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Automation and Robotics

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Recently published articles

- A software modeling approach for the design and analysis of cooperative optimization systems
- Nature Inspired Cooperative Strategies for Optimization
- A new fuzzy linguistic approach to qualitative Cross Impact Analysis
- The role of cardinality and neighborhood sampling strategy in agent-based cooperative strategies for Dynamic Optimization Problems
- A centralised cooperative strategy for continuous optimisation: The influence of cooperation in performance and behaviour
- Exploring Innovative and Successful Applications of Soft Computing
- A Linguistic Approach to Structural Analysis in Prospective Studies
- Using knowledge discovery in cooperative strategies: two case studies
- On the Performance of Homogeneous and Heterogeneous Cooperative Search Strategies

Motivation

- Intelligent Environments are aimed at improving the inhabitants' experience and task performance
 - Automate functions in the home
 - Provide services to the inhabitants
- Decisions coming from the decision maker(s) in the environment have to be executed.
 - Decisions require actions to be performed on devices
 - Decisions are frequently not elementary device interactions but rather relatively complex commands
 - Decisions define set points or results that have to be achieved
 - Decisions can require entire tasks to be performed

Automation and Robotics in Intelligent Environments

- Control of the physical environment
 - Automated blinds
 - Thermostats and heating ducts
 - Automatic doors
 - Automatic room partitioning
- Personal service robots
 - House cleaning
 - Lawn mowing
 - Assistance to the elderly and handicapped
 - Office assistants
 - Security services

Robots

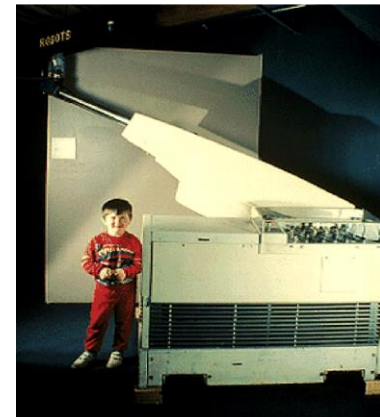
- Robota (Czech) = A worker of forced labor
From Czech playwright Karel Capek's 1921 play "R.U.R"
("Rossum's Universal Robots")
- Japanese Industrial Robot Association (JIRA) :
"A device with degrees of freedom that can be controlled."
 - Class 1 : Manual handling device
 - Class 2 : Fixed sequence robot
 - Class 3 : Variable sequence robot
 - Class 4 : Playback robot
 - Class 5 : Numerical control robot
 - Class 6 : Intelligent robot

A Brief History of Robotics

- Mechanical Automata
 - Ancient Greece & Egypt
 - Water powered for ceremonies
 - 14th – 19th century Europe
 - Clockwork driven for entertainment
- Motor driven Robots
 - 1928: First motor driven automata
 - 1961: Unimate
 - First industrial robot
 - 1967: Shakey
 - Autonomous mobile research robot
 - 1969: Stanford Arm
 - Dextrous, electric motor driven robot arm



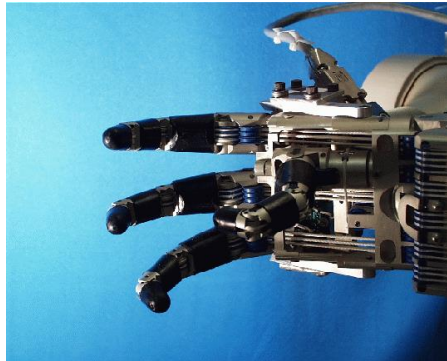
Maillardet's Automaton



Unimate

Robots

- Robot Manipulators

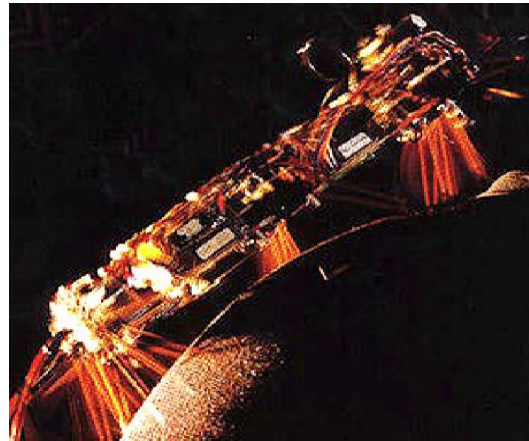


- Mobile Robots

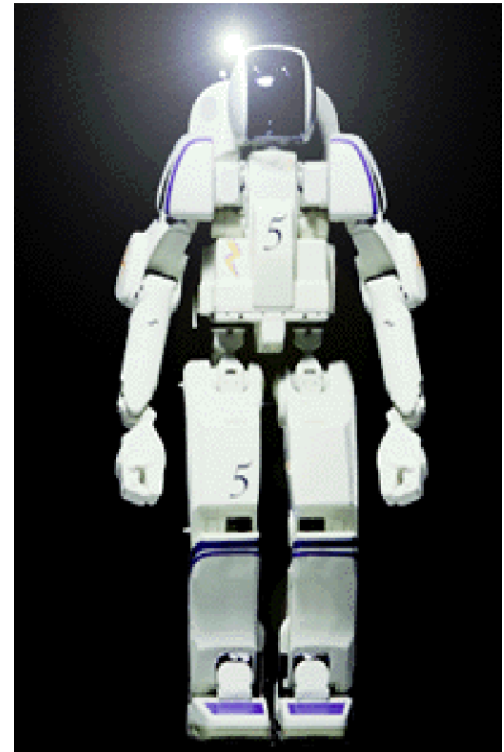


Robots

- Walking Robots



- Humanoid Robots



Autonomous Robots

- The control of autonomous robots involves a number of subtasks
 - Understanding and modeling of the mechanism
 - Kinematics, Dynamics, and Odometry
 - Reliable control of the actuators
 - Closed-loop control
 - Generation of task-specific motions
 - Path planning
 - Integration of sensors
 - Selection and interfacing of various types of sensors
 - Coping with noise and uncertainty
 - Filtering of sensor noise and actuator uncertainty
 - Creation of flexible control policies
 - Control has to deal with new situations

Traditional Industrial Robots

- Traditional industrial robot control uses robot arms and largely pre-computed motions
 - Programming using “teach box”
 - Repetitive tasks
 - High speed
 - Few sensing operations
 - High precision movements
 - Pre-planned trajectories and task policies
 - No interaction with humans



Problems

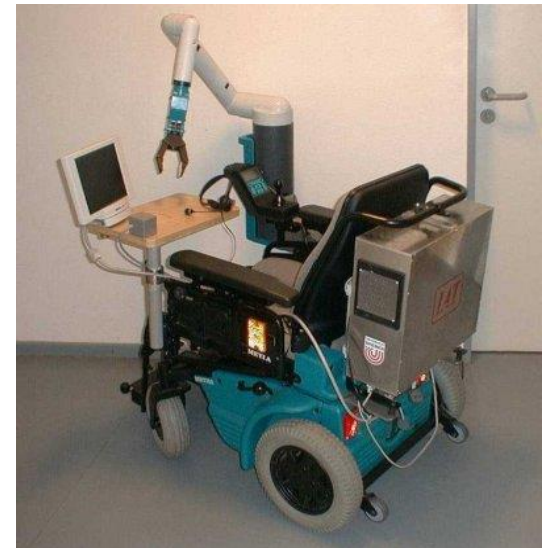
- Traditional programming techniques for industrial robots lack key capabilities necessary in intelligent environments
 - Only limited on-line sensing
 - No incorporation of uncertainty
 - No interaction with humans
 - Reliance on perfect task information
 - Complete re-programming for new tasks

Requirements for Robots in Intelligent Environments

- **Autonomy**
 - Robots have to be capable of achieving task objectives without human input
 - Robots have to be able to make and execute their own decisions based on sensor information
- **Intuitive Human-Robot Interfaces**
 - Use of robots in smart homes can not require extensive user training
 - Commands to robots should be natural for inhabitants
- **Adaptation**
 - Robots have to be able to adjust to changes in the environment

Robots for Intelligent Environments

- Service Robots
 - Security guard
 - Delivery
 - Cleaning
 - Mowing
- Assistance Robots
 - Mobility
 - Services for elderly and People with disabilities

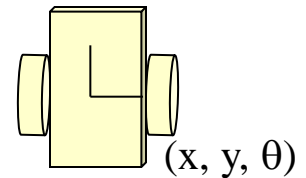
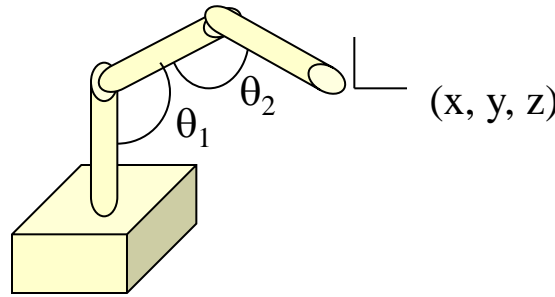


Autonomous Robot Control

- To control robots to perform tasks autonomously a number of tasks have to be addressed:
 - Modeling of robot mechanisms
 - Kinematics, Dynamics
 - Robot sensor selection
 - Active and passive proximity sensors
 - Low-level control of actuators
 - Closed-loop control
 - Control architectures
 - Traditional planning architectures
 - Behavior-based control architectures
 - Hybrid architectures

Modeling the Robot Mechanism

- Forward kinematics describes how the robots joint angle configurations translate to locations in the world



- Inverse kinematics computes the joint angle configuration necessary to reach a particular point in space.
- Jacobians calculate how the speed and configuration of the actuators translate into velocity of the robot

Mobile Robot Odometry

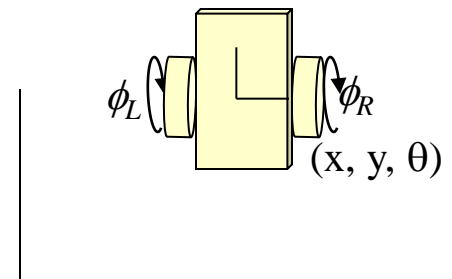
- In mobile robots the same configuration in terms of joint angles does not identify a unique location
 - To keep track of the robot it is necessary to incrementally update the location (this process is called odometry or dead reckoning)

$$\begin{pmatrix} x \\ y \\ \theta \end{pmatrix}^{t+\Delta t} = \begin{pmatrix} x \\ y \\ \theta \end{pmatrix}^t + \begin{pmatrix} v_x \\ v_y \\ \omega \end{pmatrix} \Delta t$$

- Example: A differential drive robot

$$v_x = \cos(\theta) \frac{r(\dot{\phi}_L + \dot{\phi}_R)}{2}, v_y = \sin(\theta) \frac{r(\dot{\phi}_L + \dot{\phi}_R)}{2}$$

$$\omega = \frac{r}{d} (\dot{\phi}_L - \dot{\phi}_R)$$



Actuator Control

- To get a particular robot actuator to a particular location it is important to apply the correct amount of force or torque to it.
 - Requires knowledge of the dynamics of the robot
 - Mass, inertia, friction
 - For a simplistic mobile robot: $F = m a + B v$
 - Frequently actuators are treated as if they were independent (i.e. as if moving one joint would not affect any of the other joints).
 - The most common control approach is PD-control (proportional, differential control)
 - For the simplistic mobile robot moving in the x direction:

$$F = K_P(x_{desired} - x_{actual}) + K_D(v_{desired} - v_{actual})$$

Robot Navigation

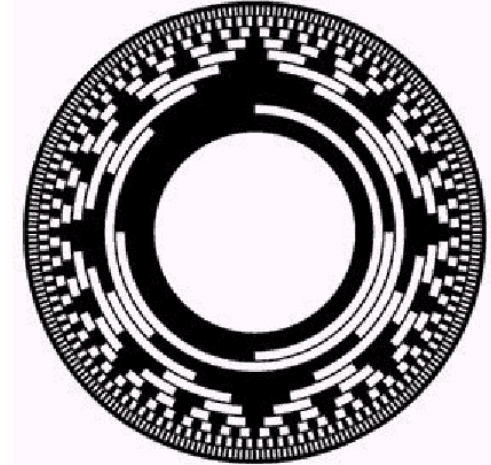
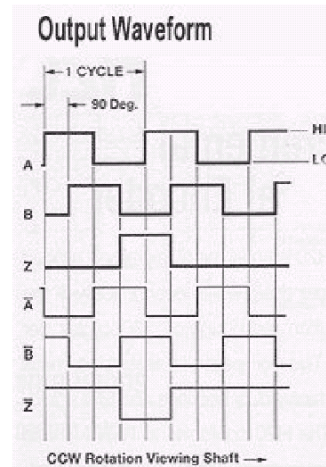
- Path planning addresses the task of computing a trajectory for the robot such that it reaches the desired goal without colliding with obstacles
 - Optimal paths are hard to compute in particular for robots that can not move in arbitrary directions (i.e. nonholonomic robots)
 - Shortest distance paths can be dangerous since they always graze obstacles
 - Paths for robot arms have to take into account the entire robot (not only the endeffector)

Sensor-Driven Robot Control

- To accurately achieve a task in an intelligent environment, a robot has to be able to react dynamically to changes in its surrounding
 - Robots need sensors to perceive the environment
 - Most robots use a set of different sensors
 - Different sensors serve different purposes
 - Information from sensors has to be integrated into the control of the robot

Robot Sensors

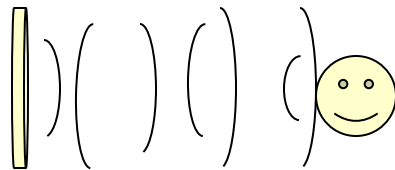
- Internal sensors to measure the robot configuration
 - Encoders measure the rotation angle of a joint



- Limit switches detect when the joint has reached the limit

Robot Sensors

- Proximity sensors are used to measure the distance or location of objects in the environment. This can then be used to determine the location of the robot.
 - Infrared sensors determine the distance to an object by measuring the amount of infrared light the object reflects back to the robot
 - Ultrasonic sensors (sonars) measure the time that an ultrasonic signal takes until it returns to the robot

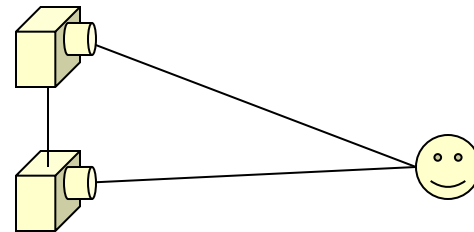


- Laser range finders determine distance by measuring either the time it takes for a laser beam to be reflected back to the robot or by measuring where the laser hits the object



Robot Sensors

- Computer Vision provides robots with the capability to passively observe the environment
 - Stereo vision systems provide complete location information using triangulation



- However, computer vision is very complex
 - Correspondence problem makes stereo vision even more difficult

Uncertainty in Robot Systems

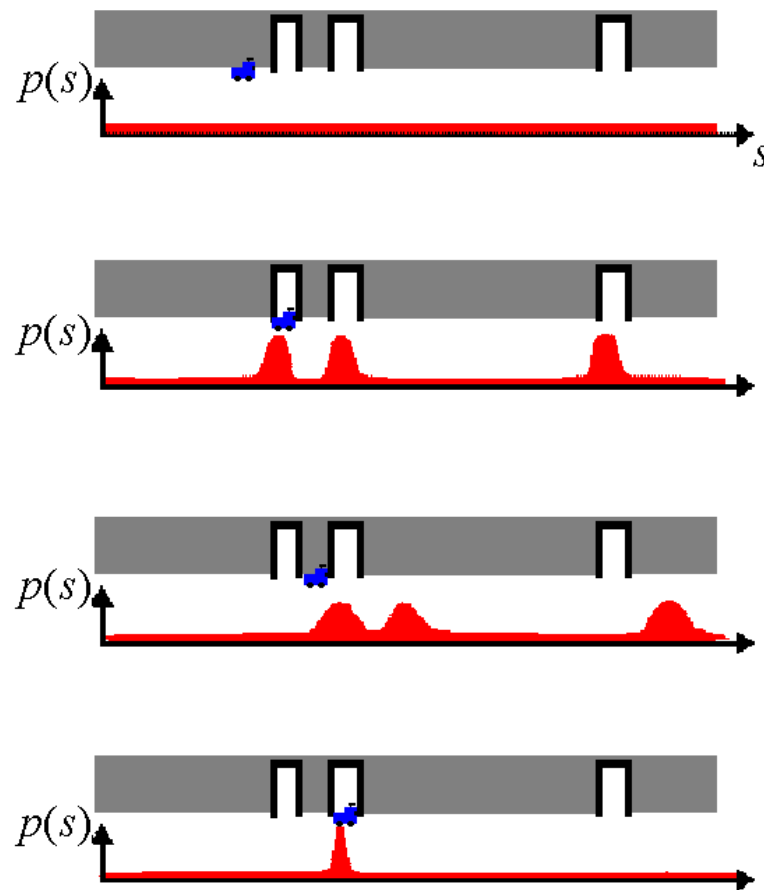
- Robot systems in intelligent environments have to deal with sensor noise and uncertainty
 - Sensor uncertainty
 - Sensor readings are imprecise and unreliable
 - Non-observability
 - Various aspects of the environment can not be observed
 - The environment is initially unknown
 - Action uncertainty
 - Actions can fail
 - Actions have nondeterministic outcomes

Probabilistic Robot Localization

- Explicit reasoning about Uncertainty using Bayes filters:

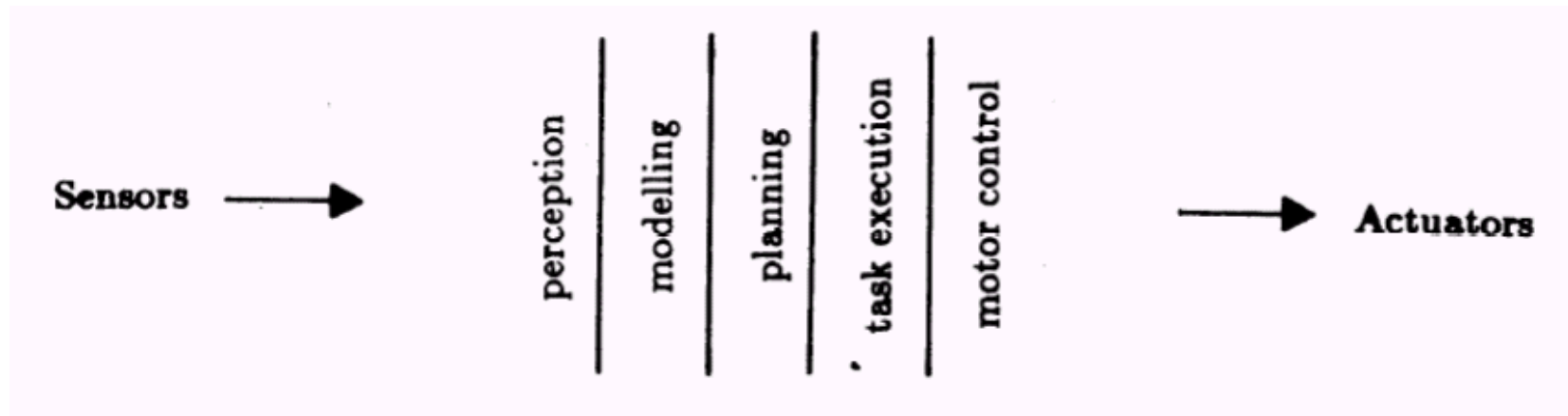
$$b(x_t) = \eta p(o_t | x_t) \int p(x_t | x_{t-1}, a_{t-1}) b(x_{t-1}) dx_{t-1}$$

- Used for:
 - Localization
 - Mapping
 - Model building



Deliberative Robot Control Architectures

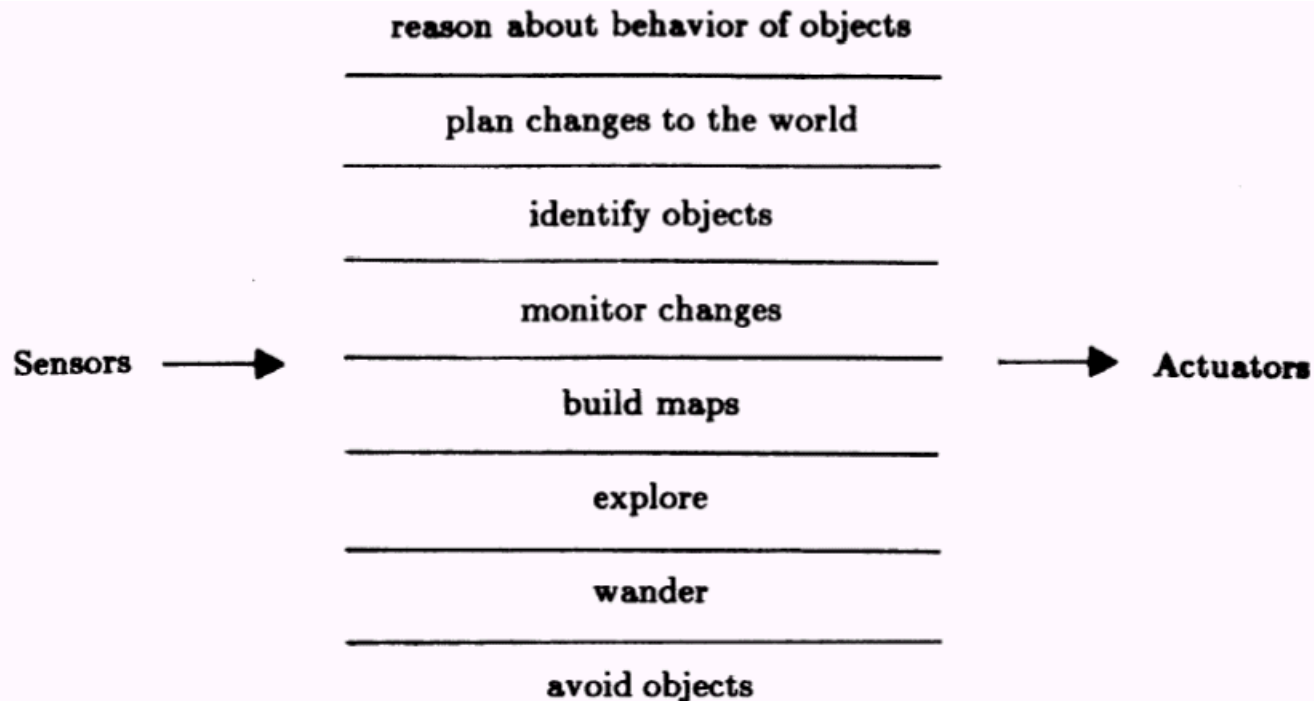
- In a deliberative control architecture the robot first plans a solution for the task by reasoning about the outcome of its actions and then executes it



- control process goes through a sequence of sensing, model update, and planning steps

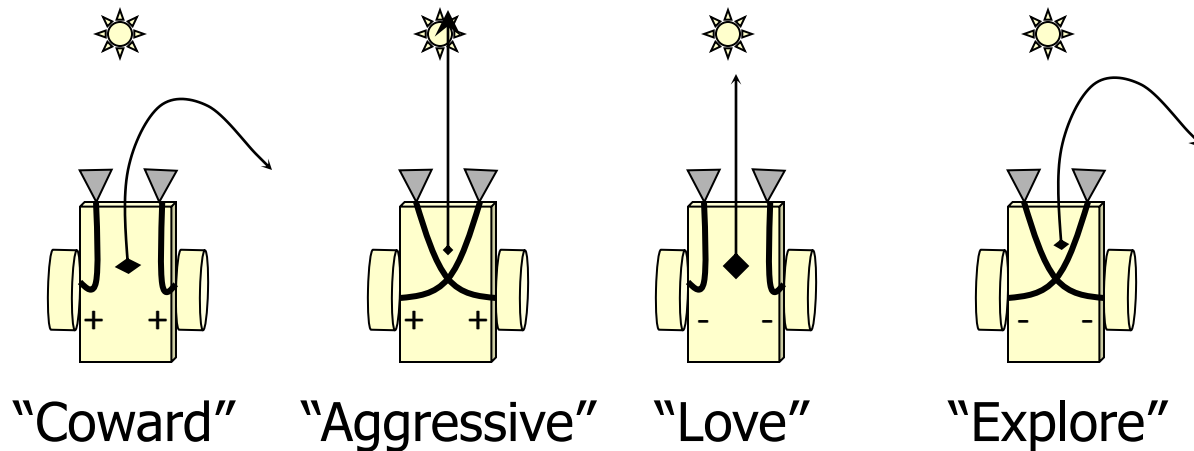
Behavior-Based Robot Control Architectures

- In a behavior-based control architecture the robot's actions are determined by a set of parallel, reactive behaviors which map sensory input and state to actions.



Complex Behavior from Simple Elements: Braitenberg Vehicles

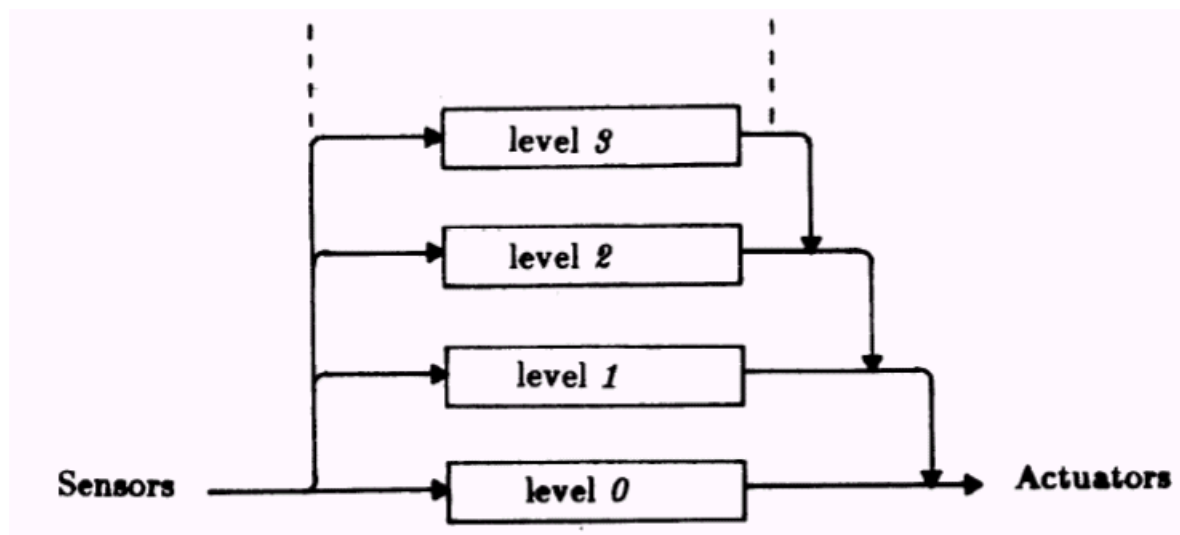
- Complex behavior can be achieved using very simple control mechanisms
 - Braitenberg vehicles: differential drive mobile robots with two light sensors



- Complex external behavior does not necessarily require a complex reasoning mechanism

Behavior-Based Architectures: Subsumption Example

- Subsumption architecture is one of the earliest behavior-based architectures
 - Behaviors are arranged in a strict priority order where higher priority behaviors subsume lower priority ones as long as they are not inhibited.



Subsumption Example

- A variety of tasks can be robustly performed from a small number of behavioral elements

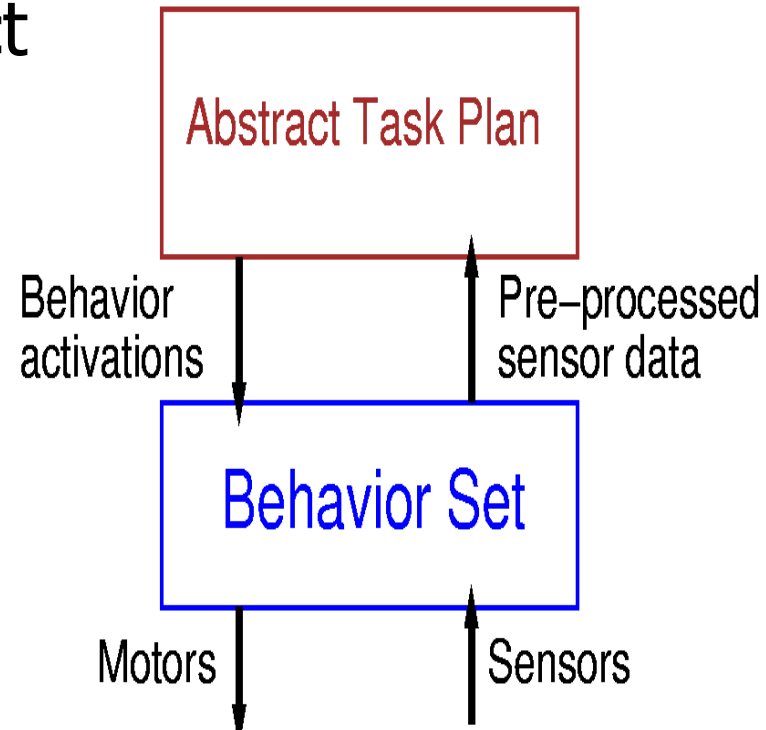


Reactive, Behavior-Based Control Architectures

- Advantages
 - Reacts fast to changes
 - Does not rely on accurate models
 - “The world is its own best model”
 - No need for replanning
- Problems
 - Difficult to anticipate what effect combinations of behaviors will have
 - Difficult to construct strategies that will achieve complex, novel tasks
 - Requires redesign of control system for new tasks

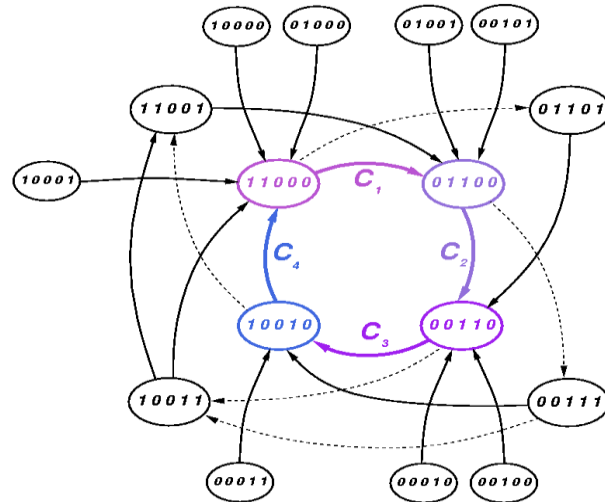
Hybrid Control Architectures

- Hybrid architectures combine reactive control with abstract task planning
 - Abstract task planning layer
 - Deliberative decisions
 - Plans goal directed policies
 - Reactive behavior layer
 - Provides reactive actions
 - Handles sensors and actuators

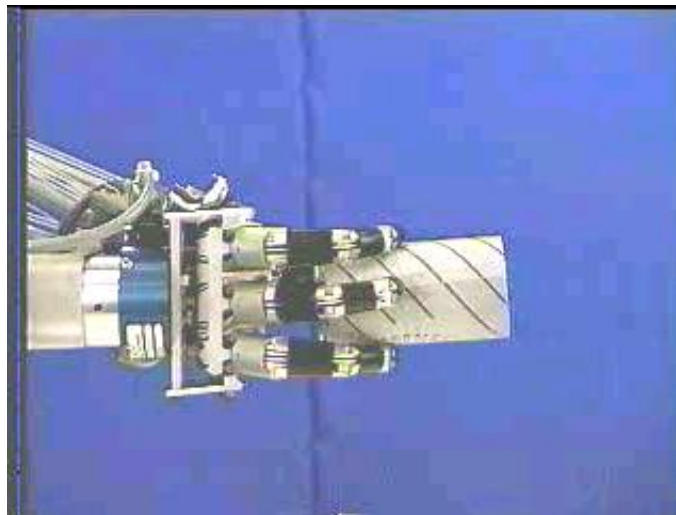


Hybrid Control Policies

Task Plan:



Behavioral
Strategy:



Example Task: Changing a Light Bulb



Traditional Human-Robot Interface: Teleoperation

- Remote Teleoperation: Direct operation of the robot by the user
 - User uses a 3-D joystick or an exoskeleton to drive the robot
 - Simple to install
 - Removes user from dangerous areas
 - Problems:
 - Requires insight into the mechanism
 - Can be exhaustive
 - Easily leads to operation errors



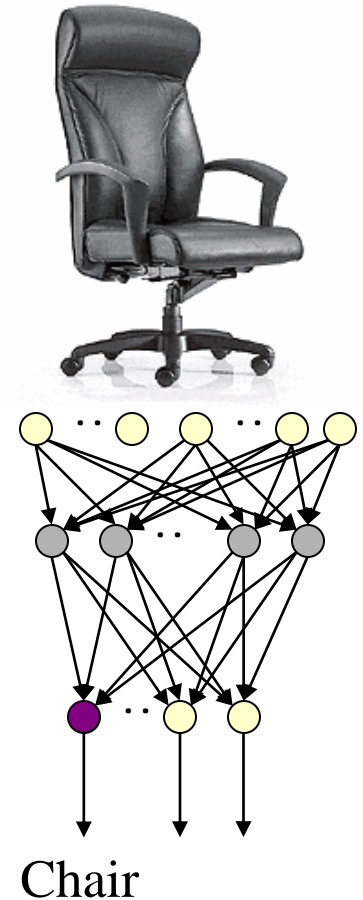
Example: Minerva the Tour Guide Robot (CMU/Bonn)



Learning Sensory Patterns

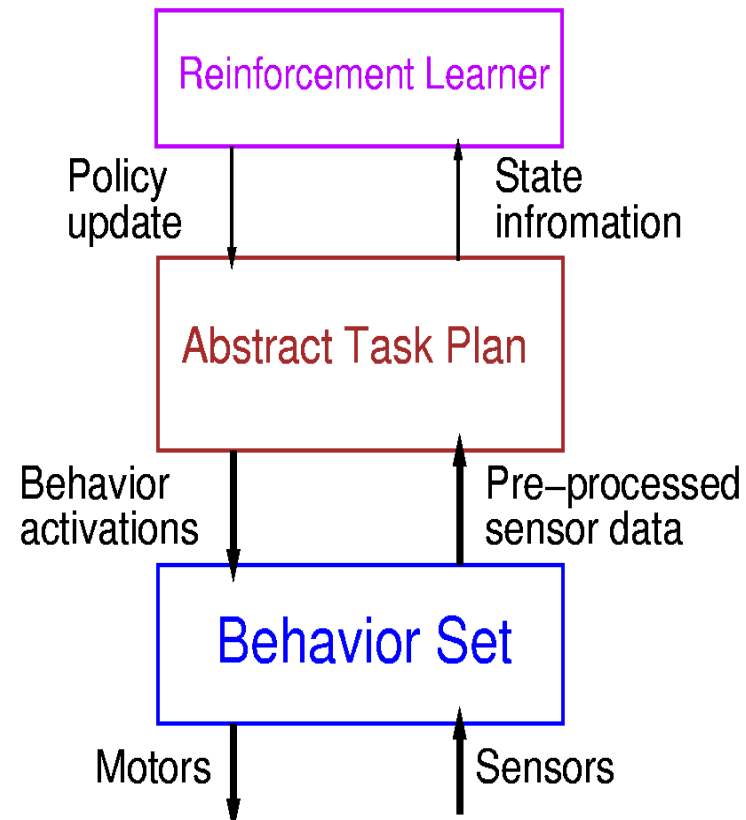
■ Learning to Identify Objects

- How can a particular object be recognized ?
 - Programming recognition strategies is difficult because we do not fully understand how we perform recognition
 - Learning techniques permit the robot system to form its own recognition strategy
- Supervised learning can be used by giving the robot a set of pictures and the corresponding classification
 - Neural networks
 - Decision trees

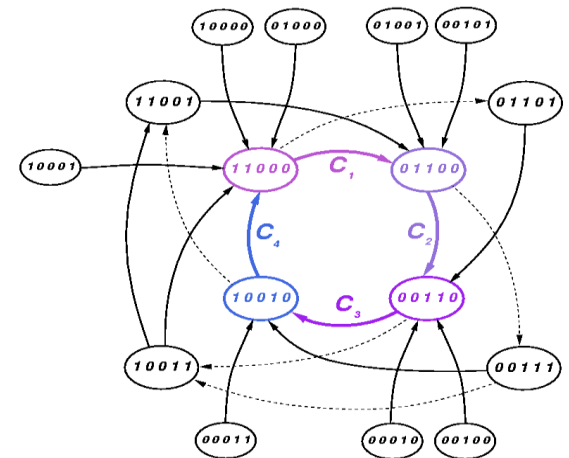
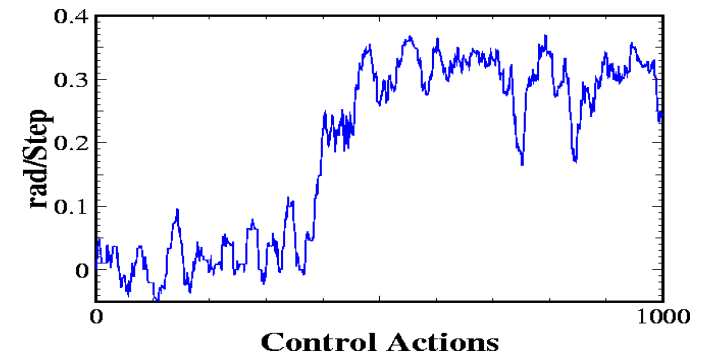
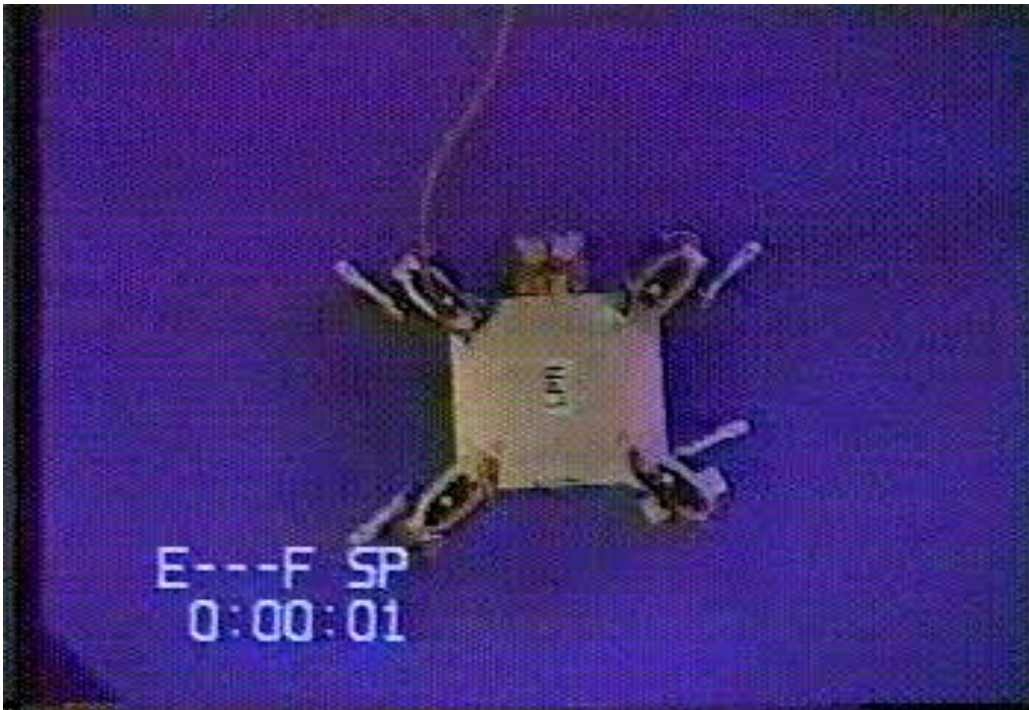


Example: Reinforcement Learning in a Hybrid Architecture

- Policy Acquisition Layer
 - Learning tasks without supervision
- Abstract Plan Layer
 - Learning a system model
 - Basic state space compression
- Reactive Behavior Layer
 - Initial competence and reactivity



Example Task: Learning to Walk



Example: Learning to Walk



Conclusions

- Robots are an important component in Intelligent Environments
 - Automate devices
 - Provide physical services
- Robot Systems in these environments need particular capabilities
 - Autonomous control systems
 - Simple and natural human-robot interface
 - Adaptive and learning capabilities
 - Robots have to maintain safety during operation
- While a number of techniques to address these requirements exist, no functional, satisfactory solutions have yet been developed
 - Only very simple robots for single tasks in intelligent environments exist

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