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Robotics

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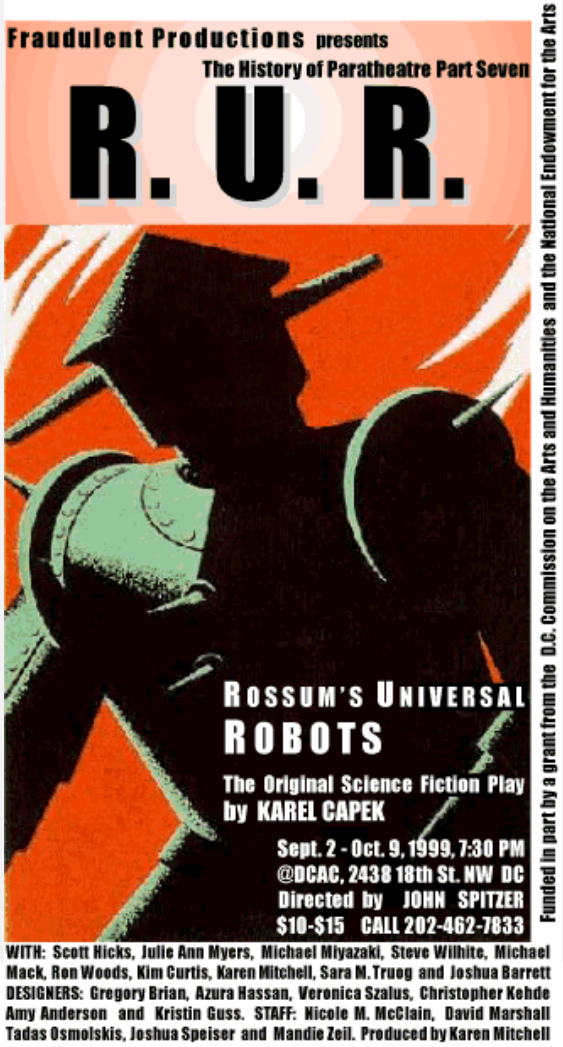
Summary

- What are robots?
- “Embodiment”
- Parts of a robot: Effectors and Sensors
- Control, Kinematics, Inverse Kinematics
- Navigation and Motion Planning
- Programming behaviours in a Robotic Platform
- Architectures
- Applications
- Challenges

What are Robots?

- The word “robot”
  - Rossum’s Universal Robots
    - January 25, 1921
    - First performance of Karel Capek’s play
  - Derived from the Czech word “robota” which means menial laborer
- An Intelligent Robot
  - A mechanical creature which can function autonomously



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What makes Robots different in AI?

- Robots are physical agents that perform tasks by “**manipulating the physical world**”
- **Embodiment**: The fact of having a body, and its associated properties, e.g., sensors and motors (effectors).

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Physical Grounding Hypothesis

- “to build a system that is intelligent it is necessary to have its representations grounded in the physical world” (Brooks, 1999, p. 114).

- *Grounding*: connecting an AI system to the world using a sensory-motor system

Brooks, R. A. (1999). Cambrian Intelligence: The Early History of the New AI. Cambridge, MA: MIT Press.

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Embodiment

- “Searle argued that the main reason for the failure of strong (traditional) AI was that it is concerned with computer programs, but ‘has nothing to tell us about machines’ (Searle, 1980), i.e. physical systems situated in and causally connected to their environments.” (Ziemke, 2001)

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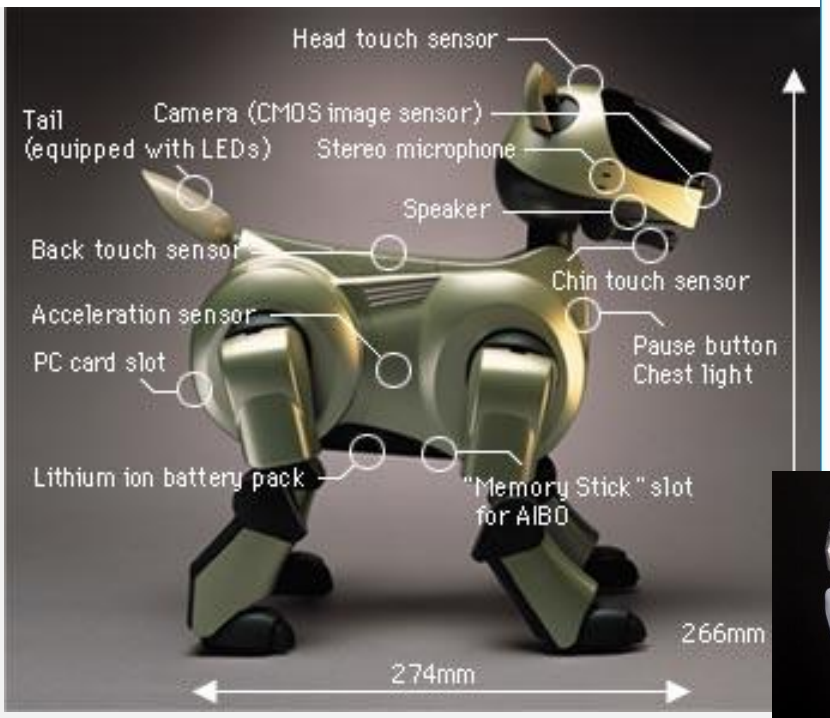
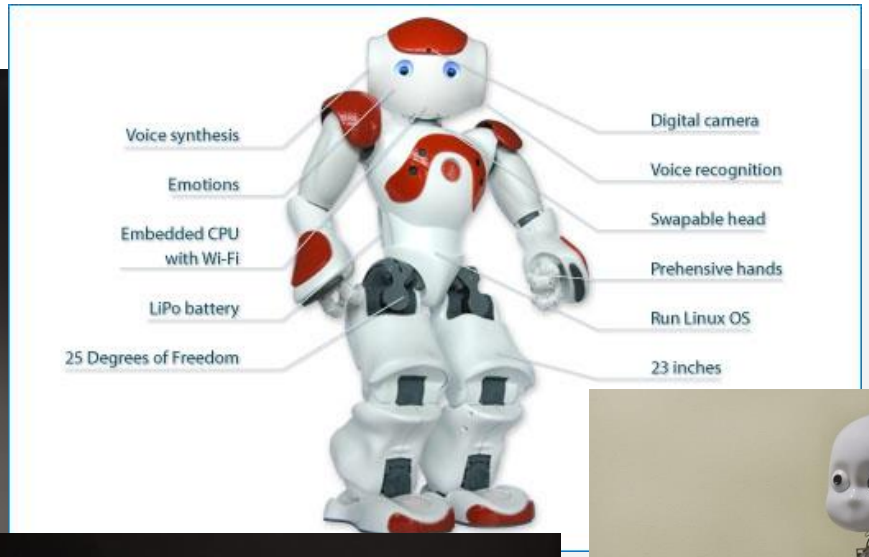
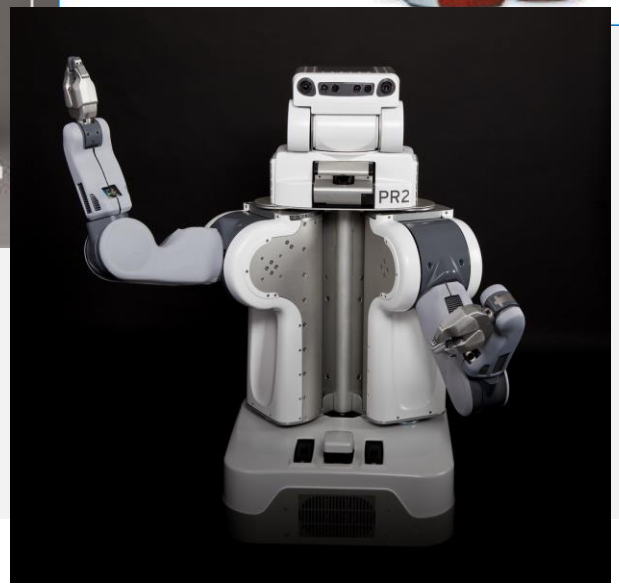
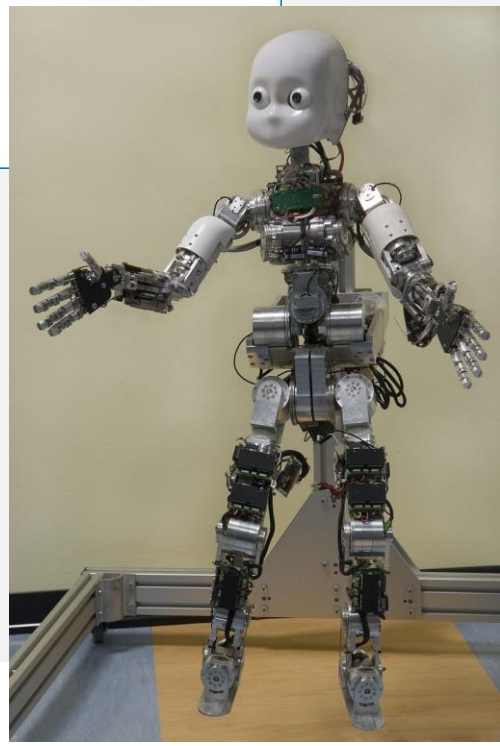
Bodies









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Bodies

- Robots are distinguished by the **effectors** and **sensors** they are equipped with
- Robots have some sort of rigid body, with rigid links that can move about.
- Links meet each other at joints.

- Attached to the links are end effectors…

Categories of robots

- Manipulators, or robot arms that are physically grounded to their workspace (for example in a factory assembly line)
- Mobile Robot- that move around in the environment using wheels, legs, or other similar mechanisms.
- Mobile manipulator (humanoid robots: mimic the human torso)

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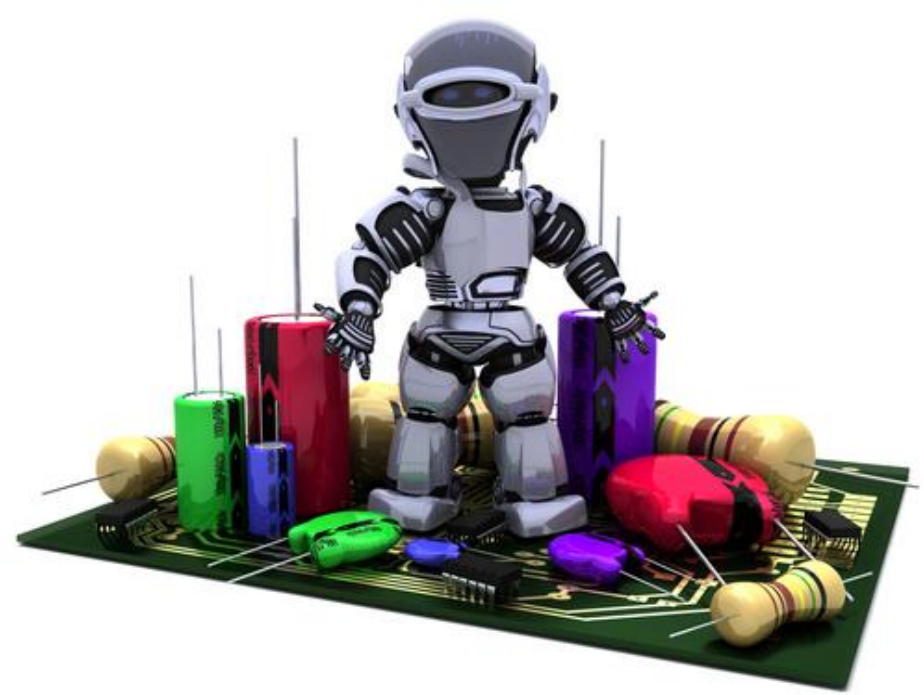
Robot Hardware



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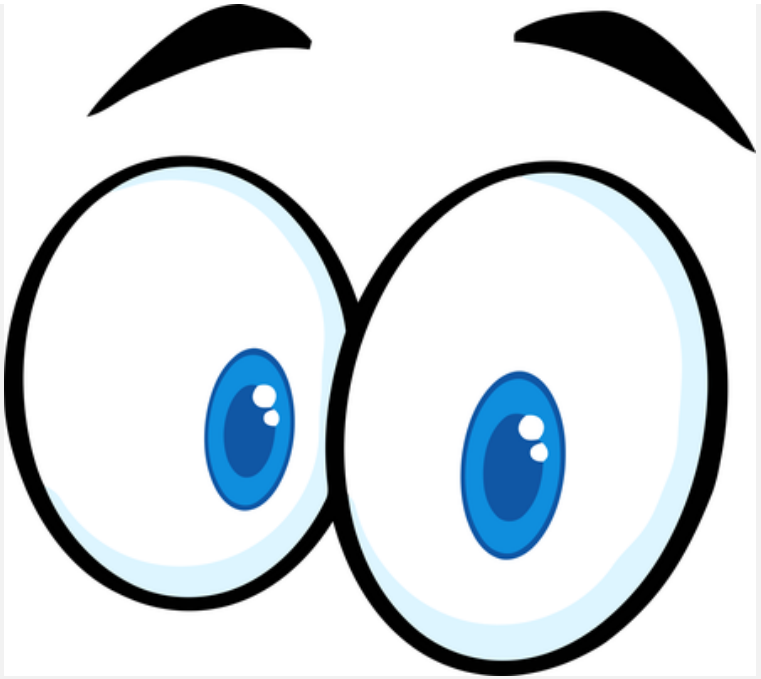
Sensors

- Sensors are the perceptual interface between the robot and the environment
- **Passive sensors** (cameras) capture signals that are generated by other sources in the environment
- **Active Sensors** (eg. Sonar) send energy into the envirommment, and rely on the fact that this energy is reflected back to the sensor



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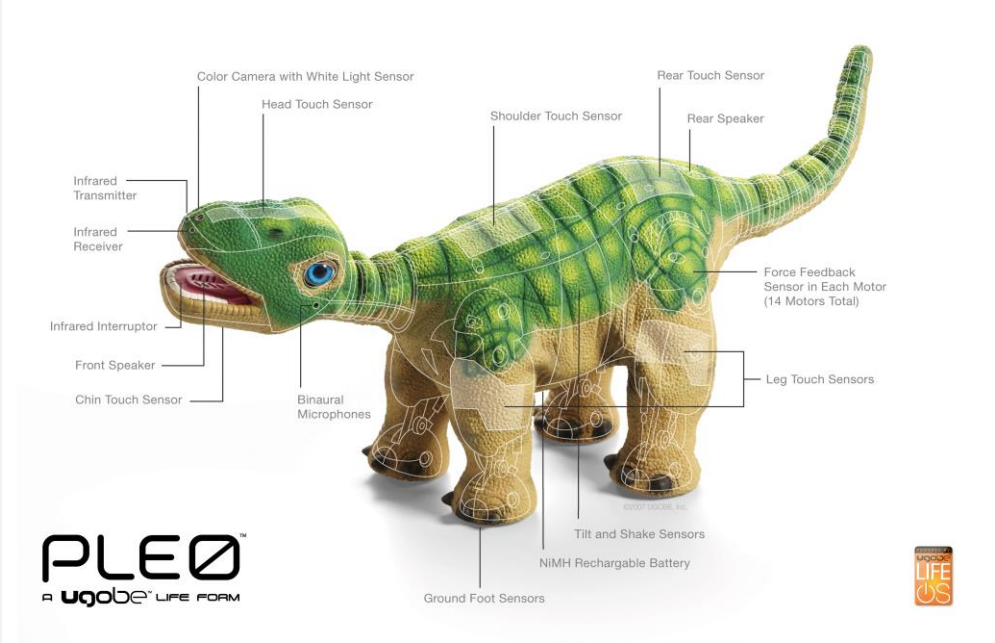
Types of Sensors

- **Range sensors:** measure the distance to nearby objects (eg. Sonar sensors)
- many ground robots use optical rage finders (emit active signals and measure the time until reflection)
- other range sensors include radar
- on the other extreme of range sensing is tactile sensors (whiskers, bumo panel, touch sensitive skin)



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Types of Sensors

- **Location Sensors** use range sensing as a primary component to determine location. Outdoors the Global Posiyioning System (GPS) is the most common solution.
- **Proprioceptive sensors** inform the robot of its own body. To measure the exact configuation of a robotic joint motors are often equiped with shaft decoders that count the revolution of the motors in small increments. Also, other important aspects of the robot state are measured by **force sensors and torque sensors**.

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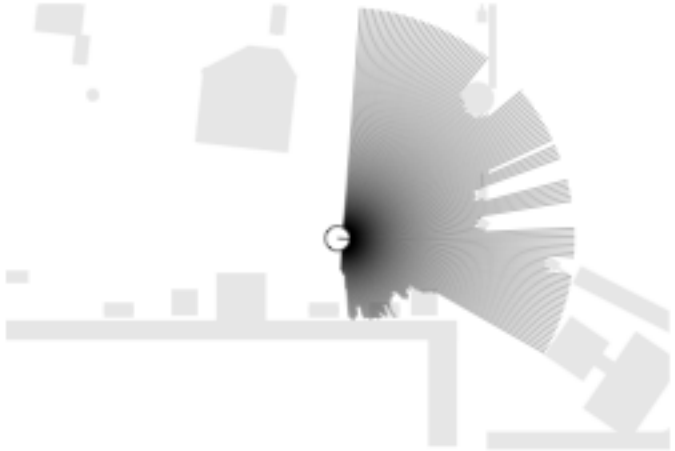
Types of Sensors

Range finders: sonar (land, underwater), laser range finder, radar (aircraft), tactile sensors, GPS



Imaging sensors: cameras (visual, infrared)

Proprioceptive sensors: shaft decoders (joints, wheels), inertial sensors, force sensors, torque sensors

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Use of Kinect

- Kinect sensor is a horizontal bar device featuring an "RGB camera, depth sensor and multi-array microphone running proprietary software”.
- The Kinect provides full-body 3D motion capture, facial recognition and voice recognition capabilities.

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Effectors

- Effectors are the means by which robots move and change the shape of their bodies.

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Effectors

- Robots have a certain number of *degrees of freedom* (DOF)
  - Variability in which they can move
- Each joint is a degree of freedom
  - Typically interested in controllable DOF's

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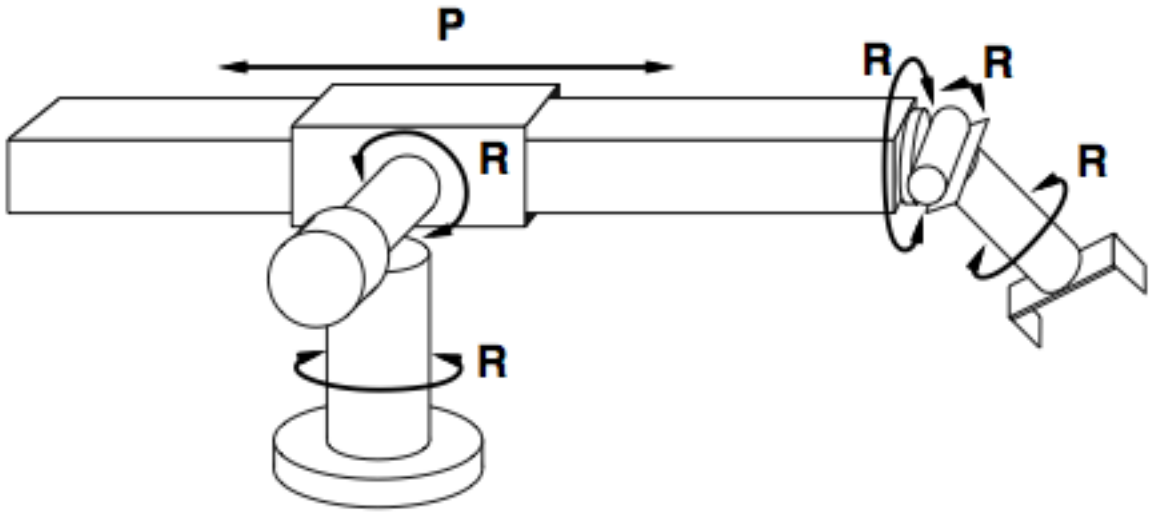
Effectors: manipulators



Configuration of robot specified by 6 numbers

$\Rightarrow$ 6 degrees of freedom (DOF)

6 is the minimum number required to position end-effector arbitrarily.
For dynamical systems, add velocity for each DOF.

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Effectors

- **Six DOF needed to place an object at a particular place in a particular orientation**
  - Need to specify (x, y, z) and pan, tilt, yaw
- End-effector
  - Handles objects, makes connections to other machines
- Actuator
  - “muscles” of the manipulator, e.g., servomotors, stepper motor, hydraulics, pneumatics

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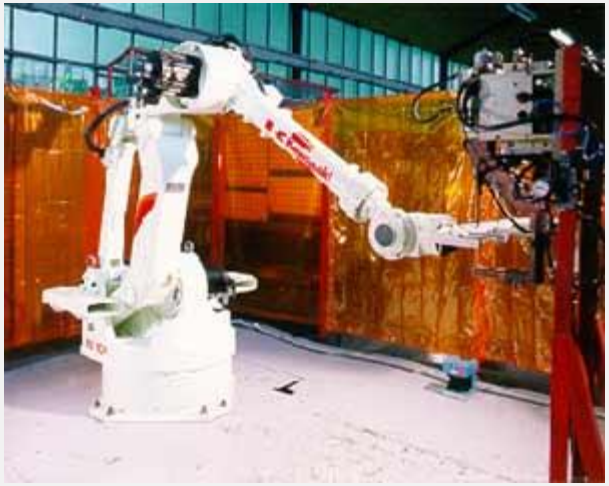
Role of effectors

- Effectors are used in different ways:
  - **Locomotion**: to change the position of the robot in the environment
  - **Manipulation**: to interact and move objects in the environment
  - **Communication**: to communicate with people in the world



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Control: Open-loop vs. Closed-loop

- Open-loop
  - Robot is controlled according to joint positions
  - No feedback from joints or position of end-effector to tell the controller the current position or velocity
  - Some issues:
    - A) May only know position of robot at start and end of motion (see Rehg, 1985, p. 47-48)
    - B) Mechanical issues such as deflection of parts may mean that desired goal is not reached
- Closed-loop
  - Feedback from joints or positions are used to assist the control of the robot

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Limits of Feedback

- For some high-speed operation, either very fast feedback may be required or control must be open-loop, at least in part
- May not be able to wait until feedback provides confirmation if the robot part must be moved very quickly
- E.g., playing a piano, hitting a baseball, typing at a keyboard, or other highly skilled activity

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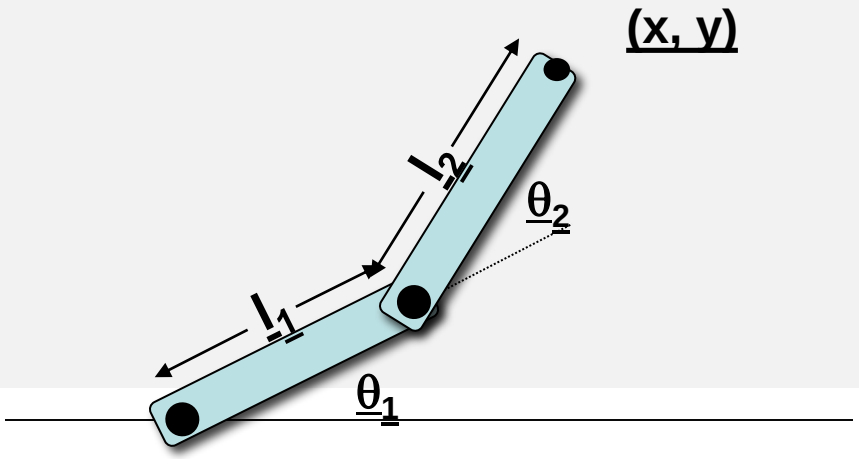
Kinematics

- Kinematics= the study of motion
  - The *kinematic state* of a robot is the position of each of its joints
- Forward kinematics
  - Calculate where the robot end effector (e.g., hand) will be if all joint variables are known
  - E.g., (x, y, z) coordinate of end effector
- Inverse kinematics
  - Calculate joint variables if we want the end effector to be located at a particular place, e.g., (x, y, z) coordinate
  - This is an important means used to control robots to achieve particular goals

Forward Kinematics Example

- Forward kinematic equations may be derived, and then solved for position, e.g., (x, y, z), (inverse taken) to generate inverse kinematic equations
- Example robot structure

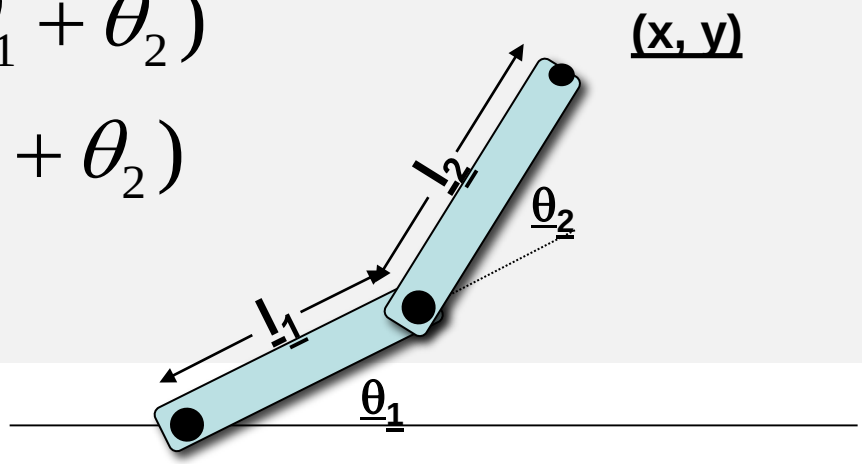


Forward Kinematics - 2

- Equations giving (x, y), i.e., position of the end of robot arm, in terms of the two joint angles, Θ_1, Θ_2, are forward kinematic equations

$$x = l_1 \cos\theta_1 + l_2 \cos(\theta_1 + \theta_2)$$

$$y = l_1 \sin\theta_1 + l_2 \sin(\theta_1 + \theta_2)$$



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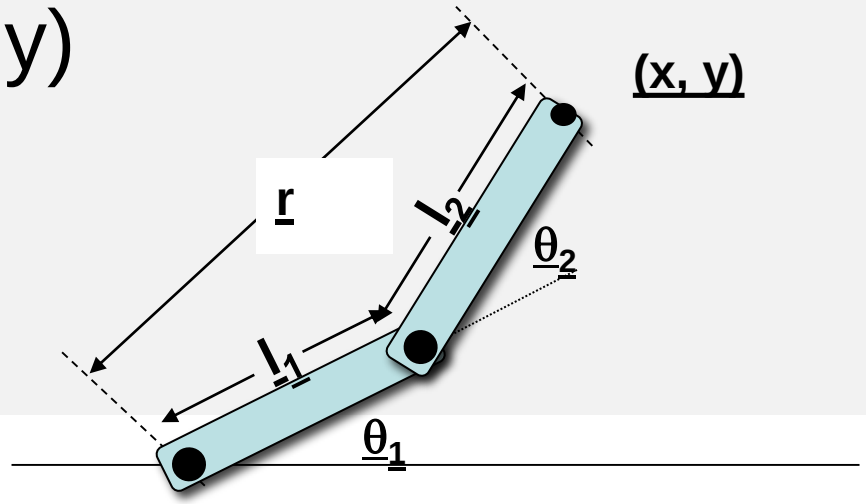
But…

- These equations don’t help us control the robot, if we want the robot end effector to achieve particular locations

Inverse Kinematics

- Solving these equations so that we compute the joint angles given the (x, y) coordinates gives us the inverse kinematic equations for this robot
- First, let r be the distance between the first joint and (x, y)
- Note that

$$r = \sqrt{x^2 + y^2}$$



Inverse Kinematics - 2

- Then, the forward kinematic equations

$$x = l_1 \cos\theta_1 + l_2 \cos(\theta_1 + \theta_2)$$

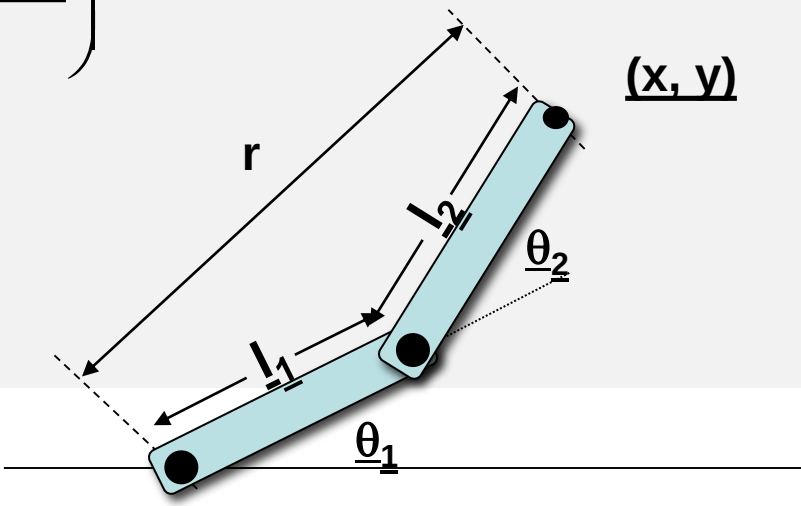
$$y = l_1 \sin\theta_1 + l_2 \sin(\theta_1 + \theta_2)$$

- can be solved to obtain

$$\theta_2 = \pi \pm \alpha \qquad \alpha = \cos^{-1}\left(\frac{l_1^2 + l_2^2 - r^2}{2 l_1 l_2}\right)$$

$$\theta_1 = \text{atan2}(y, x) \pm \beta$$

$$\beta = \cos^{-1}\left(\frac{r^2 + l_1^2 + l_2^2}{2 l_1 r}\right)$$



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Some Features of Inverse Kinematics

- There may be zero, one or many solutions depending on the desired end effector location
- If the (x, y) point cannot be reached, there will be no solution
- Multiple solutions occur when multiple joint configurations can be used to reach the desired position

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Using Inverse Kinematics

- Inverse kinematics results in final positioning
  - does not necessarily result in movement along a predictable path
- E.g., if end-effector of robot is at point A, and you command a change to point B using inverse kinematics to determine the new joint angles, the end-effector will not necessarily move in a straight line between points A & B
- A strategy to have end-effector move in a straight line between two points, is to move the end effector in a series of small steps, along that straight line, and hence recalculate joint angles for each step

pp. 80-81, Niku (2001)

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Hard Problems

- Localization
- Mapping
- Manipulation
- Learning

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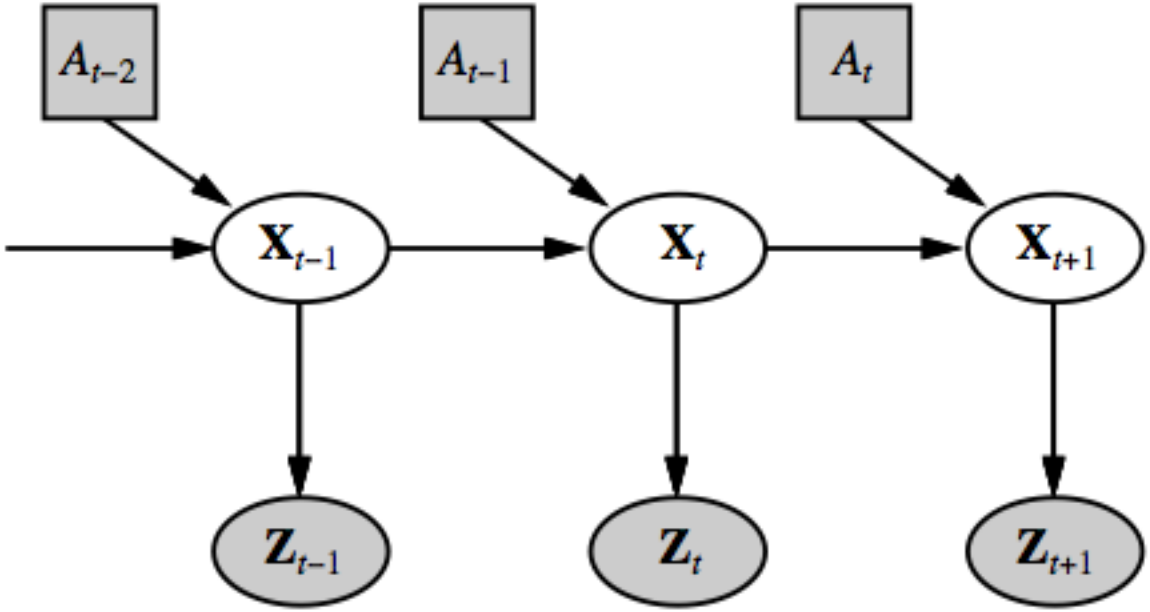
Localization: Where Am I?

Compute current location and orientation (pose) given observations:



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Mapping

Localization: given map and observed landmarks, update pose distribution

Mapping: given pose and observed landmarks, update map distribution

SLAM: given observed landmarks, update pose and map distribution

Probabilistic formulation of SLAM:

add landmark locations $L_1, \ldots, L_k$ to the state vector,
proceed as for localization

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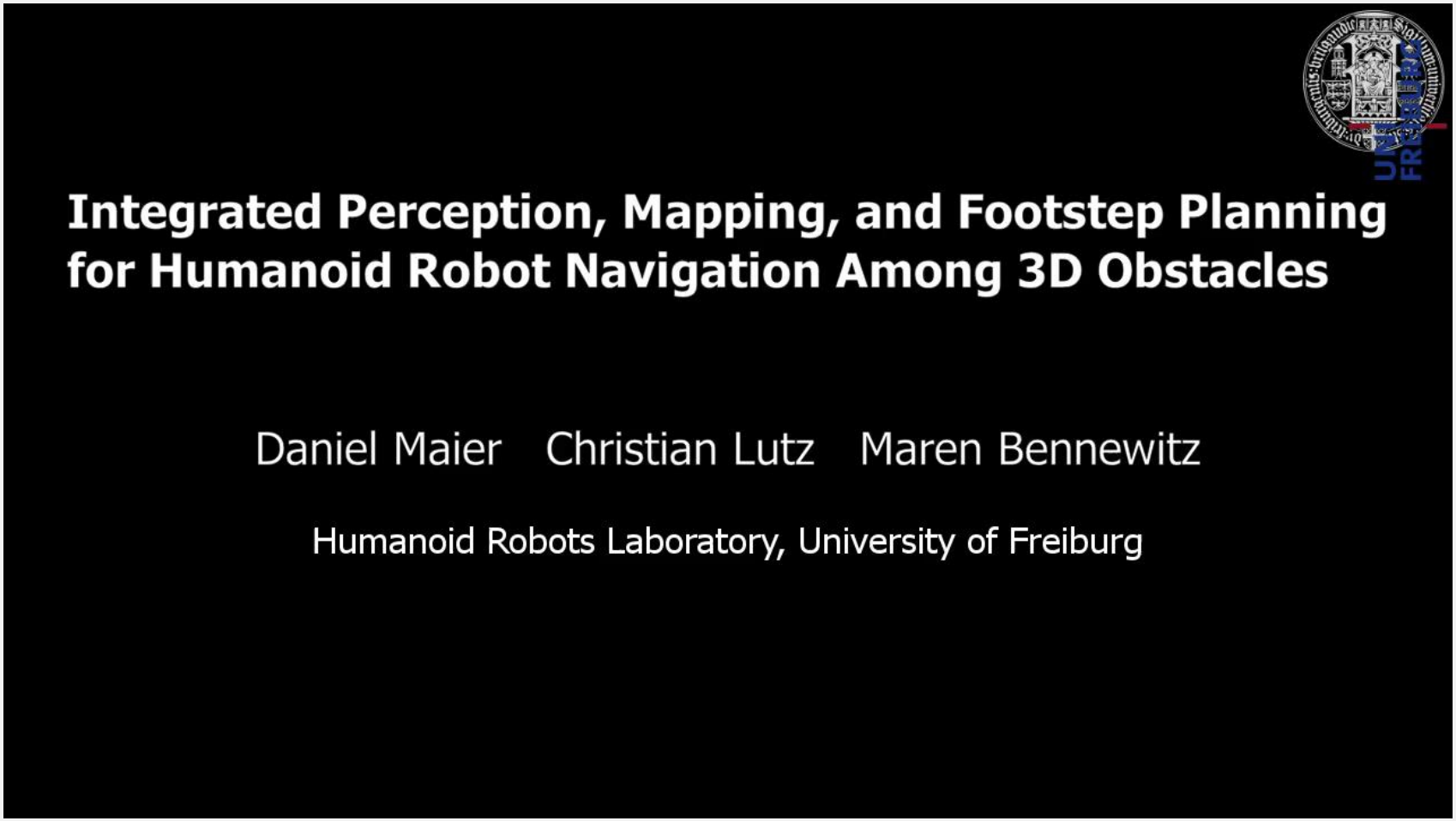

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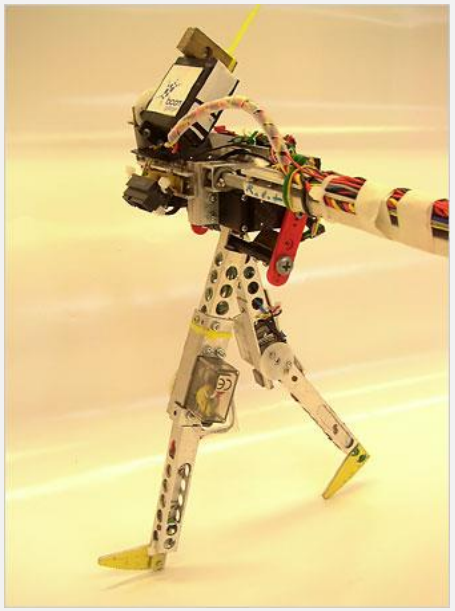
Legged Locomotion

- Advantages
  - Moving through rugged terrain
  - Low power consumption
- Examples
  - Hexapod
  - One-, two-, four-legged
- Major issues
  - Maintaining balance
  - Getting up / sitting down
  - Dynamically adapting the gaits to terrain



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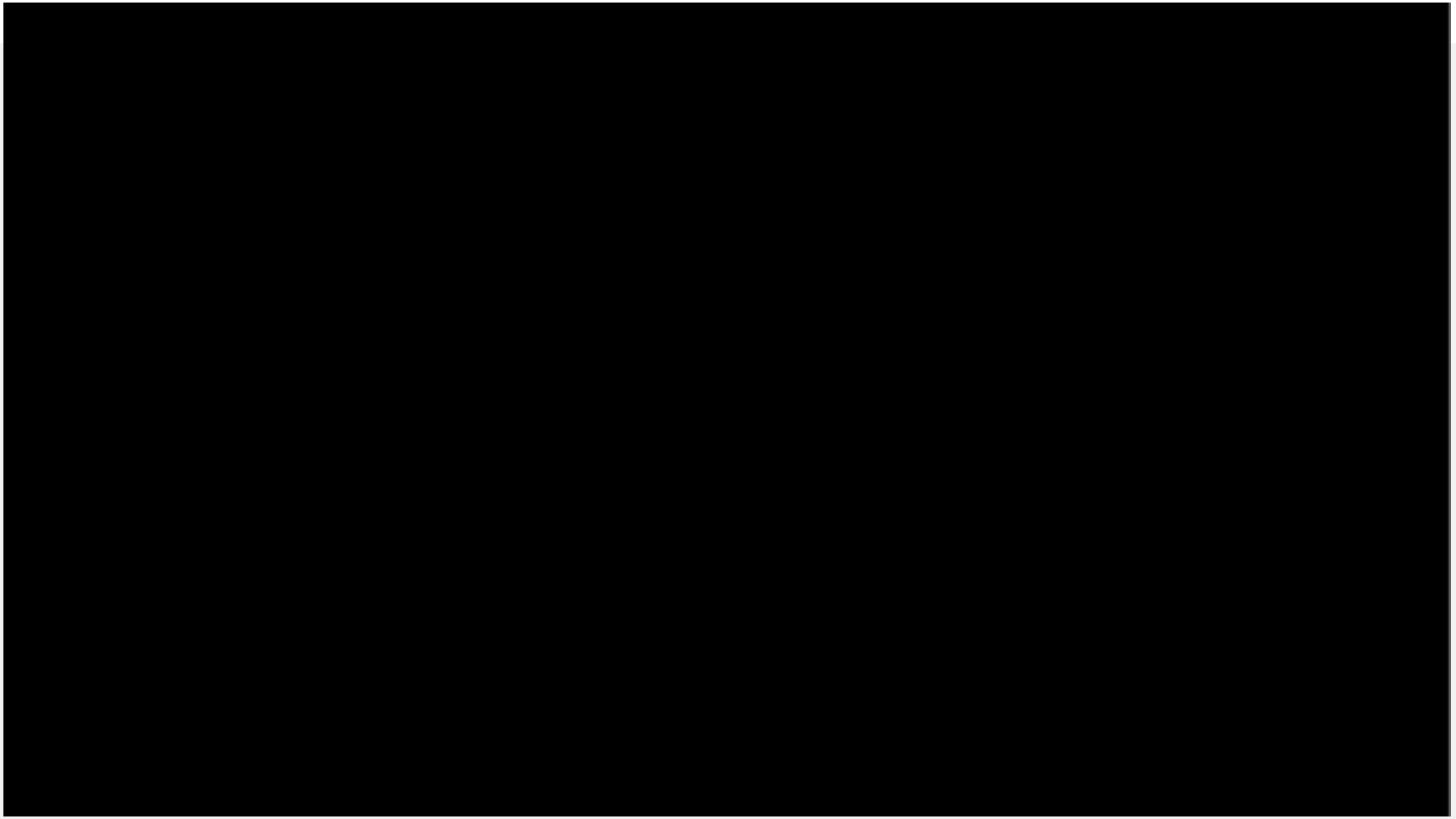
From walking to running



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Learning how to walk

Linking Sensing to Acting: Three robotic Paradigms

- Hierarchical paradigm
- Reactive paradigm
- Hybrid deliberative/reactive paradigm

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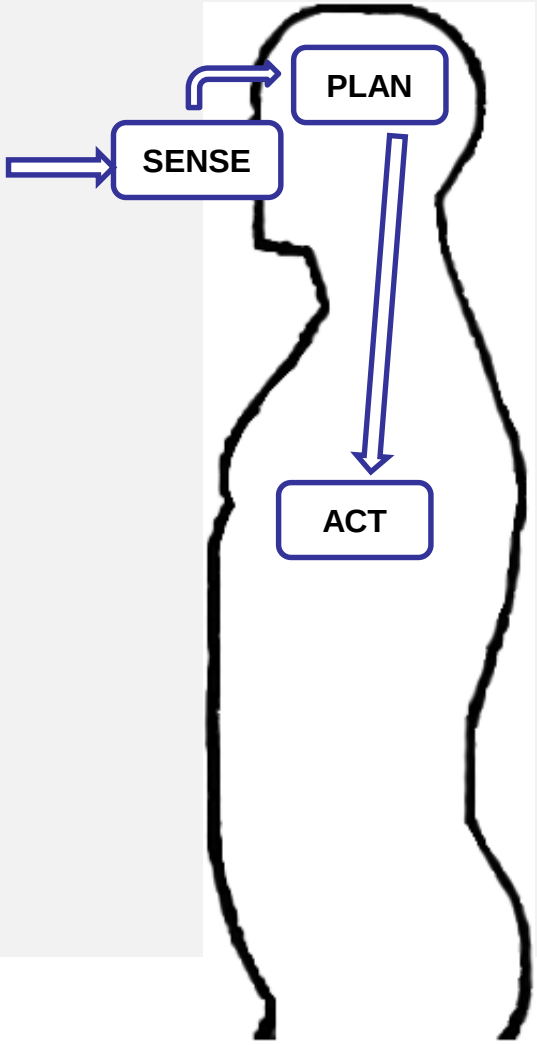
Robotic Paradigms

- The paradigms can be described in two ways
  - By the relationship between the three commonly accepted primitives
  - By the way sensory data is processed and distributed through the system.

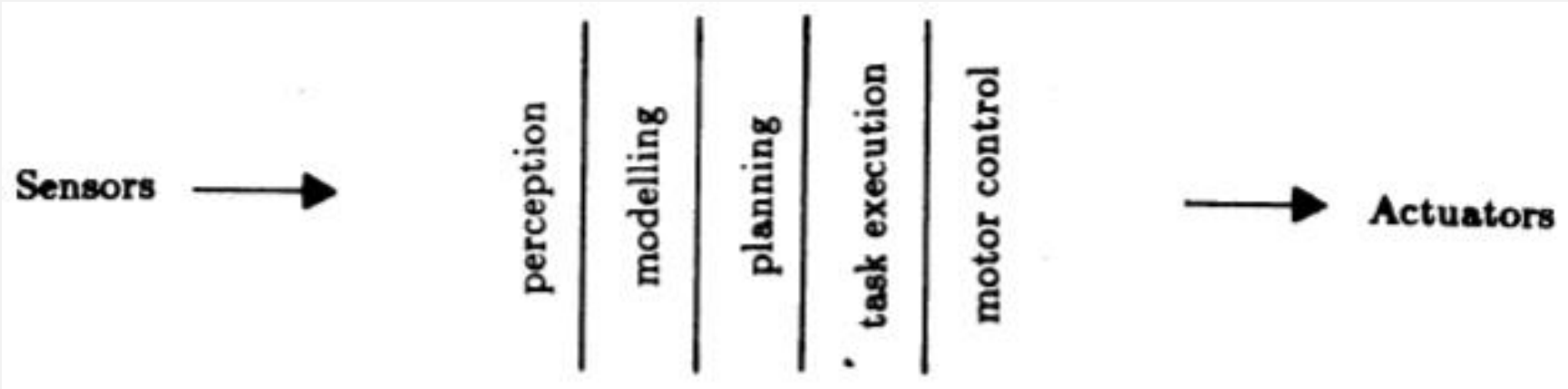
ROBOT PRIMITIVES	INPUT	OUTPUT
SENSE	Sensor data	Sensed information
PLAN	Information (sensed and/or cognitive)	Directives
ACT	Sensed information or directives	Actuator commands

Hierarchical Paradigm



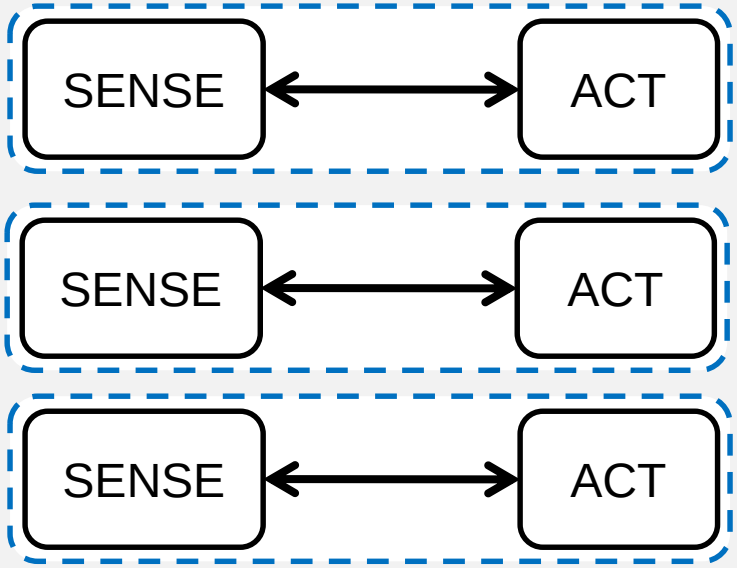
- The oldest paradigm (1967-1990)
  - Top-down fashioned operation
  - Heavy on planning
- Control people hated because it isn't "close the loop"
- AI people hated because monolithic
- Users hated because very slow

A Traditional Decomposition of a Mobile Robot Control System into Functional Modules



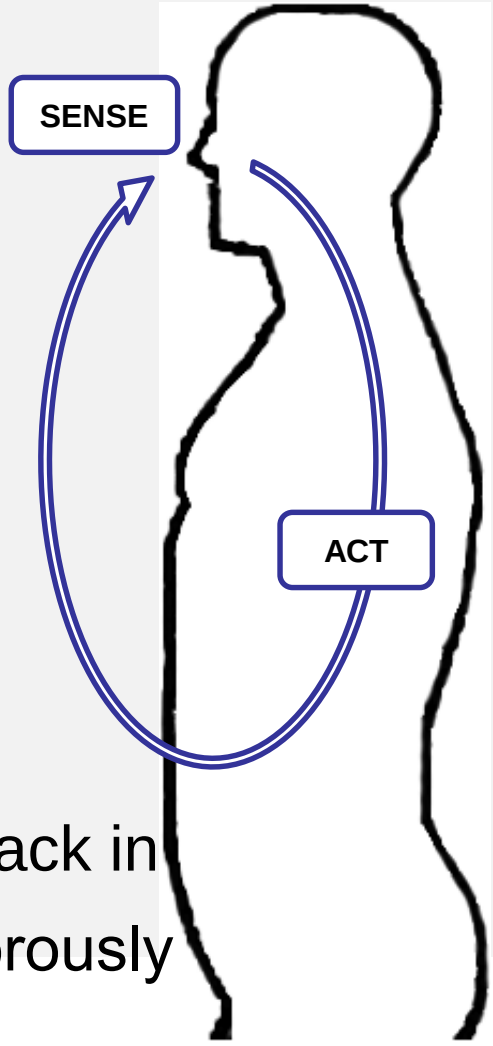
From Brooks, “A Robust Layered Control System for a Mobile Robot”, 1985

Brooks revolution: Reactive Paradigm



SENSE-ACT couplings are "behaviors"

Behaviors are independent, run in parallel



- Heavily used in 1988-1992
- Users loved it because it worked
- AI people loved it, but wanted to put PLAN back in
- Control people hated it because couldn't rigorously prove it worked

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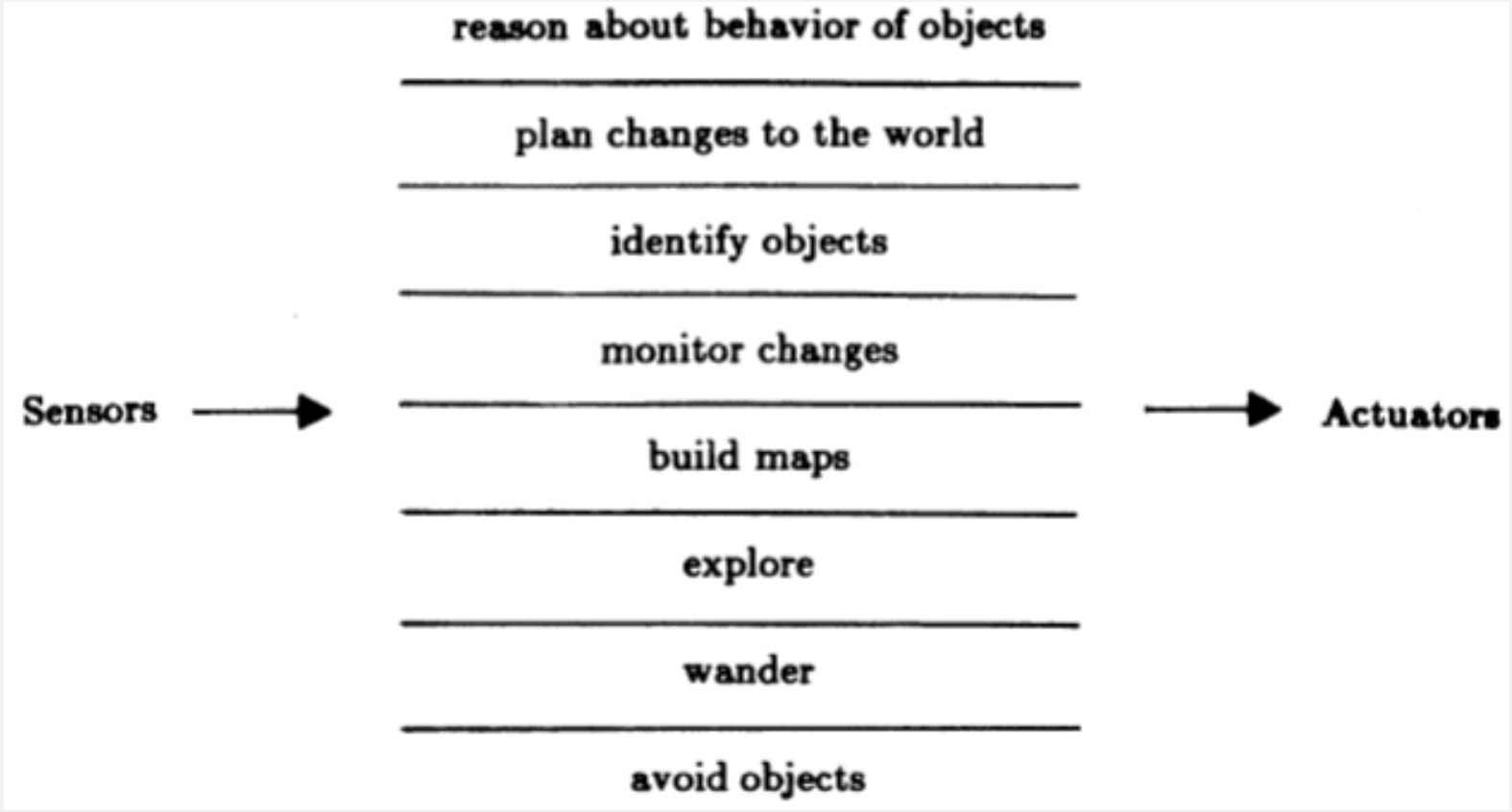
Brooks Revolution: Subsumption Architecture

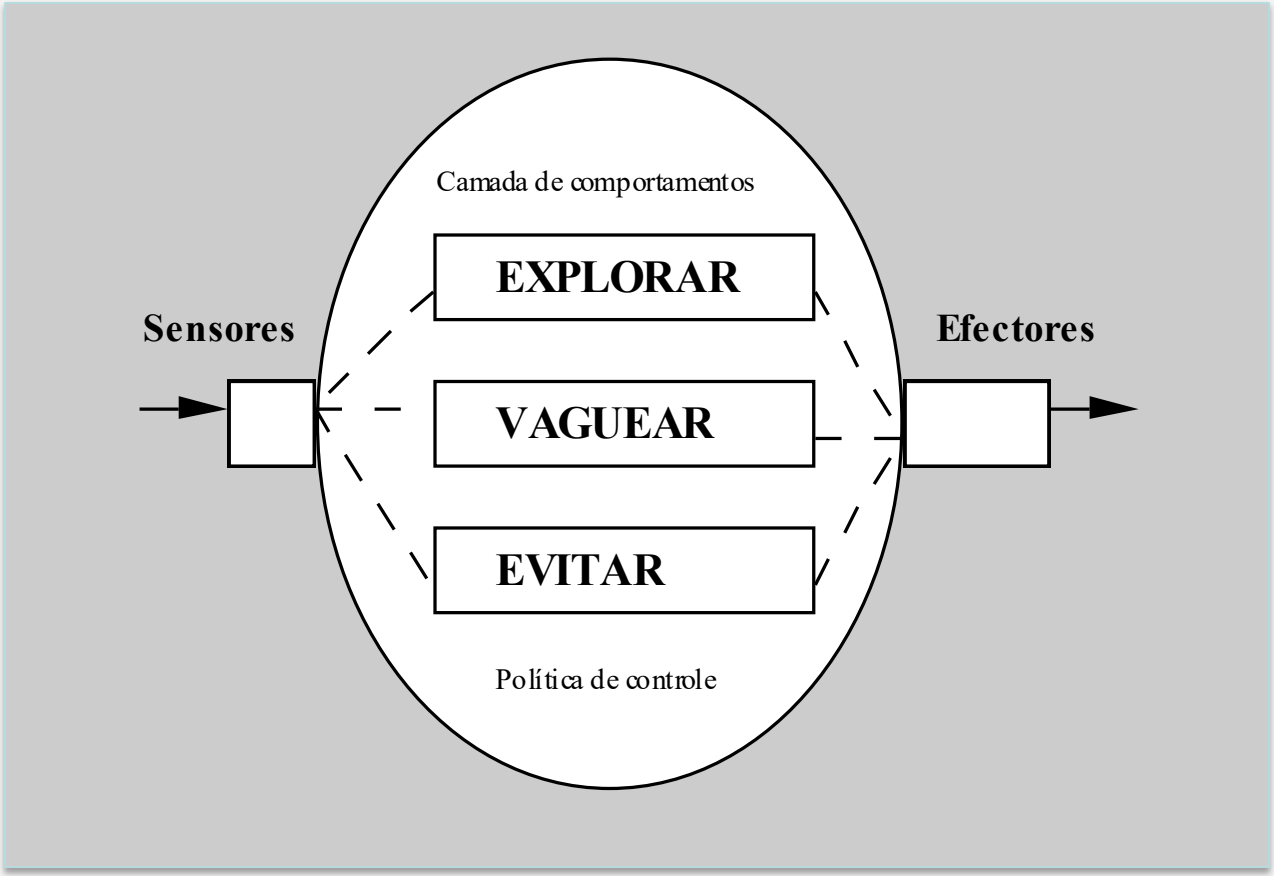
- A subsumption architecture is a hierarchy of task-accomplishing *behaviors*
- Each behavior is a rather simple rule-like structure
- Each behavior ‘competes’ with others to exercise control over the agent
- Lower layers represent more primitive kinds of behavior (such as avoiding obstacles), and have precedence over layers further up the hierarchy
- The resulting systems are, in terms of the amount of computation they do, *extremely* simple
- Some of the robots do tasks that would be impressive if they were accomplished by symbolic AI systems

A Decomposition of a Mobile Robot Control System Based on Task Achieving Behaviors



From Brooks, “A Robust Layered Control System for a Mobile Robot”, 1985

Layered Control in the Subsumption Architecture



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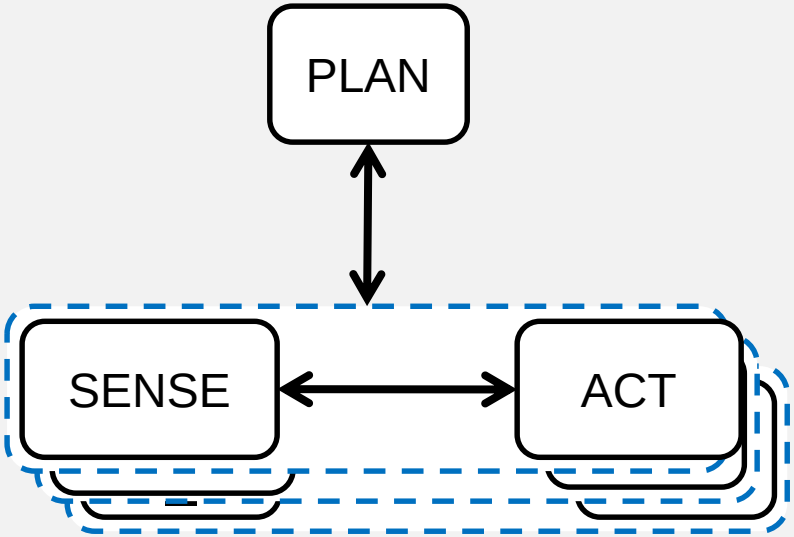
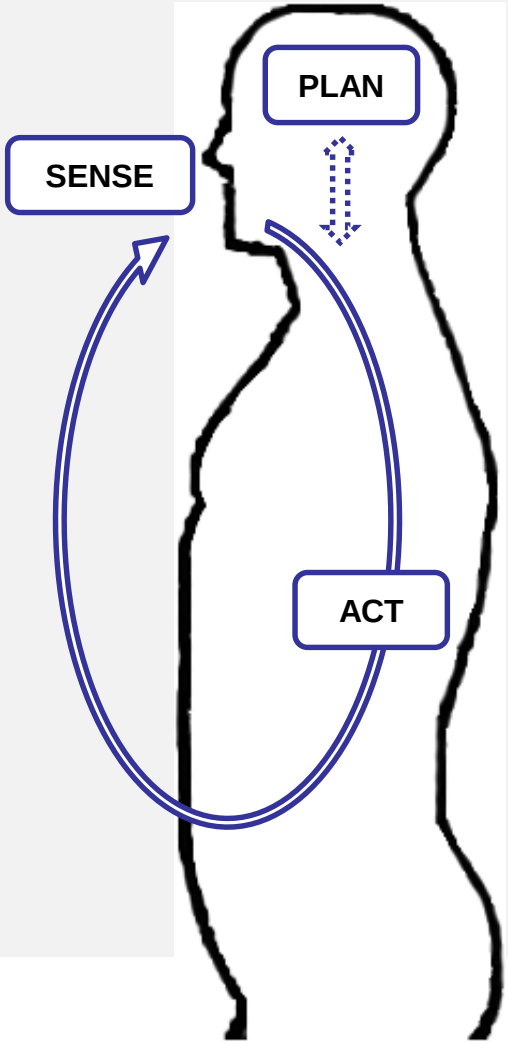
The development process using Brooks architecture

1. Create a module for one particular task. This module should link perception and action and should work by itself.
2. The, add in more modules, each one of them also linking perception and action. Every time one module is added the priorities for the behaviours need to be re-adjusted.

Hybrid deliberative/reactive paradigm





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Stanley

- Volkswagen Touared R5 (4WD)

Stanley: Guiding principles

Treat autonomous navigation as a software problem

Stanley Sensory Equipment

- Environment Perception: roof rack that houses (environment sensor group):
  - 5 SICK laser range finders
  - A color camera for long rage perception
  - 2 RADAR sensors
  - Two antennae
  - Plus, 2 additional antennae (one for GPS and one for GPS compass) and a radio antennae

Stanley control

- Three main actuators:
  - Brakes
  - Throttle
  - Steering

Stanley: a layered architecture

- Sensor interface layer- this layer is responsible for receiving and time-stamping all the data (also contains the database server with the course coordinates in RDDF)
- Perception layer- maps sensor data into internal models. The internal models include information about the environment and information about the vehicle's own state (with 15 variables, such as position, orientation, velocity)

Stanley: a layered architecture

- Planning and Control Layer- responsible for regulating the steering, throttle and brake. A key module here is the path planner, which sets the trajectory of the vehicle.
  - The trajectory created is passed to two controllers: one for the steering and the other for the throttle and brake.
- Vehicle Interface Layer- responsible for interfacing with the concrete actuators.

Stanley: a layered architecture

- The User Interface Layer- comprises the remote E-stop and a touch screen for starting up the software.
- The Global Services Layer- provides services to be used by all the modules.

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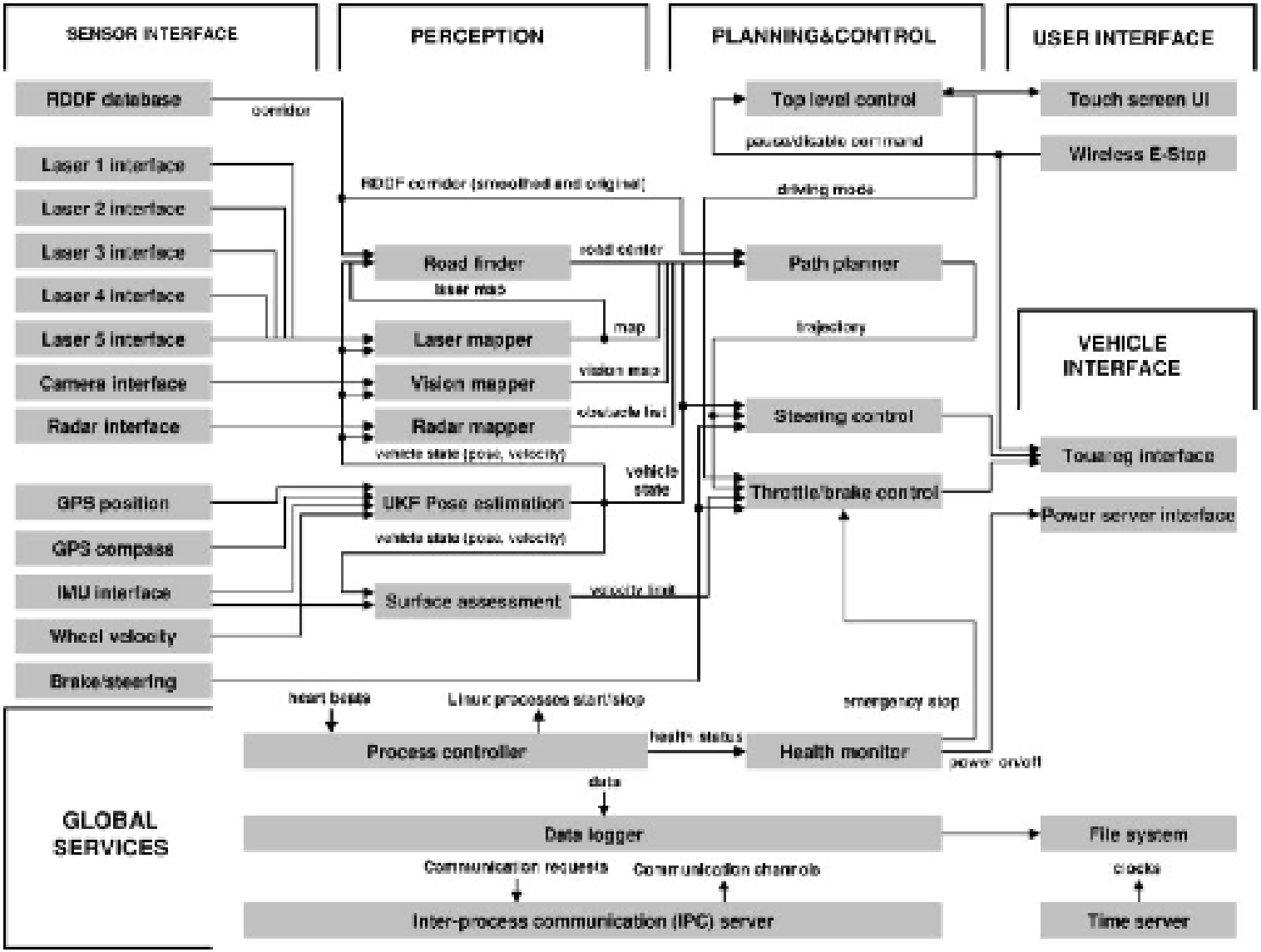
Stanley



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Stanley

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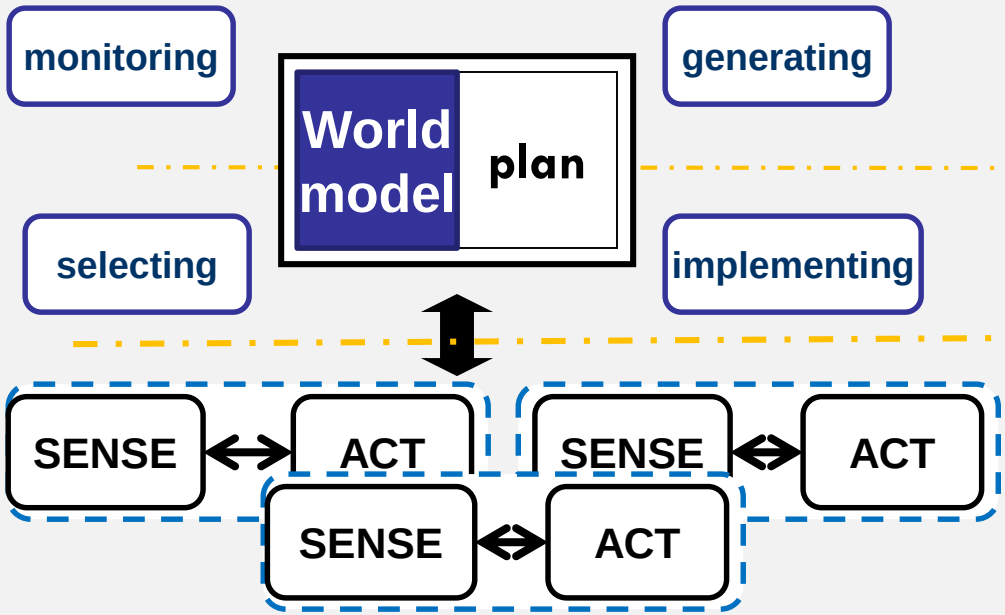
DARPA Grand Challenge

How AI related to a robot system?



Deliberative:

- Upper level is *mission generation* & *monitoring*
  - But World Modeling & Monitoring is hard
- Lower level is *selection* of behaviors to accomplish task (*implementation*) & local monitoring

Reactive (fly by wire, inner loop control):

- Many concurrent stimulus-response behaviors, strung together with simple scripting
- Action is generated by sensed or internal stimulus
- No awareness, no monitoring
- Models are of the vehicle, not the "larger" world

Current Challenge: RoboCup

- **RoboCup** is an international robotics competition

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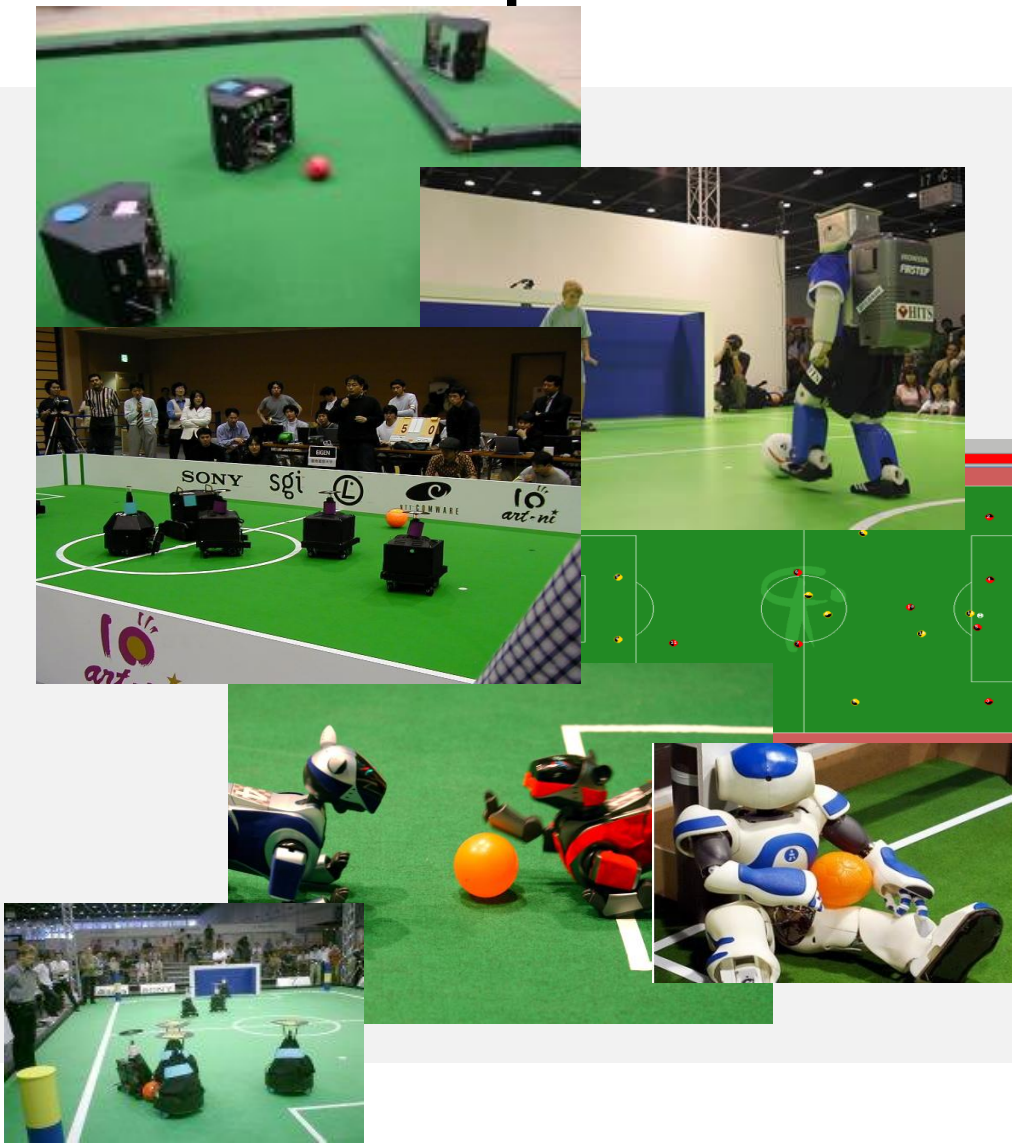
What is RoboCup?!

- Started in 1992 as the Robot J-League (Japan)
- First games and conferences in 1997
- Workshops, conferences and yearly competitions
- Slogan of games:

> *"By the year 2050, a team of fully autonomous humanoid robots that can win against the human world soccer champion team (FIFA winner)."*

The Different Competitions

- RoboCup Soccer
  - Small size
  - Middle size
  - Standard Platform
  - Humanoid
  - Simulation
- RoboCup Rescue
- RoboCup@Home
- RoboCup Junior
  - Soccer Challenge
  - Dance Challenge
  - Rescue Challenge
  - Genereal



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The Goal of Robocup?

- RoboCup envisions a set of longer range challenges over next few decades
- A standard problem for research in:
  - Artificial Intelligence and Machine Learning
  - Machine Vision and Image Processing
  - Natural Language Processing
  - Multi-Agent Team Planning
  - And different challenges in Control and Electronics and Computer Science…

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Small size

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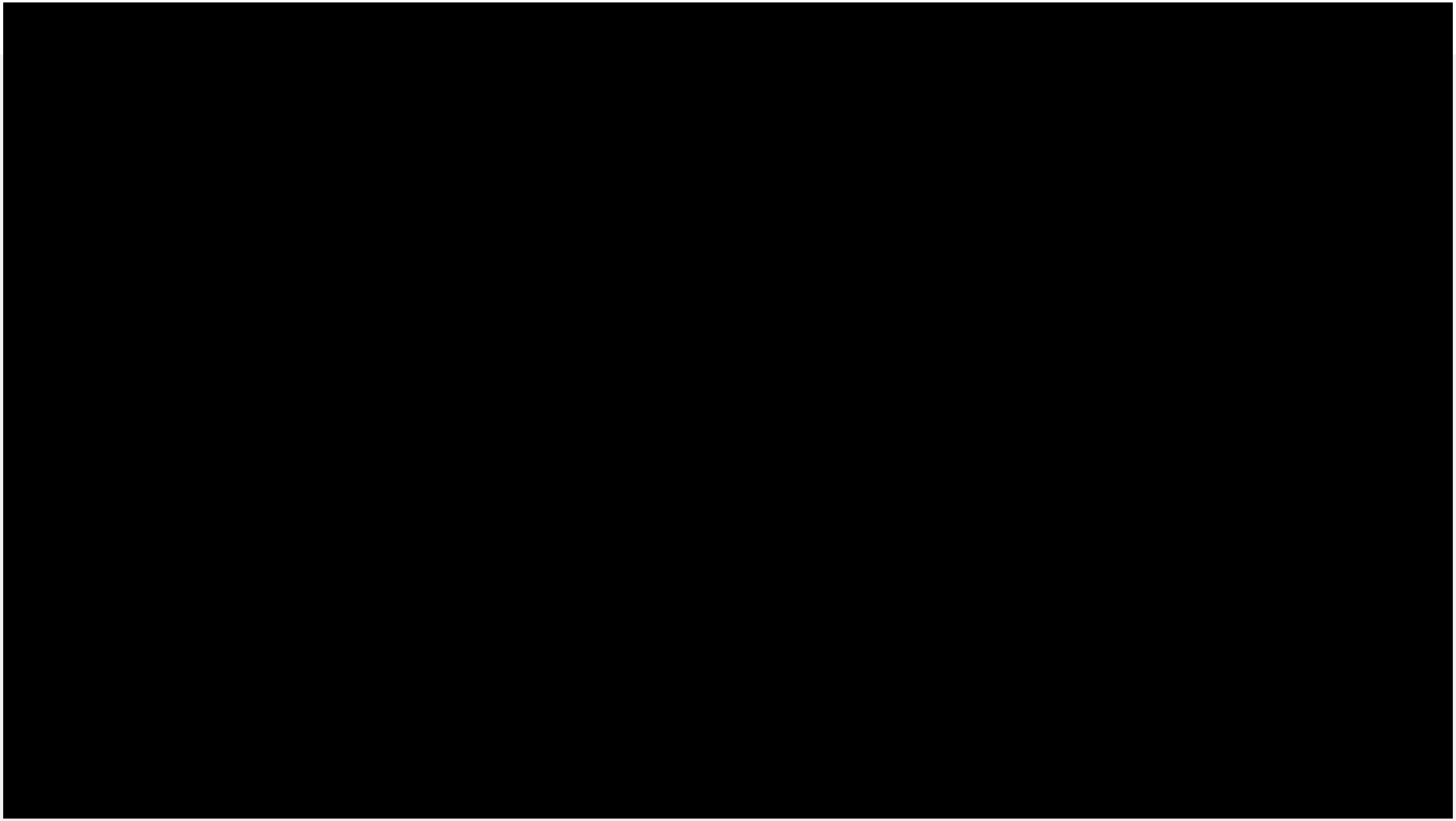
Small size: the final in 2013



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Standard Platform

- In the Standard Platform League, soccer is played with a standardized robot platform
- All teams compete with identical robots and only differ in the software they develop.
- The robots operate fully autonomously, such that there is no external control by humans or computers.
- The robots can communicate with their teammates and receive the decisions of the referee via wireless communication.
- Each game is composed of two 10-minute halves. In these games, teams of five robots play against each other on a 9m x 6m field.

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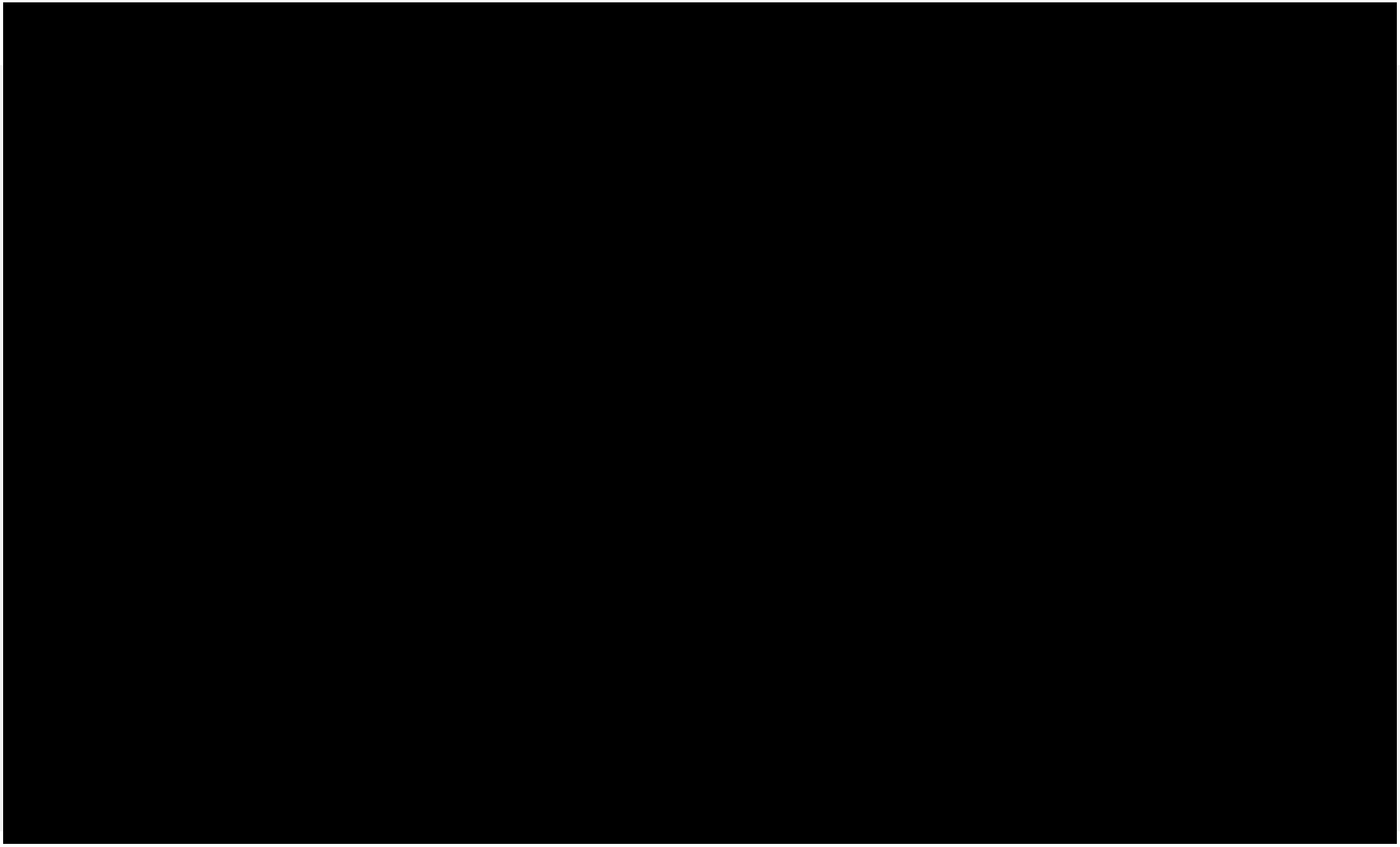
Standard Platform



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Humanoid League

- In the Humanoid League, autonomous robots with a human-like body plan and human-like senses play soccer against each other.
- The task of perception and world modeling is not simplified by using non-human like range sensors.
- In addition to soccer competitions technical challenges take place. Dynamic walking, running, and kicking the ball while maintaining balance, visual perception of the ball, other players, and the field, self-localization, and team play are among the many research issues investigated in the Humanoid League.

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RoboCup@Home

- The competition of RoboCup@Home consists of tests which the robots have to solve. The ultimate scenario is the real world itself. To build up the required technologies gradually a basic home environment is provided as a general scenario.
- In the first years (the league started in 2006) it will consist of a living room and a kitchen but soon it should also involve other areas of daily life, such as a garden/park area, a shop, a street or other public places.

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RoboCup@Home

- Focus lies on the following domains but is not limited to: Human-Robot-Interaction and Cooperation, Navigation and Mapping in dynamic environments, Computer Vision and Object Recognition under natural light conditions, Object Manipulation, Standardization and System Integration.

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For fun....

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Questions