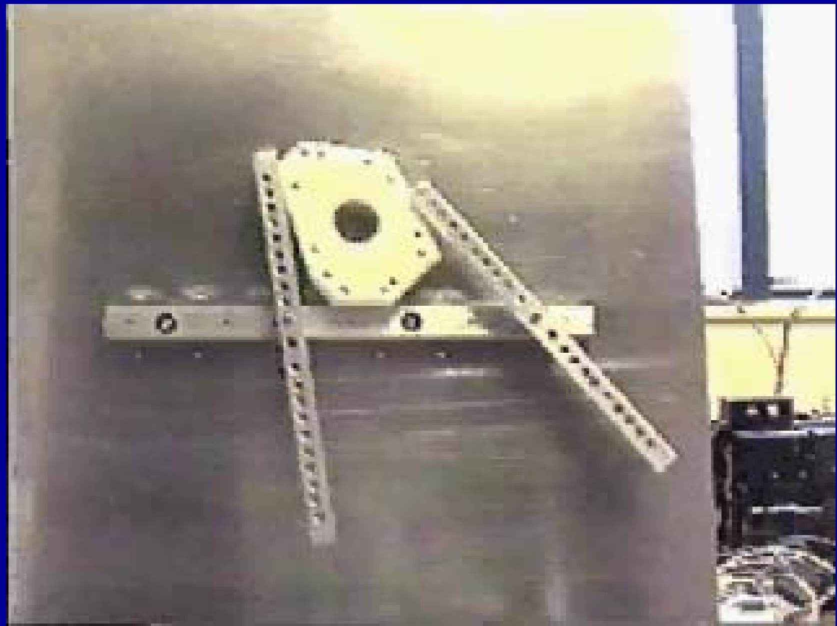
- To move, arrange, operate, or control by the hands or by mechanical means, especially in a skillful manner.
- Examples of manipulation include moving, joining, grinding, bending, and reshaping objects.

Manipulation

- How a robot can choose actions to accomplish a given goal? The main idea is that the robot might have a model of how the world works, which allows the robot to search through sequences of actions until a suitable plan is found.
- Develop techniques for rigid body mechanics, kinematic constraint, Coulomb friction, gravity, and impact, and apply these techniques to manipulation problems.

Manipulation- The Original Vision (Dynamic)

Manipulation- The Reality (Quasistatic)



Jeff Trinkle @ RPI

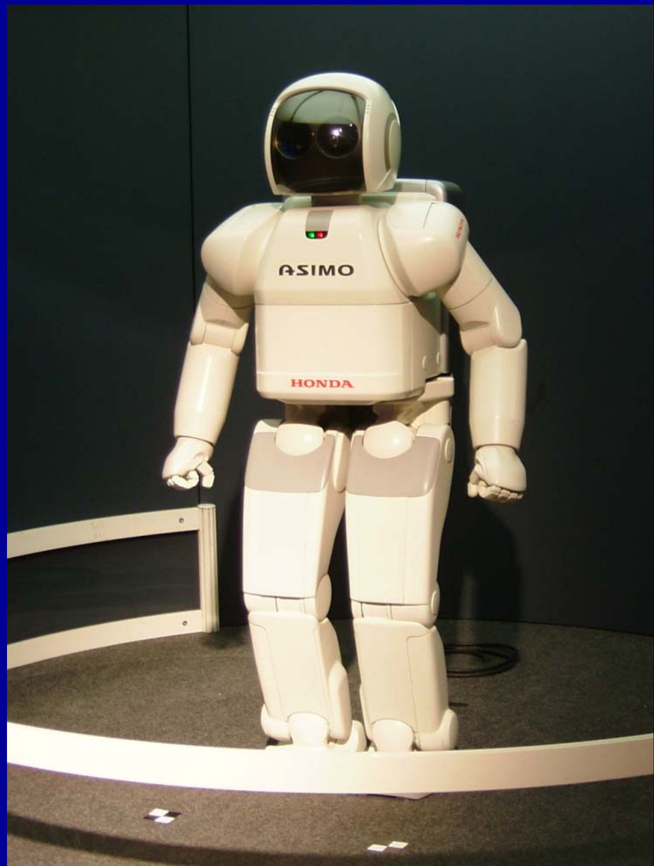
Manipulation- Bulldog

Jeff Trinkle @ RPI

Locomotion

- In biology, locomotion is the self-powered, patterned motion of limbs or other anatomical parts by which an individual customarily moves itself from place to place.
- Forms of locomotion are walking, running, crawling, climbing, swimming, and flying.

Biped Locomotion



Biped Locomotion (Video)

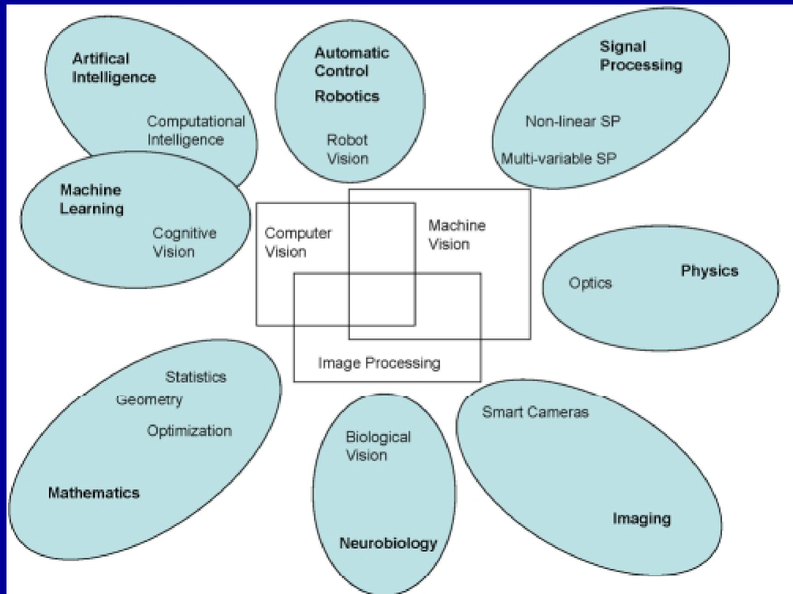
Locomotion on Rough Terrain: Boston Dynamics

http://www.bostondynamics.com/

Locomotion (ICRA04 Video)

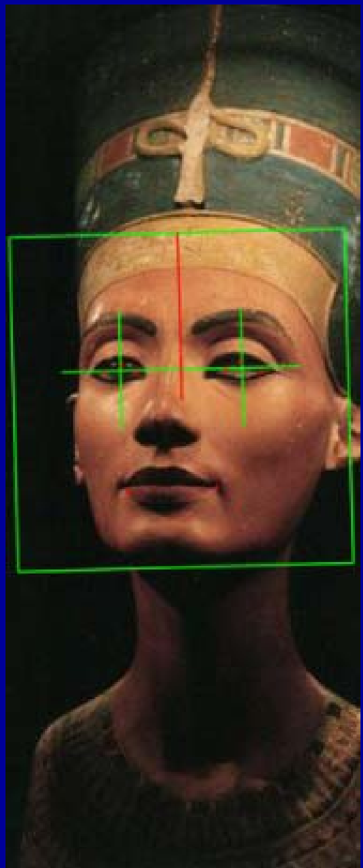
Computer Vision

- Building artificial systems that obtain information from images or multi-dimensional data. Since perception can be seen as the extraction of information from sensory signals, computer vision can be seen as the scientific investigation of artificial systems for perception from images or multi-dimensional data.



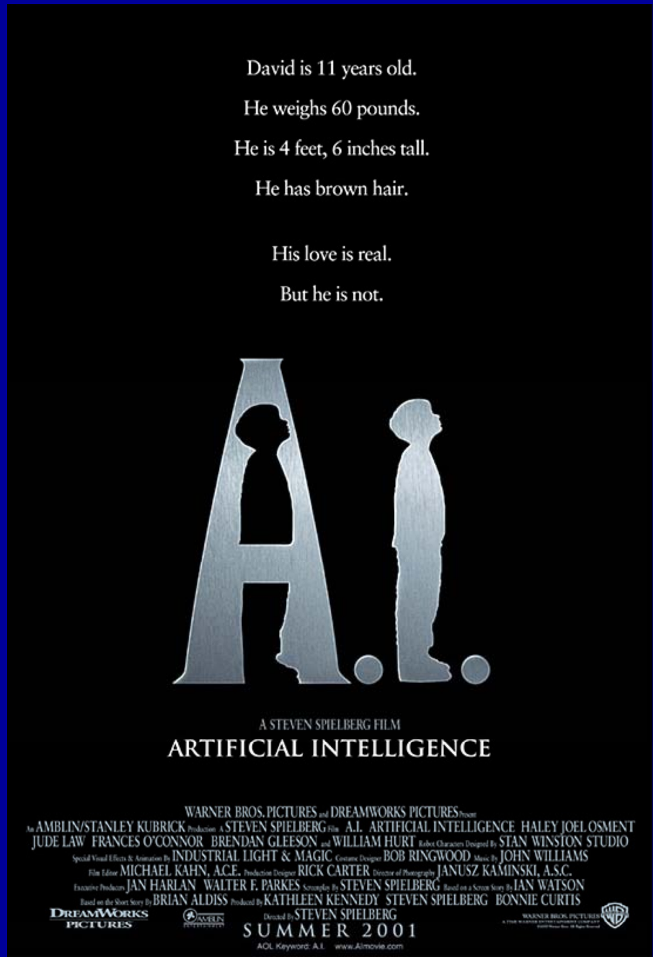
Wikipedia

Computer Vision



Artificial Intelligence

- the science of making machines act intelligently
- deals with intelligent behavior, learning, and adaptation in robots.



The Seven Areas of AI

- Knowledge representation
- Understanding natural language
- Learning
- Planning and problem solving
- Inference
- Search
- Vision

Three paradigms for organizing intelligence

- Hierarchical paradigm (1967-1990); a top-down fashion, heavy on planning
- Reactive paradigm (1988-1992); biological evidence, stimulus-response, fast execution time
- Hybrid deliberative/reactive paradigm (1992-); plan how to decompose a task into subtasks and what are the suitable behaviors for each subtask

Robot Primitives

Robot Primitives	Input	Output
Sense	Sensor data	Sensed information
Plan	Information (sensed and/or cognitive)	Directives
Act	Sensed information or directives	Actuator commands

* A fourth primitive- Learn

Hierarchical Paradigm

Robot Primitives	Input	Output
Sense	Sensor data	Sensed information
Plan	Information (sensed and/or cognitive)	Directives
Act	[redacted] directives	Actuator commands

Frame problem, closed world assumption

Reactive Paradigm

Robot Primitives	Input	Output
Sense	Sensor data	Sensed information
[redacted]		
Act	Sensed information [redacted]	Actuator commands

A dead end in explaining the entire range of human intelligence

Hybrid deliberative/reactive

Robot Primitives	Input	Output
Plan	Information (sensed and/or cognitive)	Directives
Sense-Act (behaviors)	Sensor data	Actuator commands

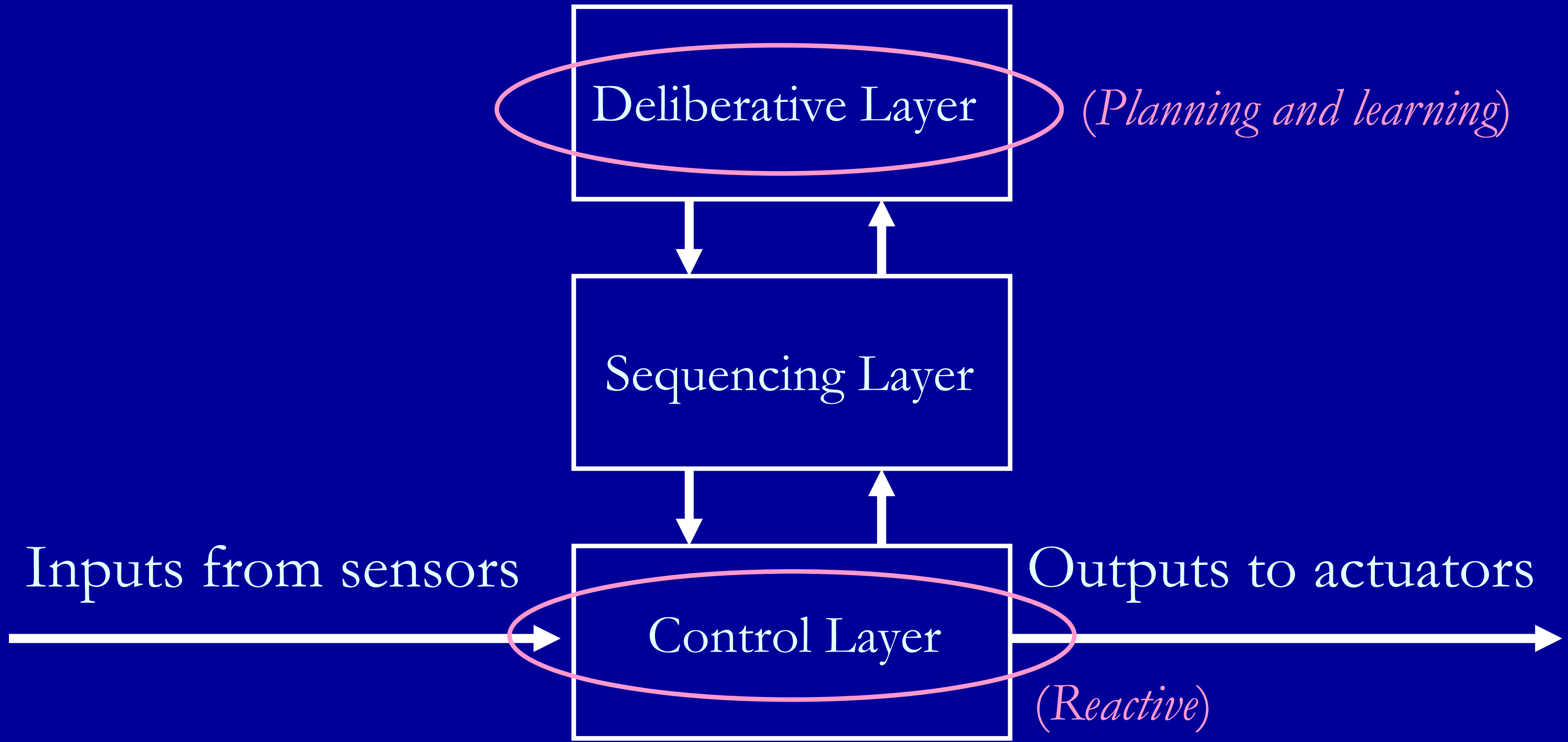
Architectures

- How to program a robot
- How to organize a control software
- The principles of connecting control software components together
- Imposes constraints on the way the control problem can be solved

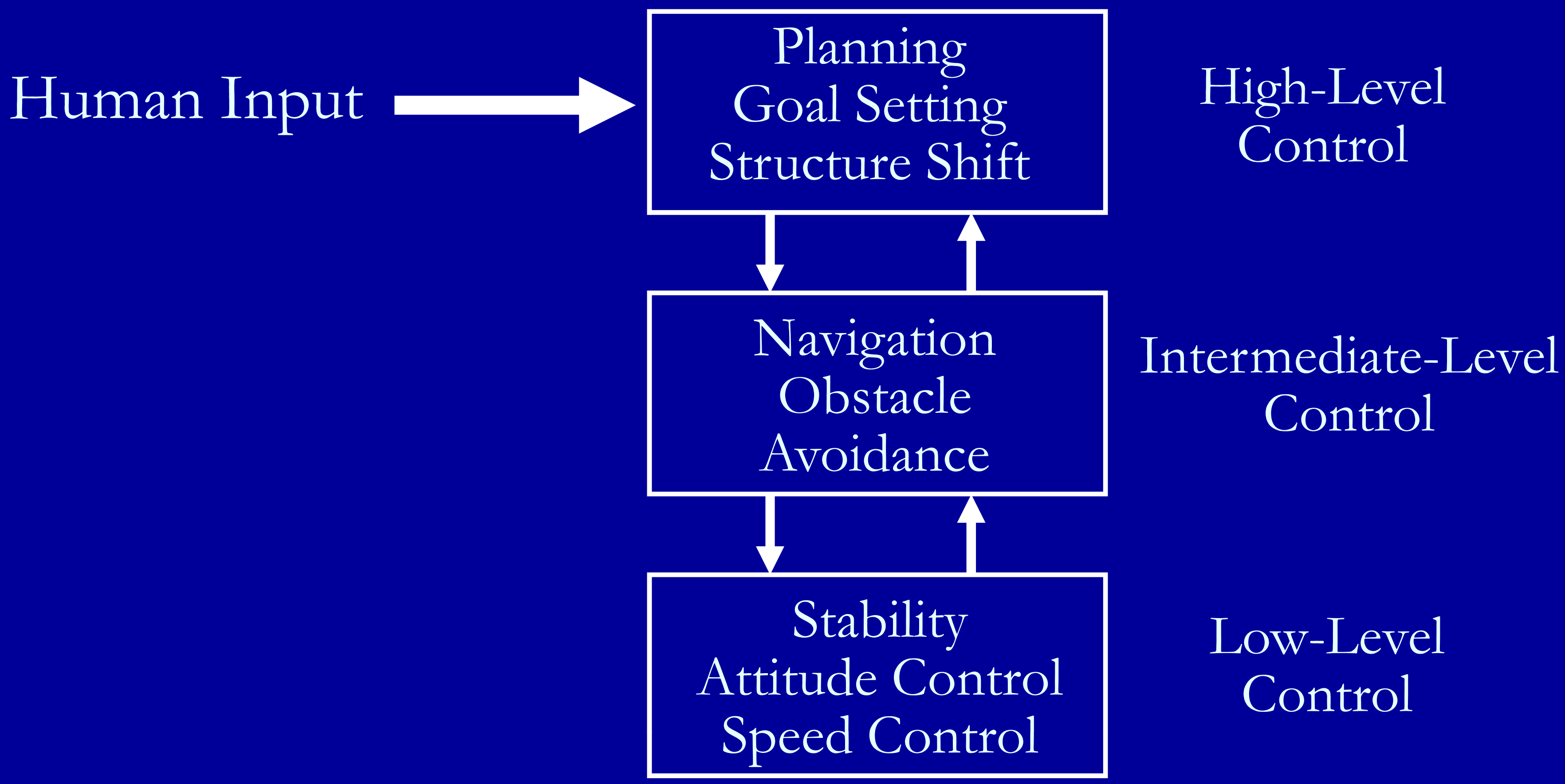
Intelligence Issues in Mobile Robots

- Sensor processing
- Reflex behaviors – rapid reaction paths from sensing to actuation (reflexes) that do not involve higher centers in the nervous system
- Special-purpose programs – navigation, localization, obstacle avoidance
- Cognitive functions – reasoning, learning, planning

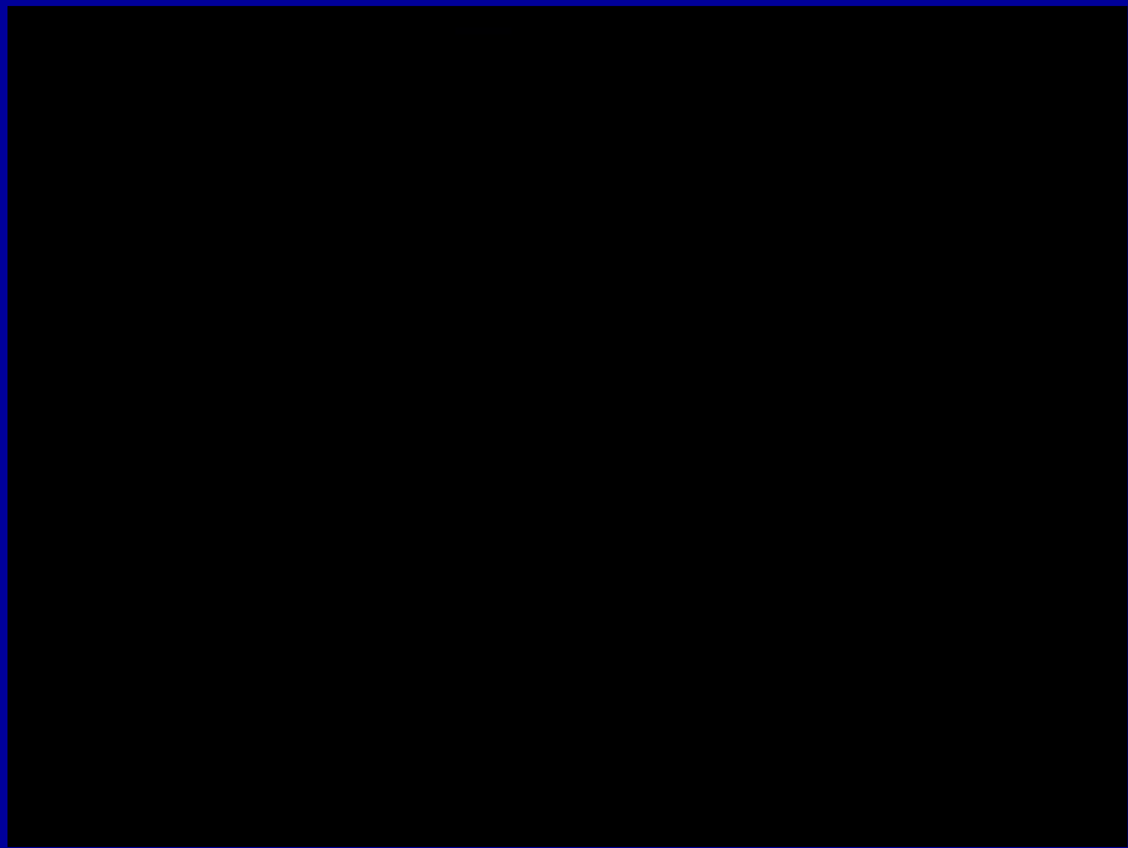
Three-Level Architecture for Mobile Robots



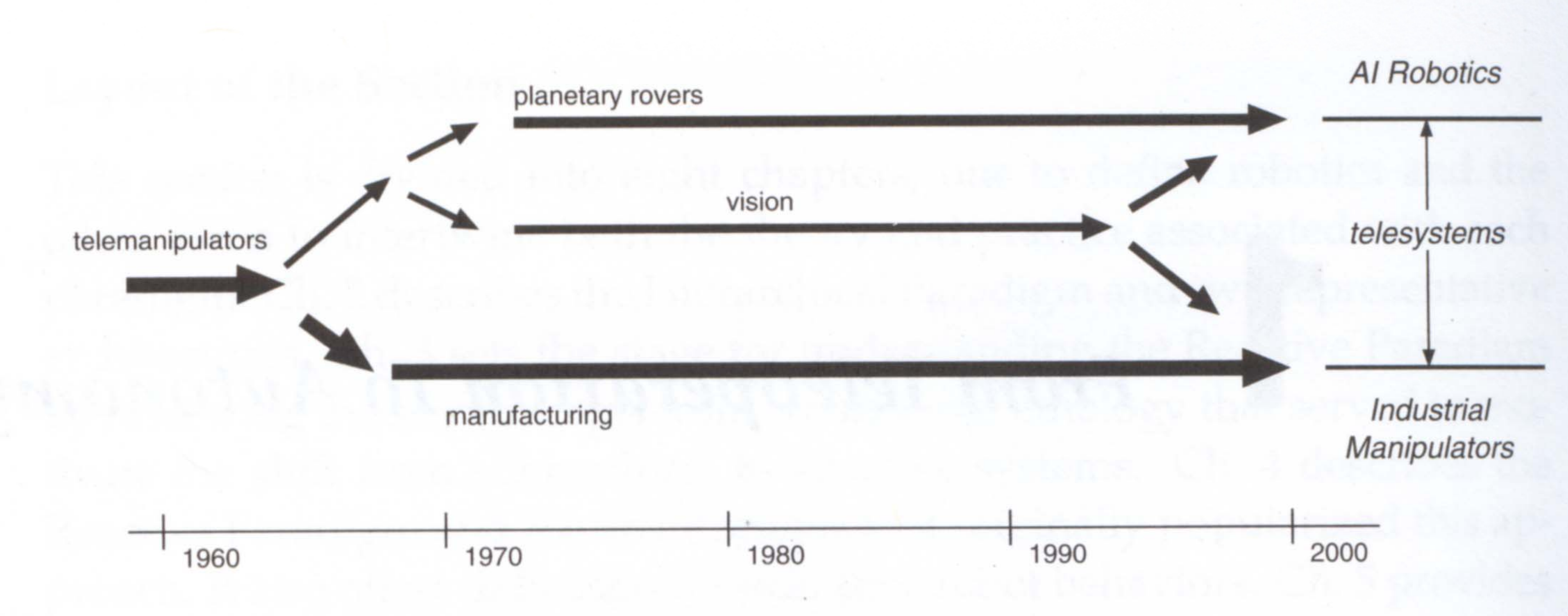
Three-Level Architecture for Mobile Robots



Artificial Intelligence (Video)



Evolution of Robots towards Intelligence (From Teleoperation to Autonomy)



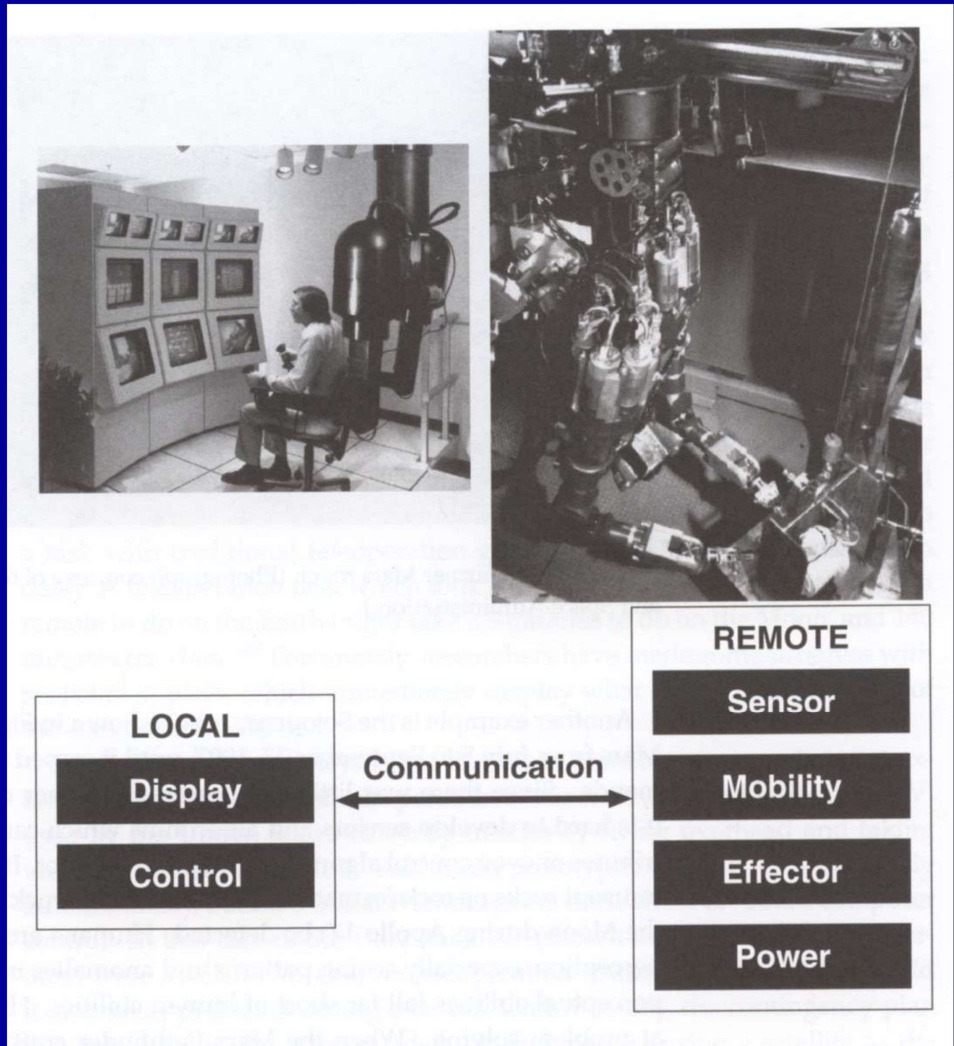
What is Autonomy?

- Autonomy refers to systems capable of operating in the real-world environment without any form of external control for extended periods of time.
- Living systems

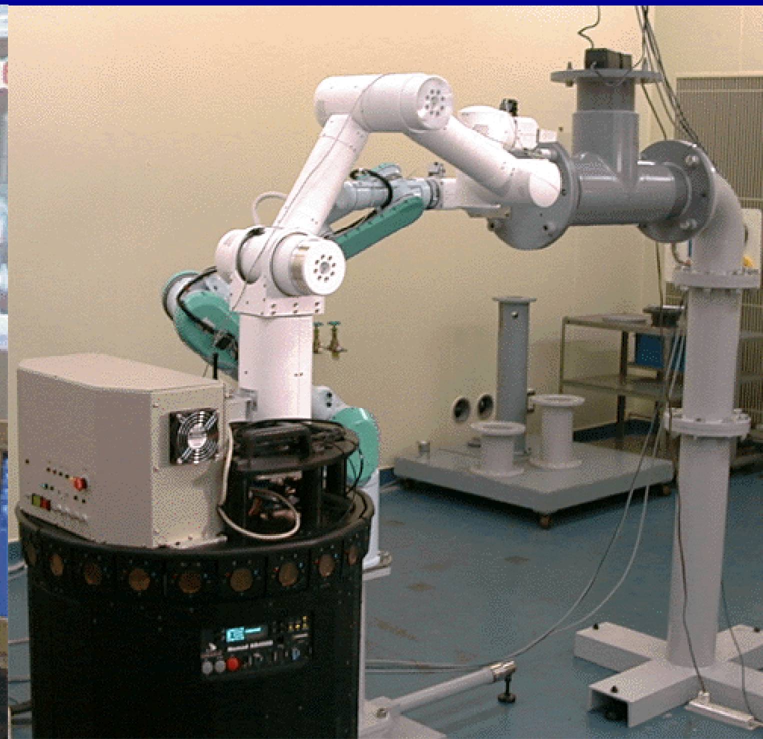
Teleoperation

- AI technology is nowhere near human levels of competence, especially in terms of perception and decision making.
- A human operator controls a robot from a distance.
- The operator and robot have some type of master-slave relationship.
- The human operator sits at a workstation and directs a robot through some sort of interface (a joystick, virtual reality gear, etc.).
- Sensors, display technology, communication link

Organization of a Telesystem (Oak Ridge National Laboratory, USA)



MOMR Teleoperation (Mechanical Engineering Laboratory, Japan)



Telepresence

- Reduce cognitive fatigue and simulator sickness
- A more natural interface to the human
- The operator has complete sensor feedback and feels as if he/she were the robot

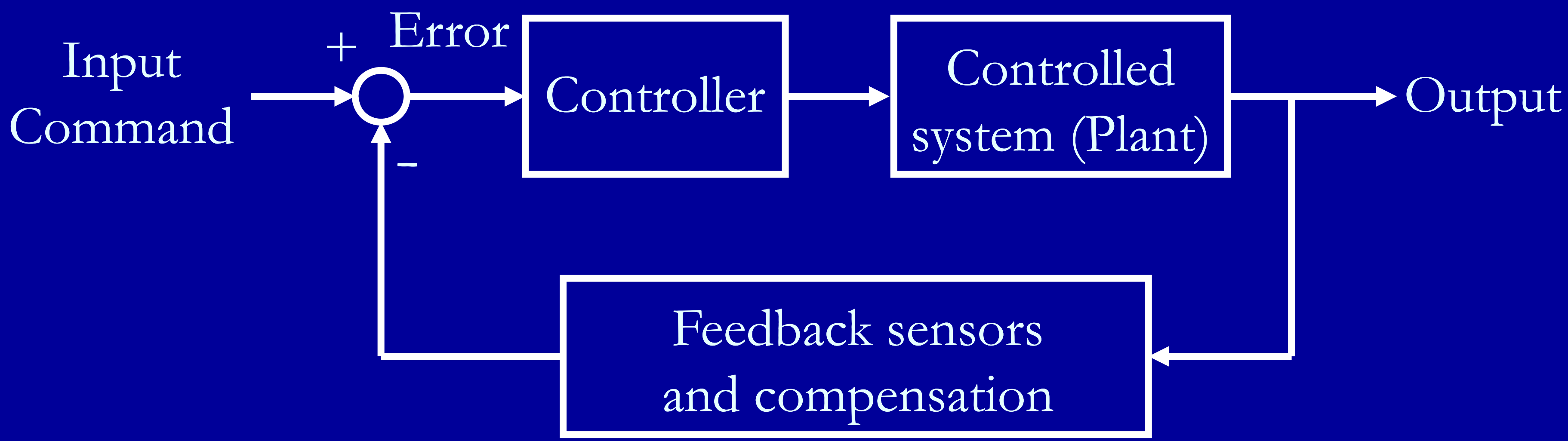
Semi-autonomous Control

- Often called supervisory control
- The remote is given an instruction or portion of a task that it can safely done on its own
- Shared control
- Control trading

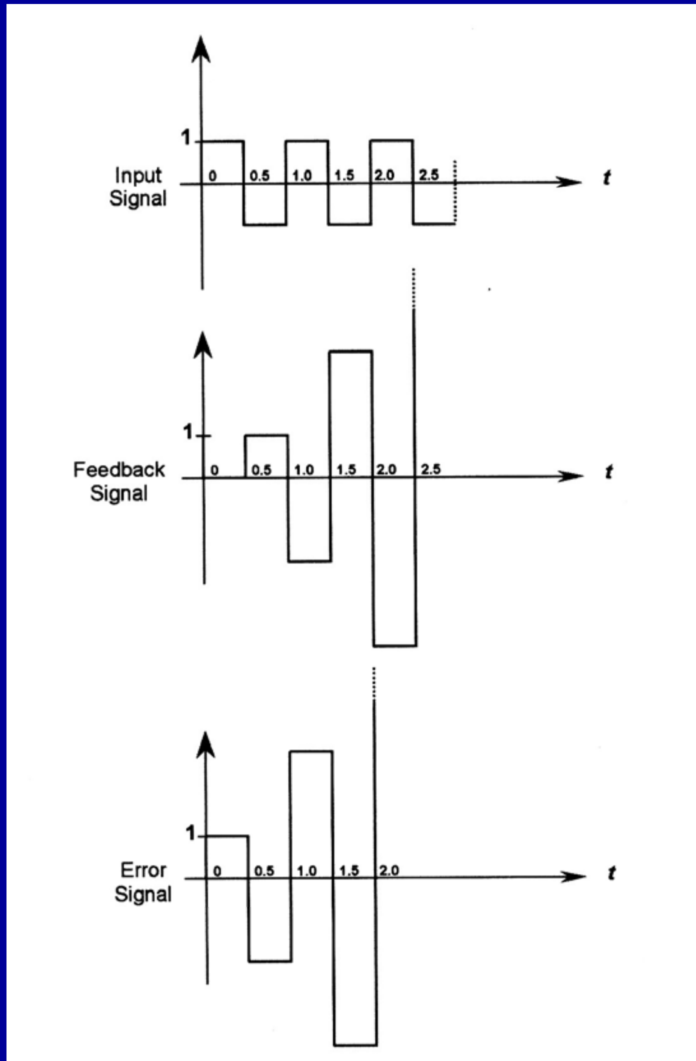
Homework #1 (1 pt.) – Due Dec. 14

- Explain the following terms:
  - Frame problem (McCarthy and Hayes 1969)
  - Subsumption architectures (Brooks 1986)
  - Behavior-based architectures (Arkin 1998)

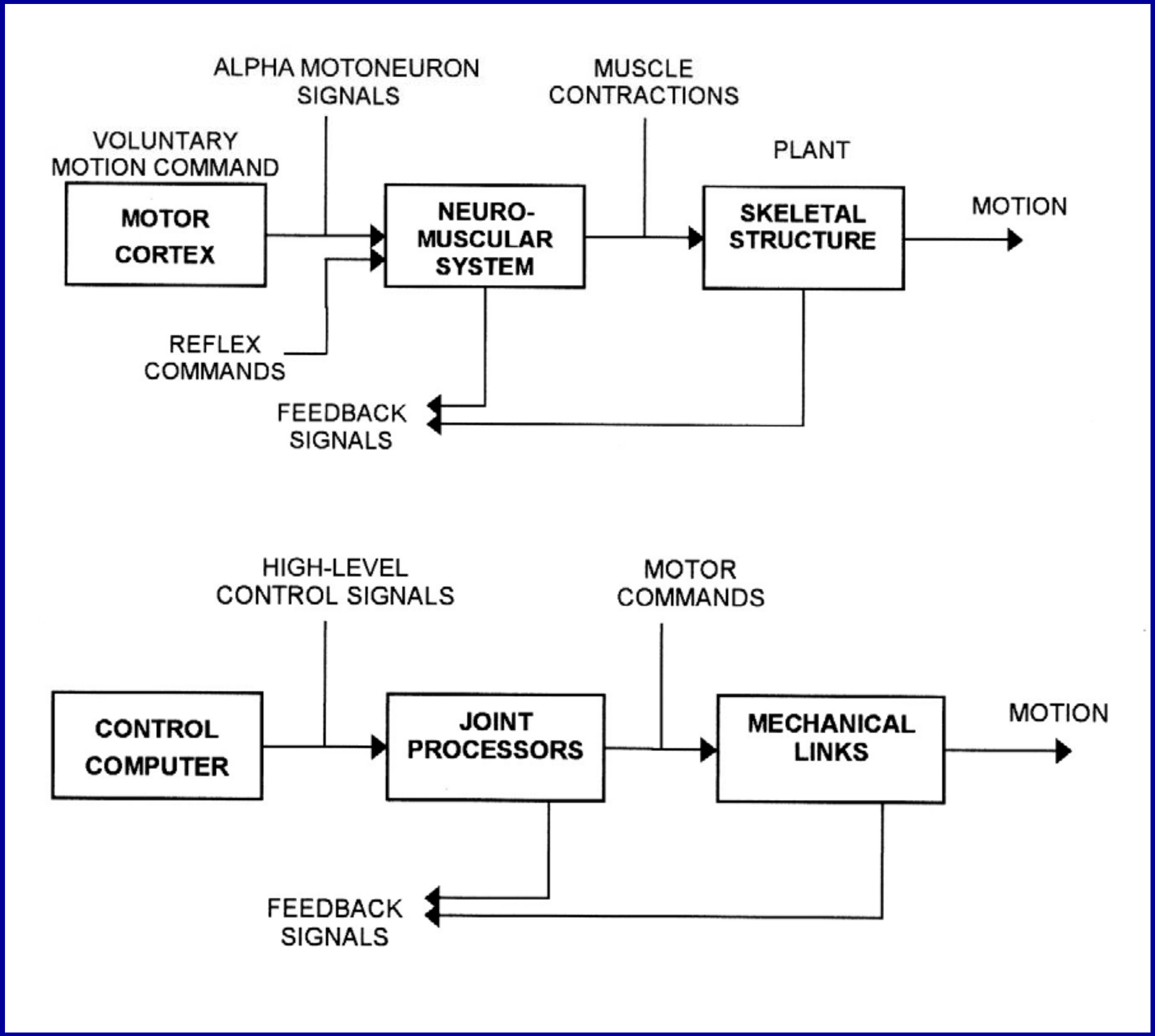
Basic Control System



Emergence of oscillations in a feedback system



Control Systems: Biological and Analogous Engineering (robot)



Sensors

- Exteroceptive sensors- obtain information from the external environment: vision, hearing, olfaction, touch, and taste
- Proprioceptive sensors- monitor the robot's internal environment (states): perception of movement and spatial orientation arising from stimuli within the body

Exteroception is more prone to *noise* and *hidden state*.

Data Filtering

- Noisy data need to be processed
- Analog filtering- requires special hardware
- Digital filtering- can be done on a computer, Butterworth, Chebyshev, Elliptic

When to use a Kalman filter?

- Elimination of noise in measurements
- Generation of non-observable states
- Prediction of future states for systems with time delays
- Optimal filtering for linear systems (Extended Kalman filter)

Actuators

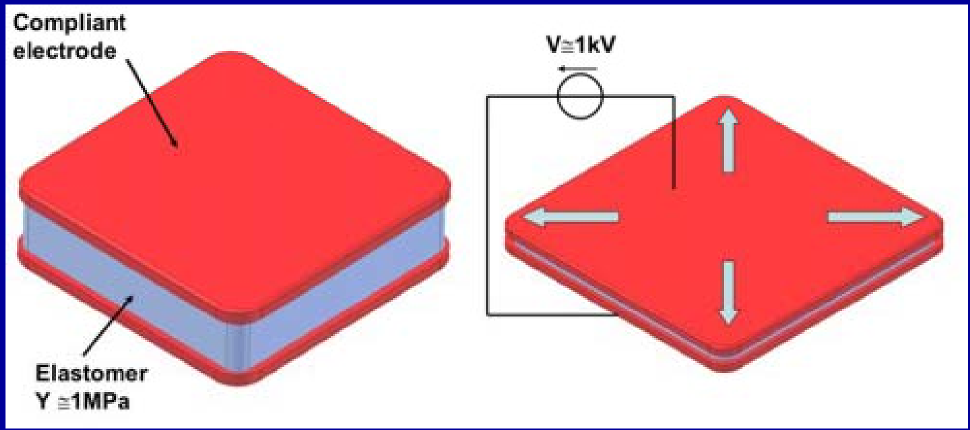
- Electric motors
- Pneumatic and hydraulic actuators
- Artificial muscles

Electroactive Polymers http://eap.jpl.nasa.gov/

Air muscles (Shadow leg)

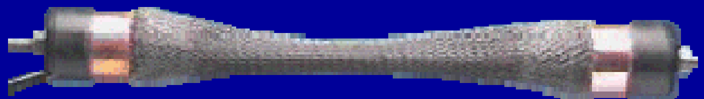
Electroactive Polymers (EAPs)

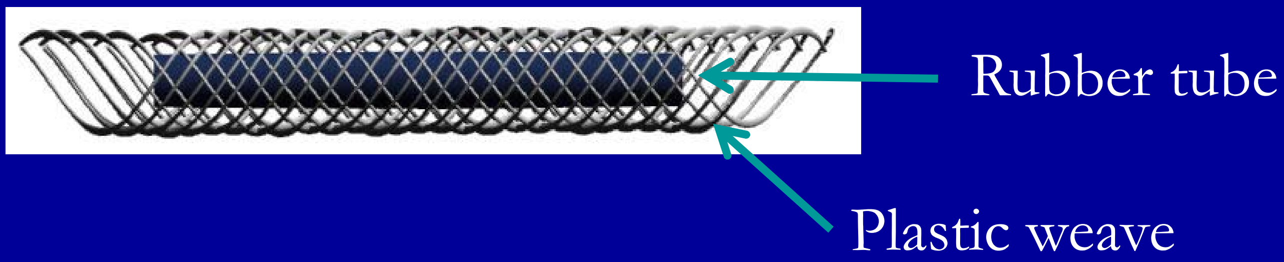
- Dielectric EAPs
- Ionic EAPs



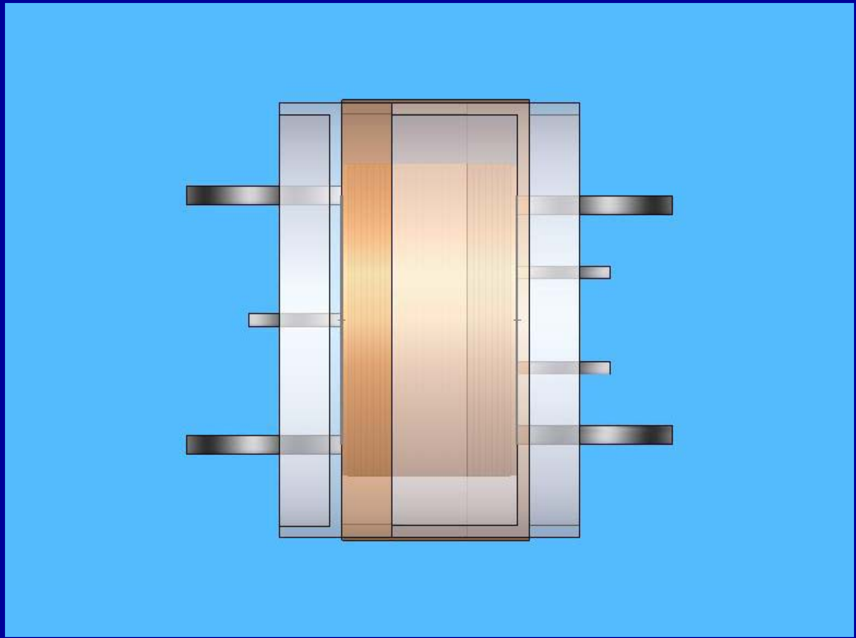
DEAP, EPFL, Switzerland

Air Muscles (Shadow Robot)

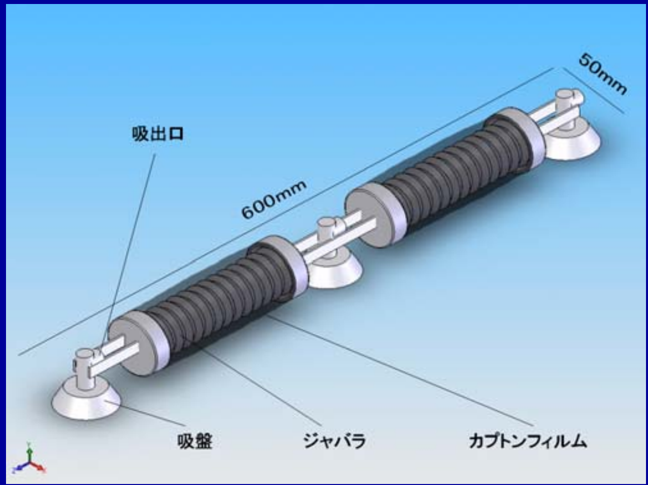


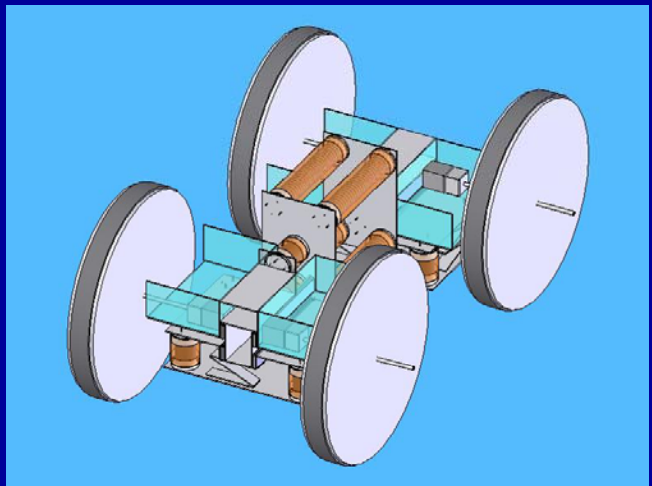


Film-surfaced Bellows (JAIST, 2004)



Jai-Worm, Jai-Rover





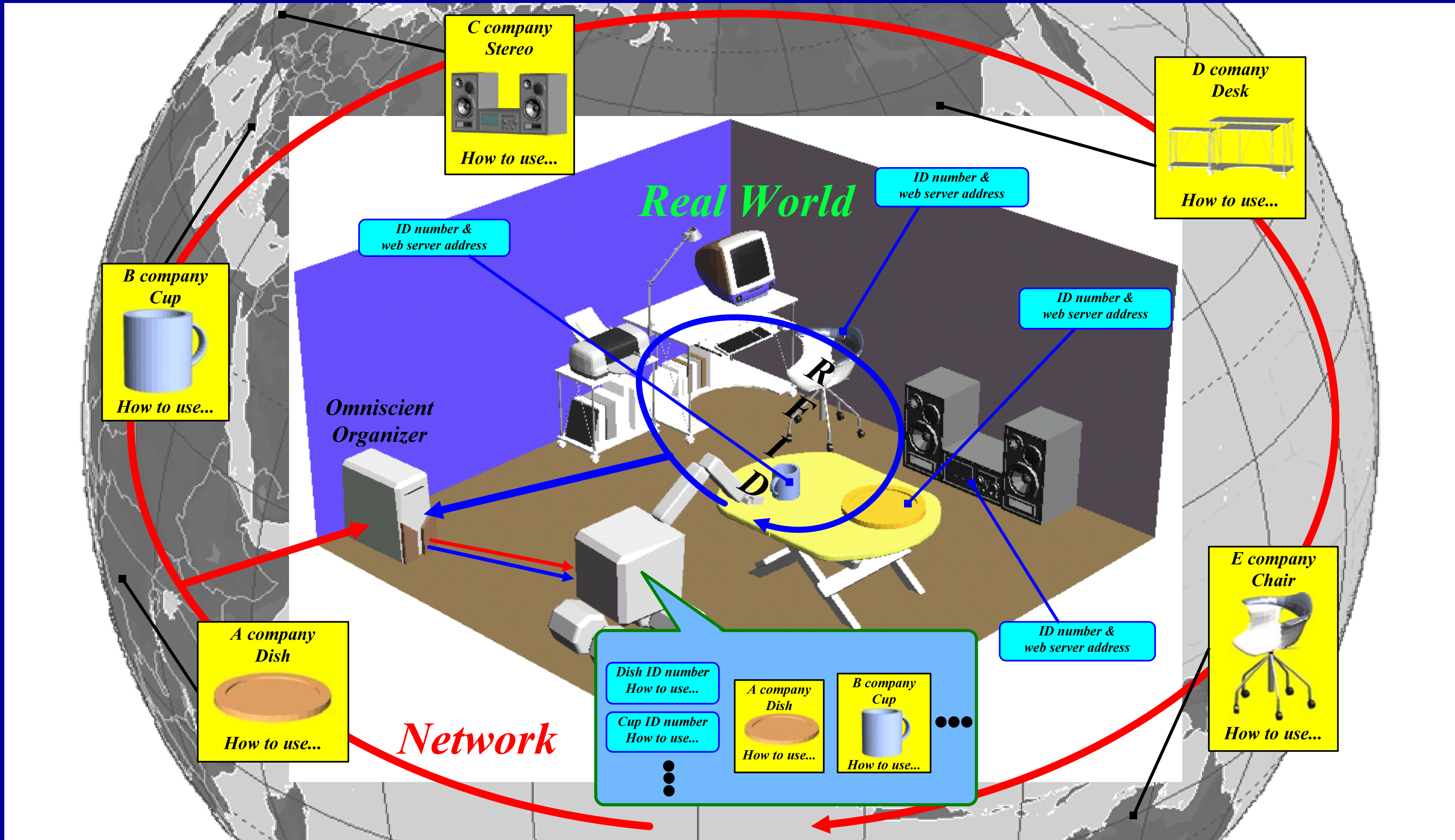
Homework #2 (1 pt.) – Due Dec. 14

- Summarize the principles of EAP actuators and air muscles (as well as the advantages and disadvantages)

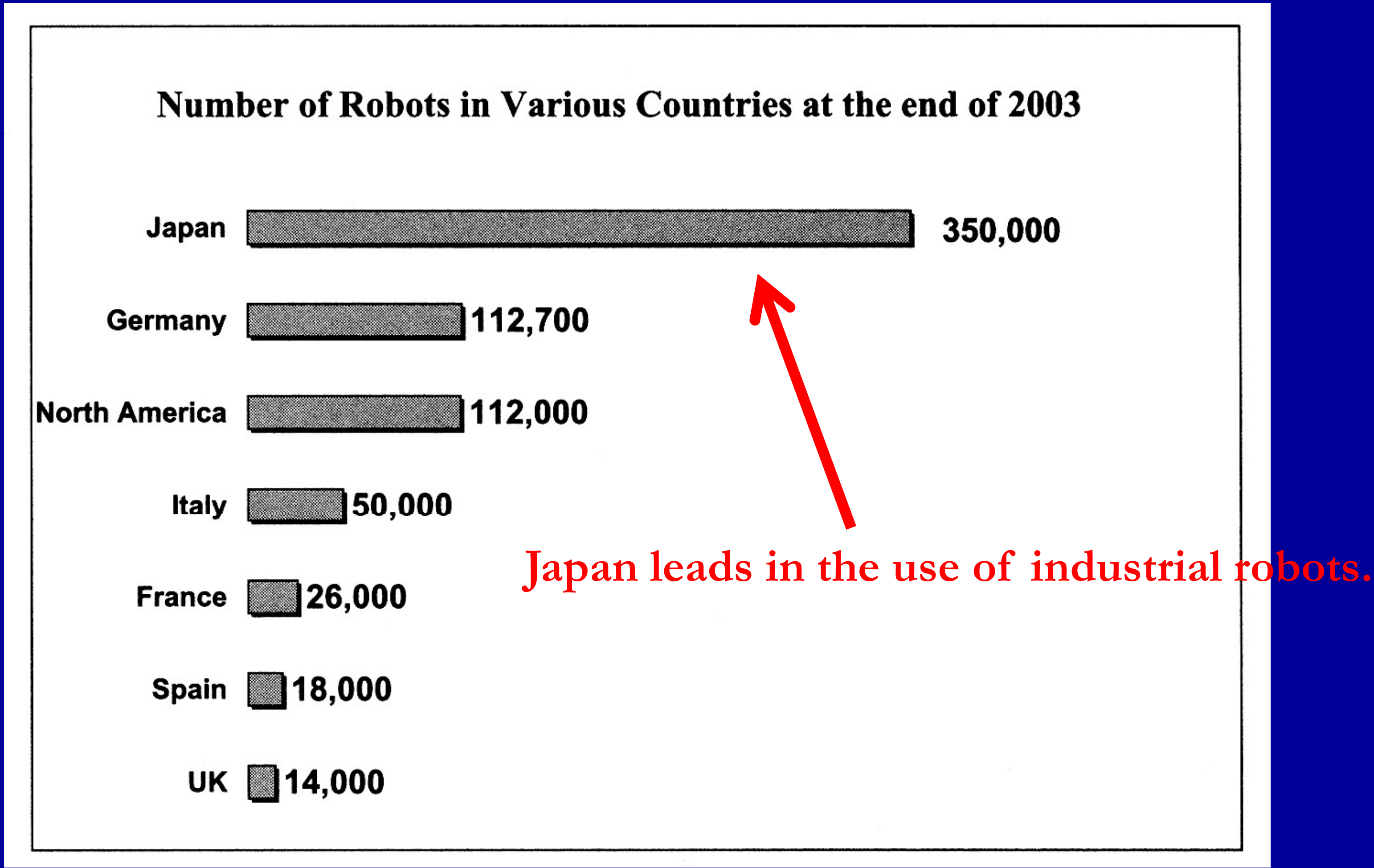
AI Robot- Coming Soon?

ASIMO Again (Video)

Environmental intelligence replaces the need for robot intelligence

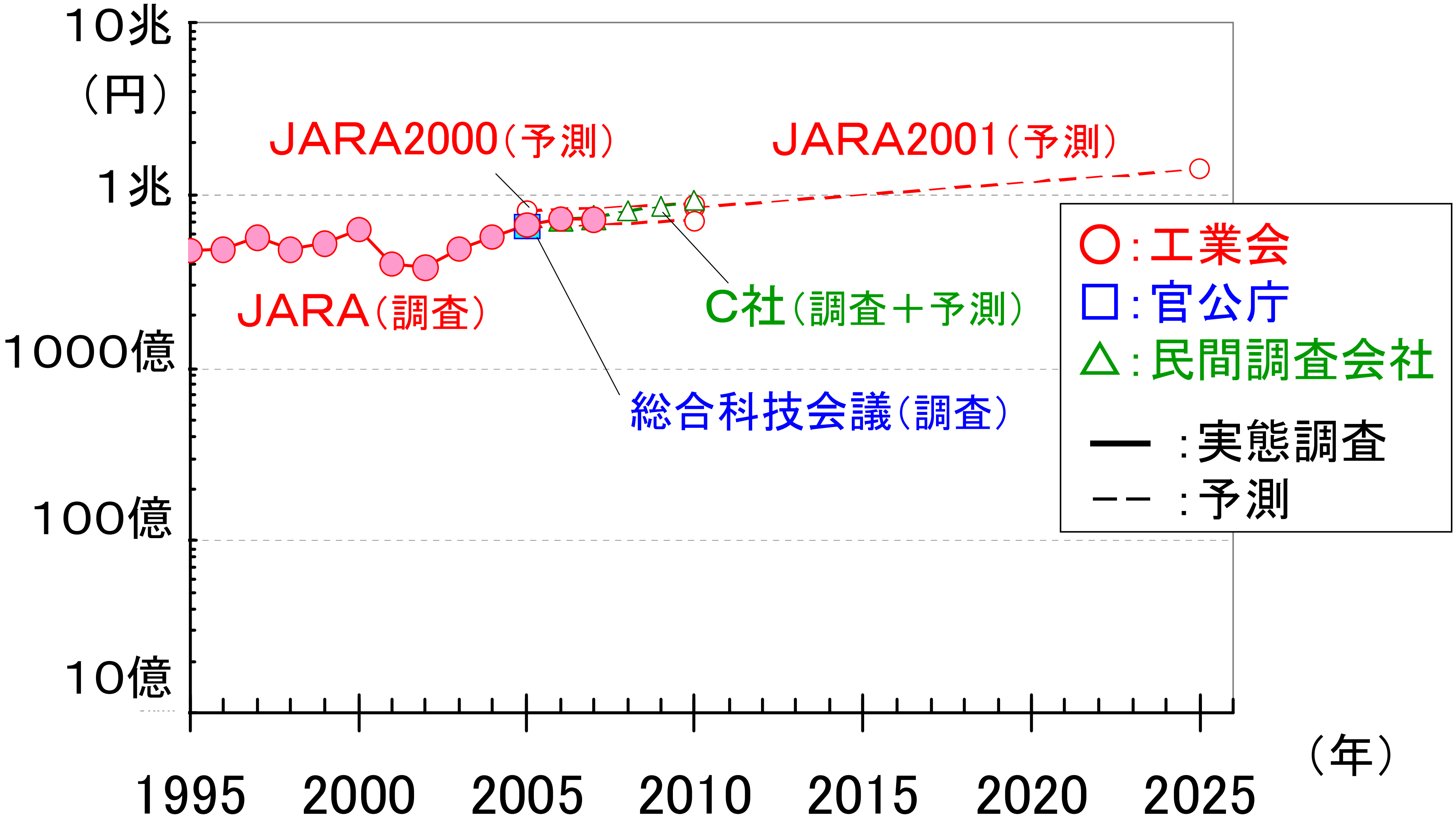


Number of Robots

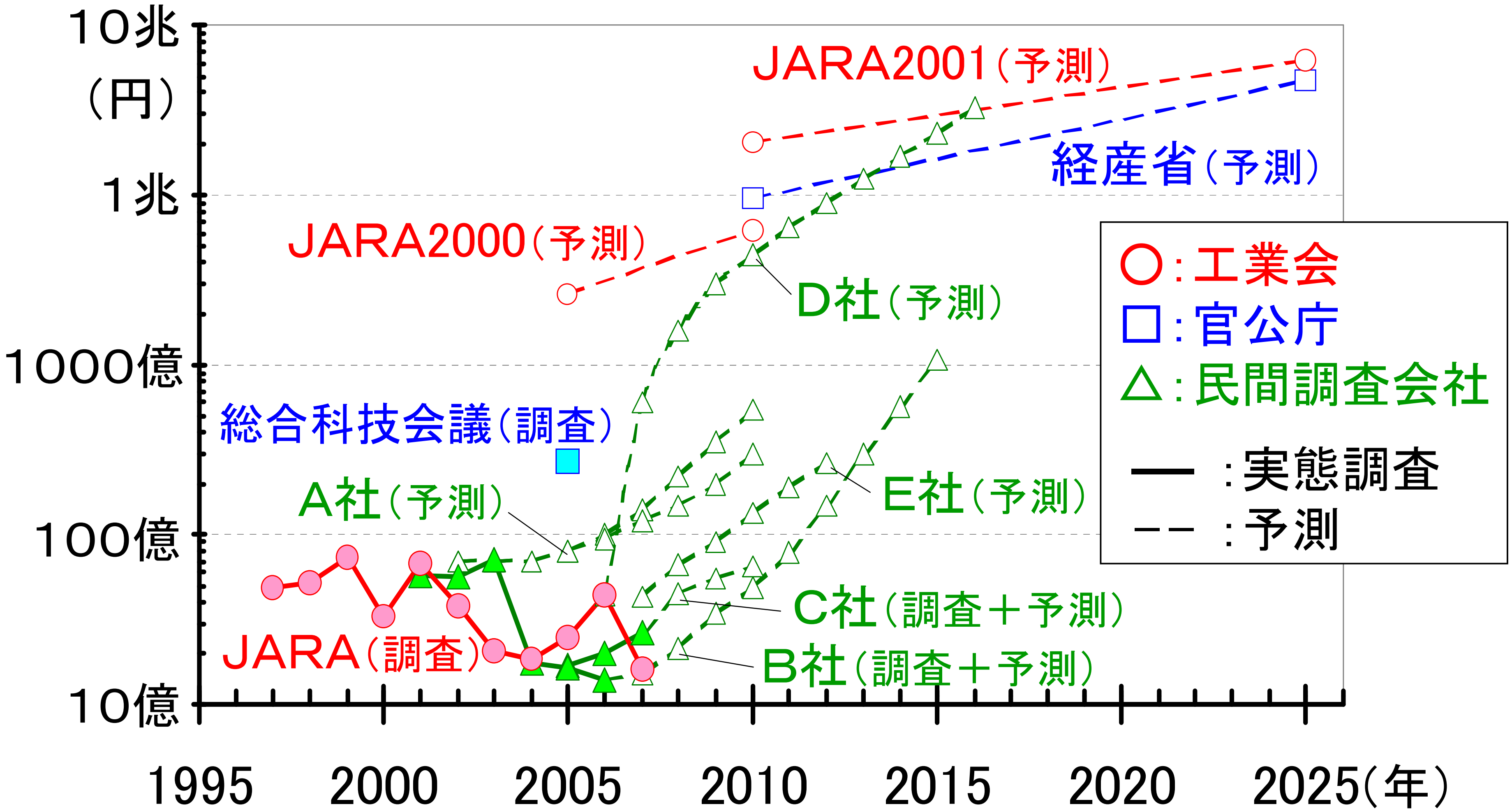


[UNECE- United Nations Economic Commission for Europe, October 2004]

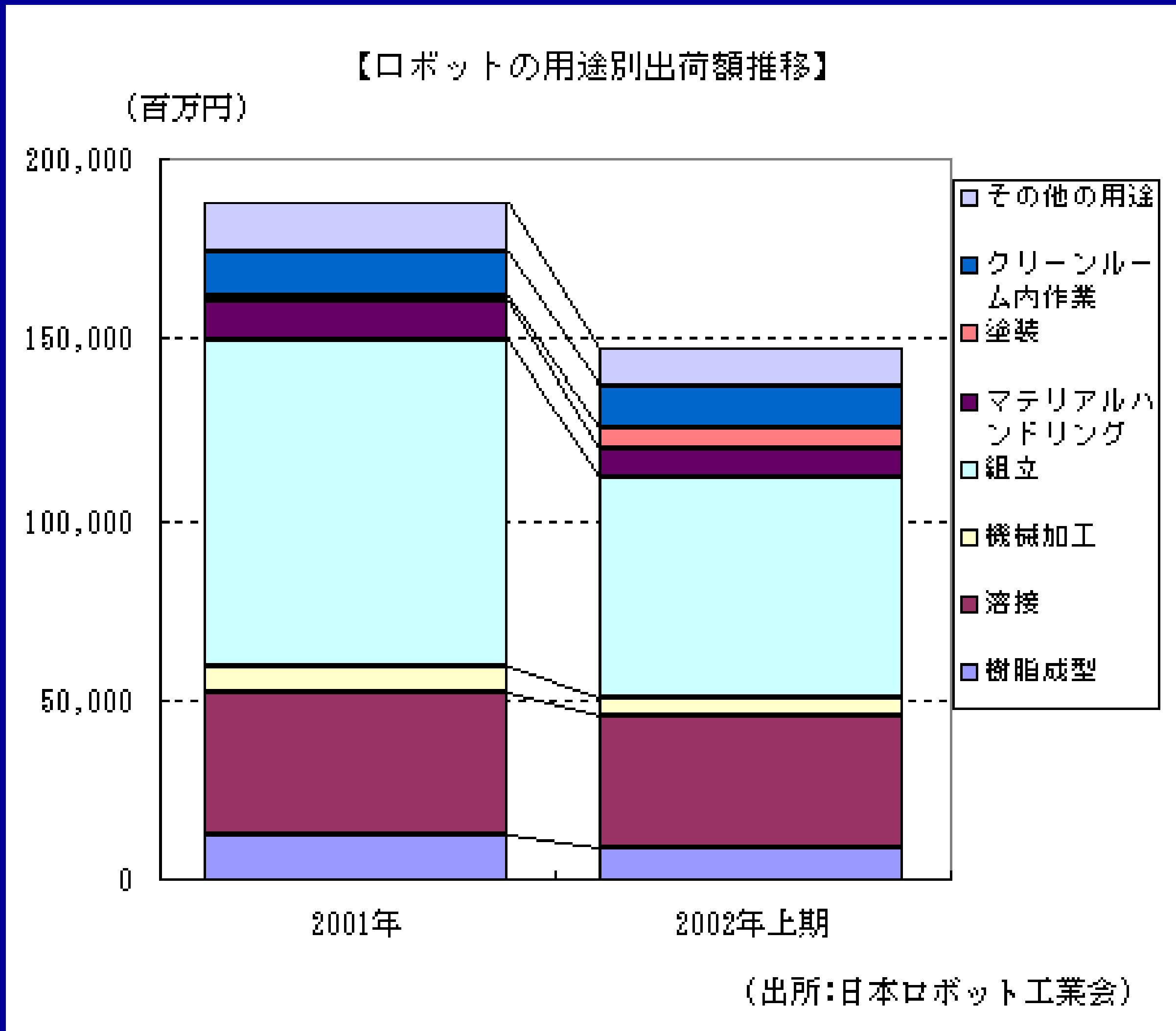
Industrial Robot (Manufacturing) Market Survey Predictions (Dr. H. Arai, AIST)



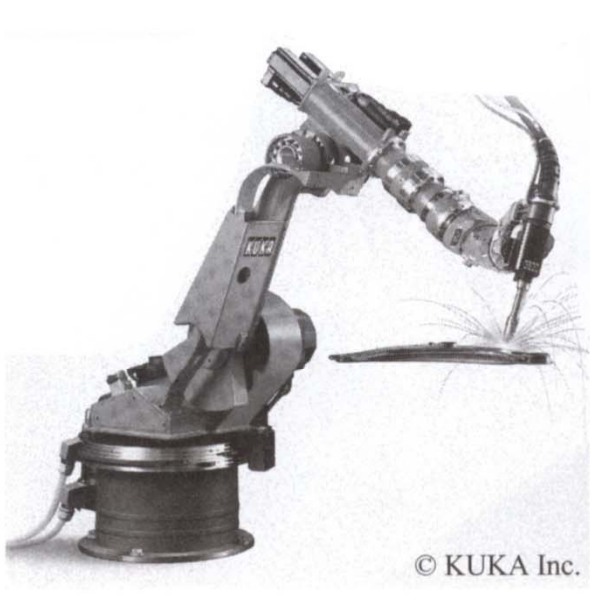
Next Generation Robot (Non-manufacturing) Market Survey Predictions (Dr. H. Arai, AIST)

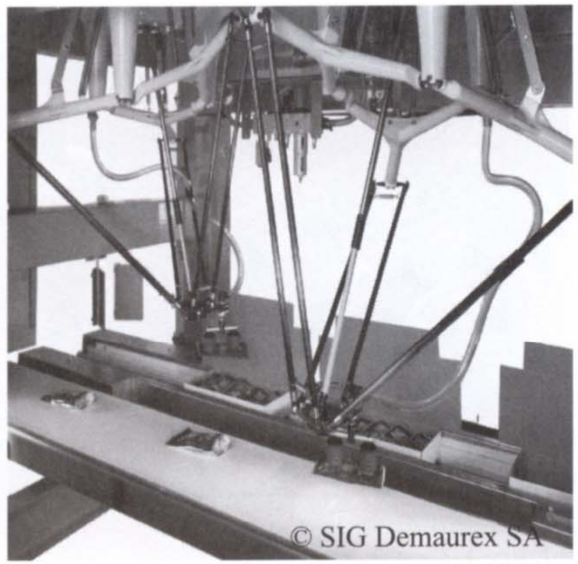


Market for Industrial Robots



Industrial Manipulators





- Began being introduced to industries in 1956 by Unimation (George Devol and Joseph Engelberger)
- In 1961, the very first industrial robot was employed in a GM automobile factory in New Jersey.
- 1980 the first year of the robot era

Benefits of Industrial Robots

- Improve the quality of life by freeing workers from 3D jobs
- Improved management control and productivity and consistently high quality products
- Work tirelessly 24/7 without any loss in performance (reduce the costs of manufactured goods)
- Will have an economic advantage on world markets

Service Robots

- Recent breakthroughs in robotics are starting to create new roles for robots
- Entertainment, education, personal, and social welfare purposes