CS148 - Building Intelligent Robots

Lecture 3: Sensors, Actuators, and Kinematics

Instructor: Chad Jenkins (cjenkins)

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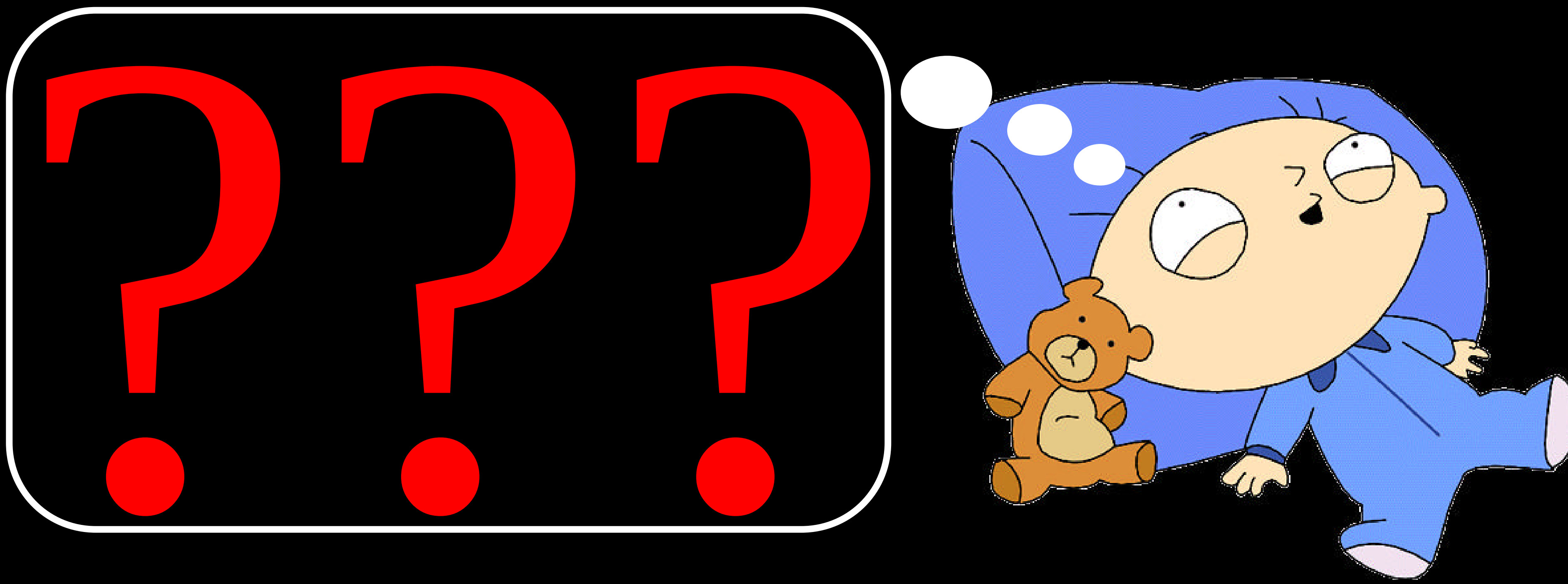
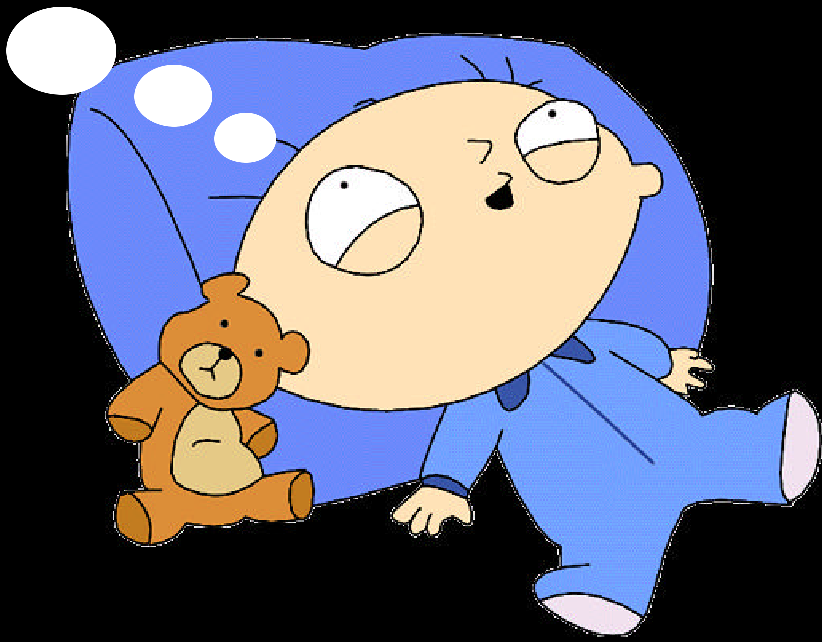


A robot is made up of three basic types of components?

???



A robot is made up of four basic types of components?

Links, Actuators, Sensors, and Controllers

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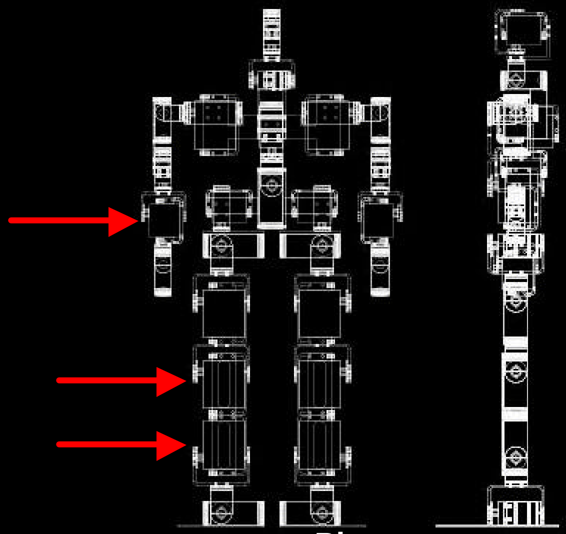
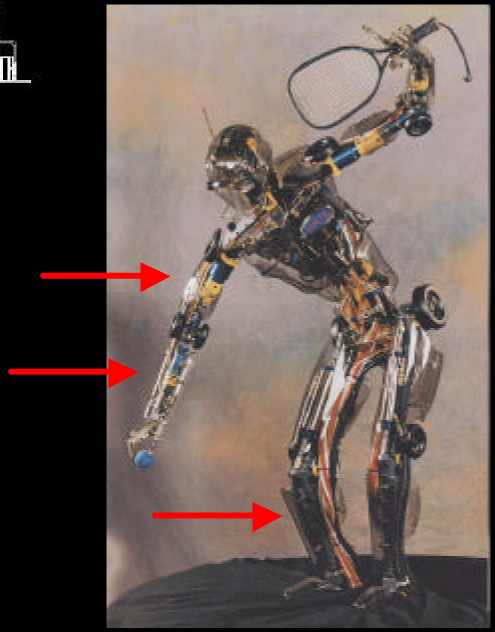
What comprises a robot?

- Links
  - typically rigid bodies



Pino

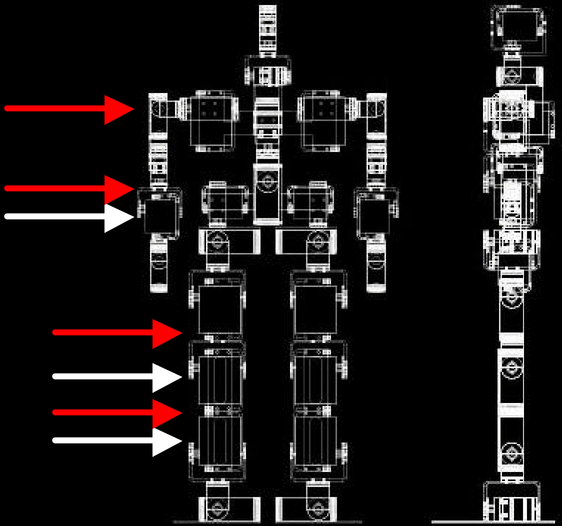
ActivMedia Pioneer



C. Atkeson/Sarcos

What comprises a robot?

- Links
  - typically rigid bodies
- Actuators
  - connect and move links



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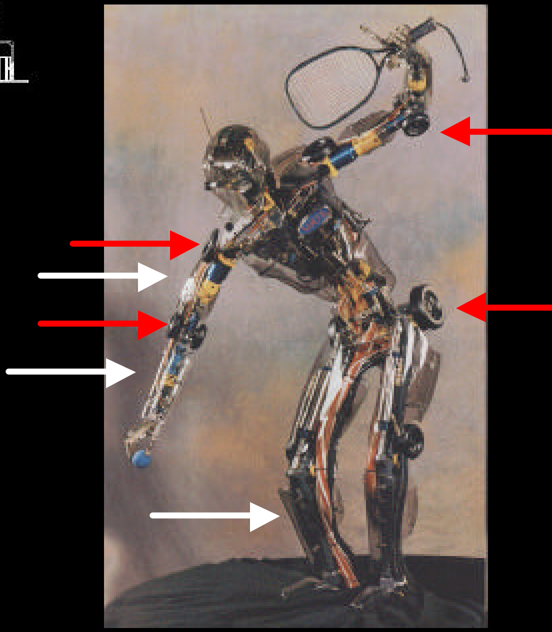
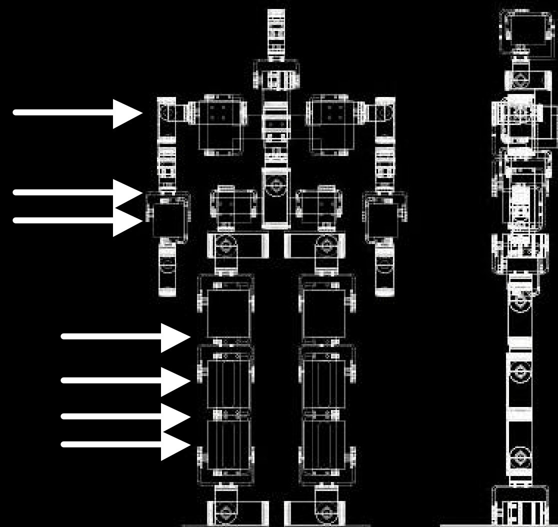


C. Atkeson/Sarcos

What comprises a robot?

- Links
  - typically rigid bodies
- Actuators
  - connect and move links
- Sensors
  - perceiving the world



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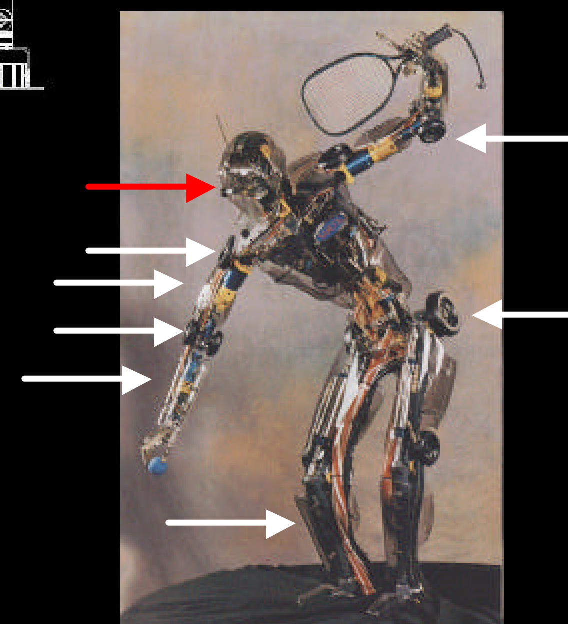

C. Atkeson/Sarcos

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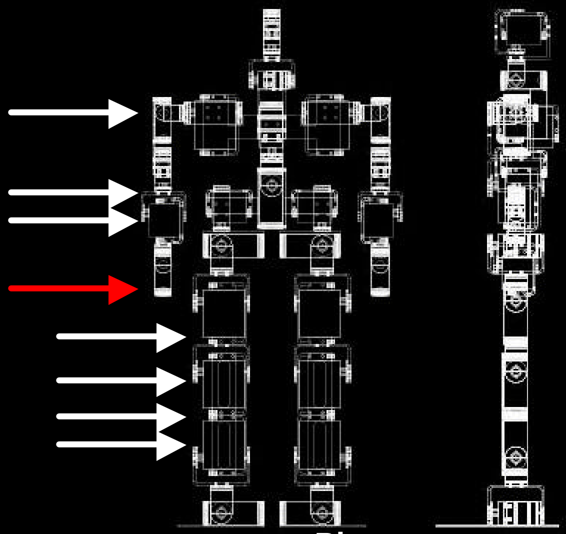
What comprises a robot?

- Links
  - typically rigid bodies
- Actuators
  - connect and move links
- Sensors
  - perceiving the world
- Other
  - endeffectors, communication, etc.
- Does perfect sensing and perfect actuation imply a perfect robot?


Pino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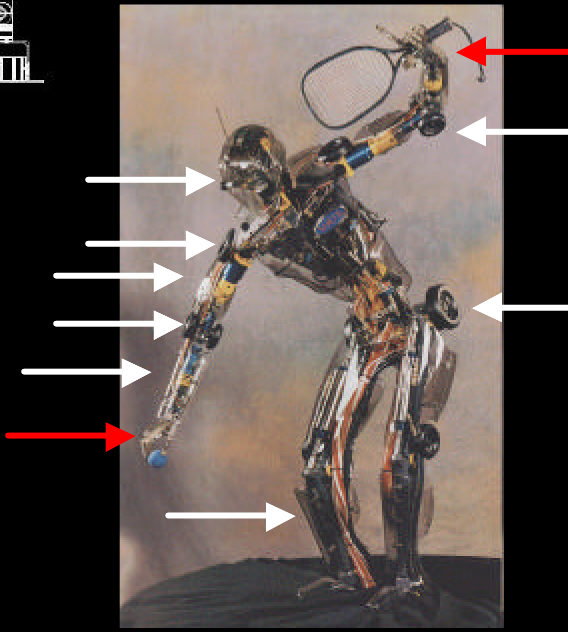
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- Sensors
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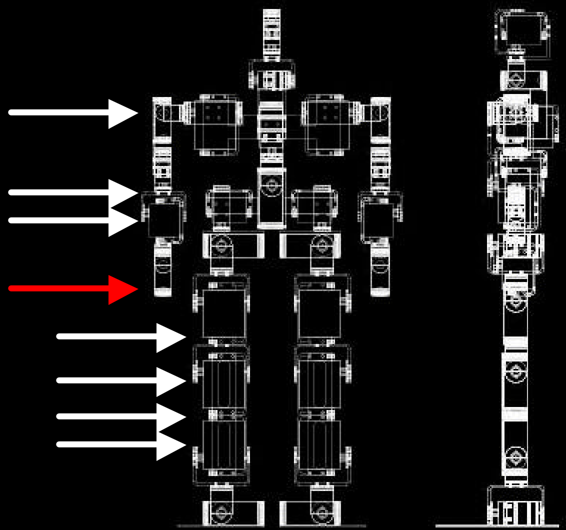
- Other
  - endeffectors, communication, etc.
- Does perfect sensing and perfect actuation imply a perfect robot?
  - No, control must still be addressed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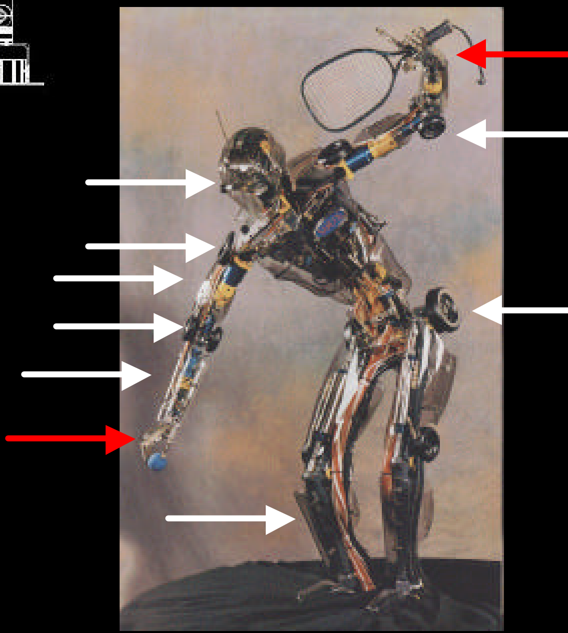
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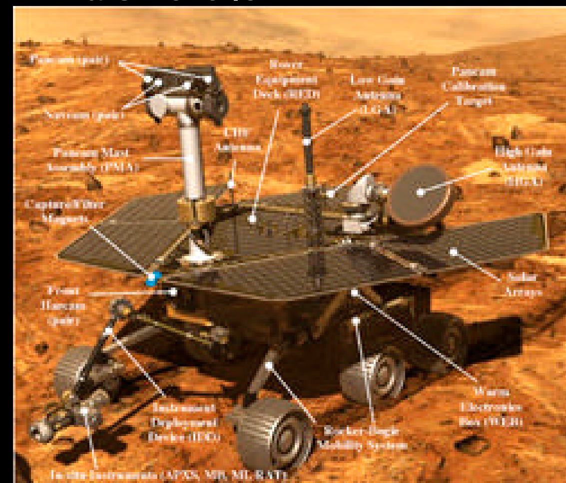
Constructing physical robots

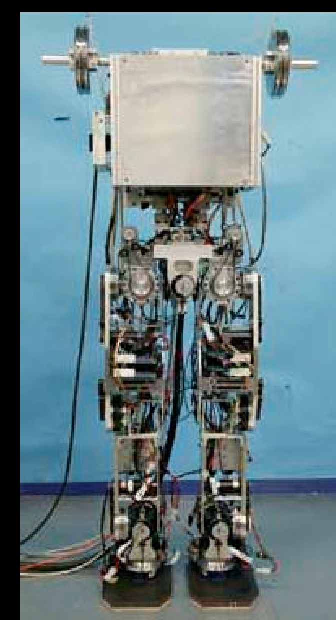
- Constructing robots can be complicated
- Why?

Mars Rover/JPL



Segwaynaut/NASA

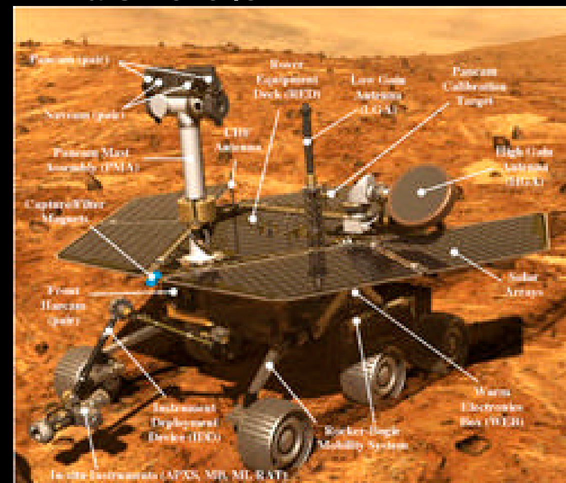
Wabian/Waseda U.



Constructing physical robots

- Constructing robots can be complicated
- Why?
  - Physical limitations
    - Sensor technology
    - Actuator technology
    - Power consumption
  - Design issues
    - General structure
      - mobile, underwater, aerial, full-body, torso, single arm
    - Interaction modality
      - facial expression, endeffector type
    - Level of articulation
- Controllers try to push the limits

Mars Rover/JPL



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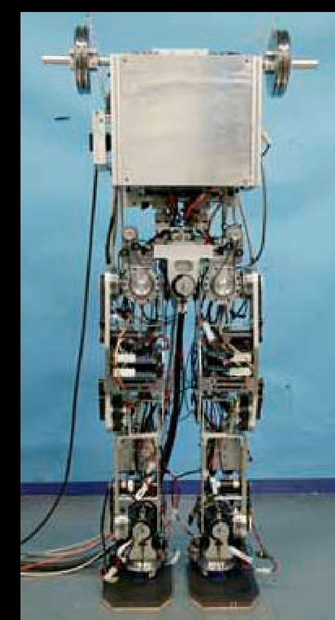


Sensor options

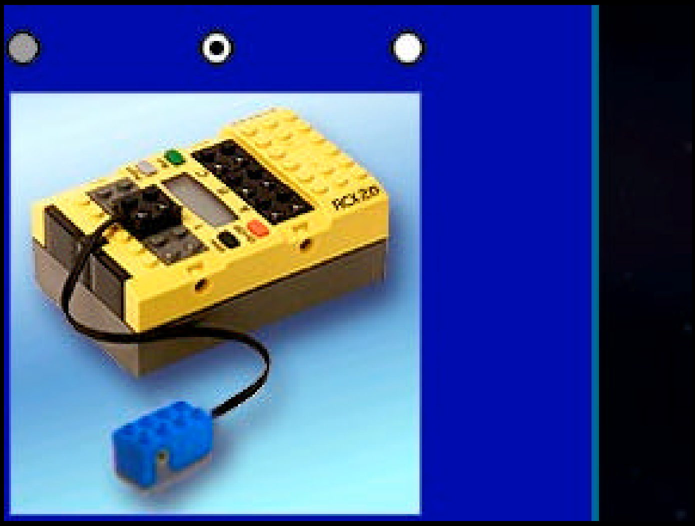
physical property		technology
contact	→	bump, switch
distance	→	ultrasound, radar, infra red
light level	→	photo cells, cameras
sound level	→	microphones
strain	→	strain gauges
rotation	→	encoders
magnetism	→	compasses
smell	→	chemical
temperature	→	thermal, infra red
inclination	→	inclinometers, gyroscopes
pressure	→	pressure gauges
altitude	→	altimeters

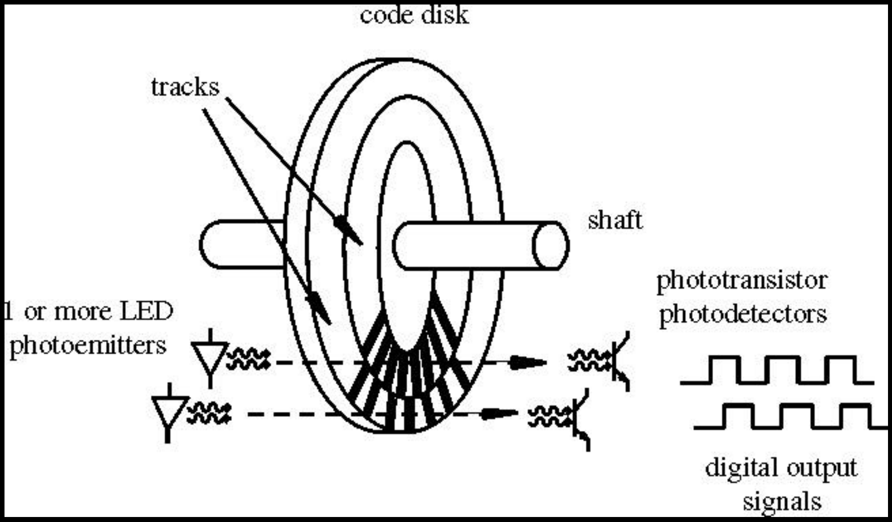
Proprioception

- The unconscious perception of movement and spatial orientation arising from stimuli within the body itself.
  - Sensing internal to the robot
- Opposed by exteroception:
  - sensitivity to stimuli originating outside of the body
- Exteroception is more prone to noise and hidden state
- Sensor choices for proprioception and exteroception

Rotation sensing

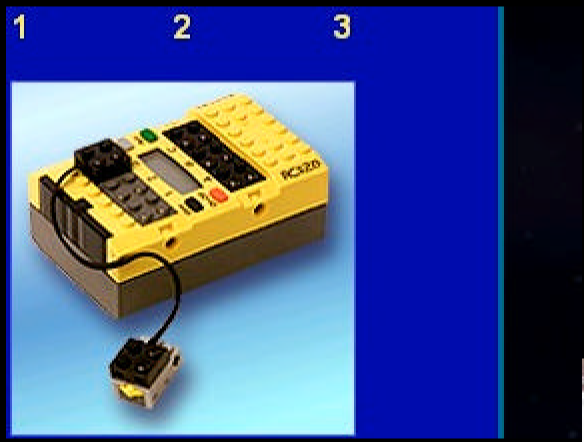
- Potentiometers
  - variable resistors
- optical encoders



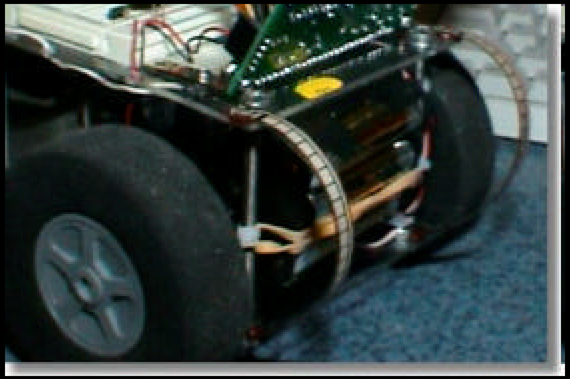


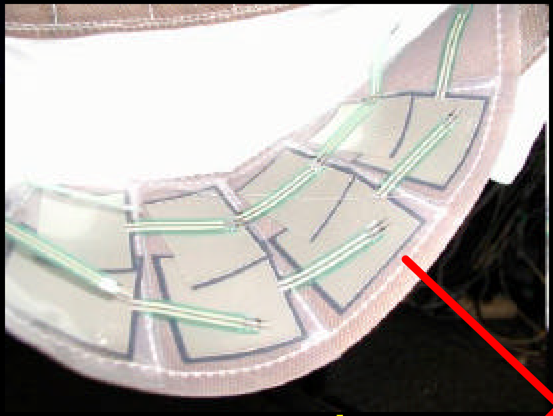
Alciatore,Histand/Colorado St.

Contact sensing



Flex Sensor/
Kronos Robotics

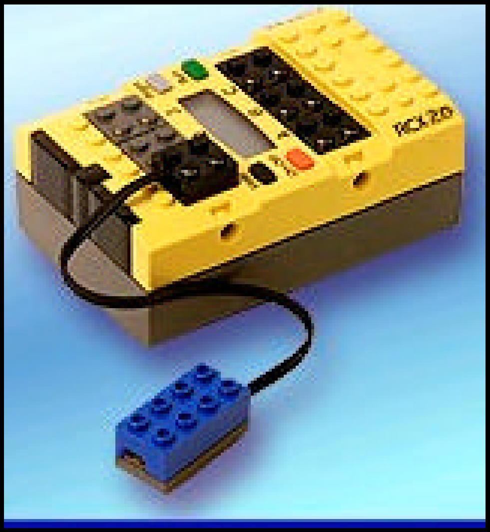




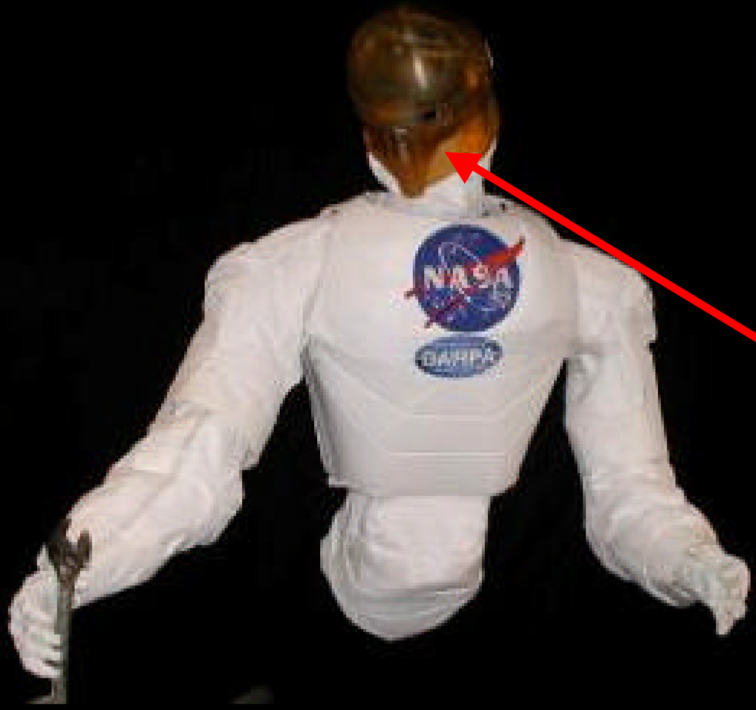
Force sensors on skin

Roomba/iRobot.

Passive optical sensing



- Light sensor
- single camera (robot color blob)
- stereo vision



Stereo example from Mars Rover

Camera calibration

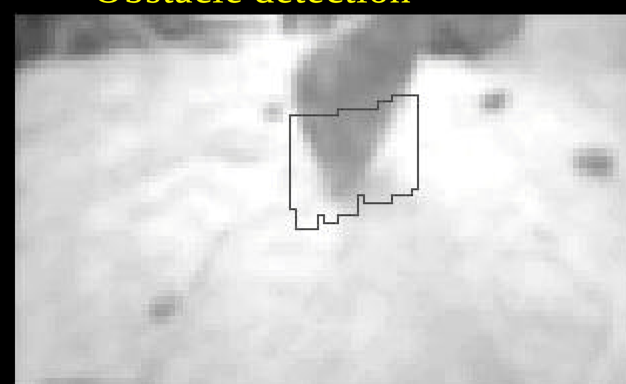
Camera images

Image processing

Stereo correspondence

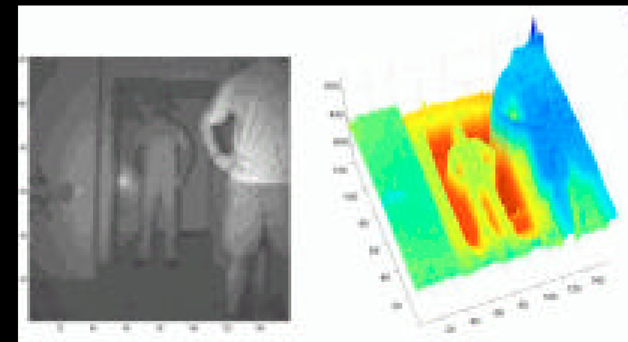
Elevation map

Obstacle detection

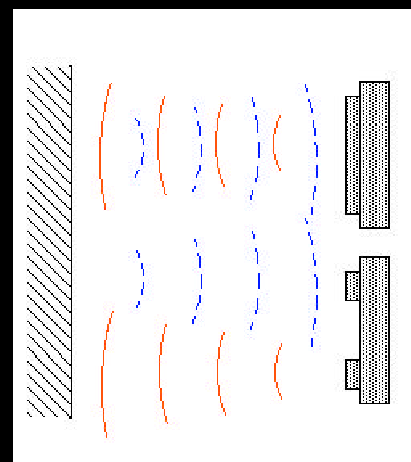


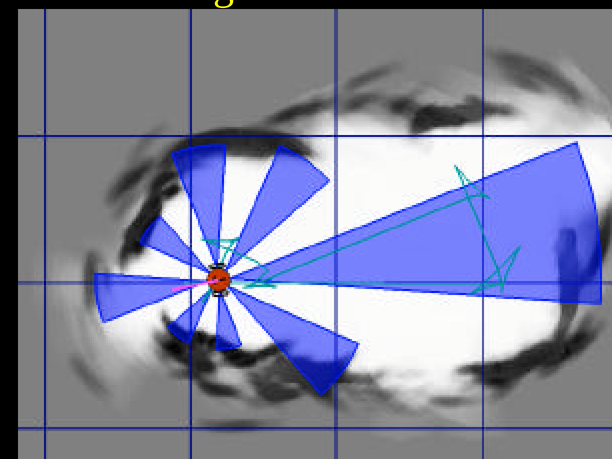
Time of flight ranging

- Active emission of
  - infrared
  - ultrasonic
  - light arrays
  - laser
- Measure distance to closest obstacle by time for emisson to reflect and return to sensor

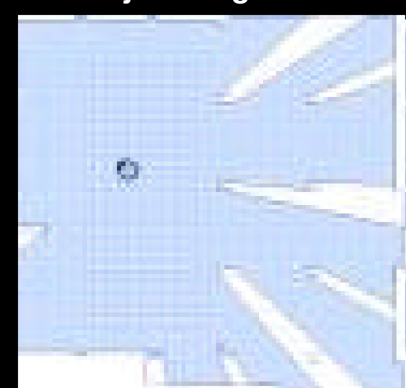


Swiss Ranger/CSEM





Crunch/jormungand.net



Planar laser ranging

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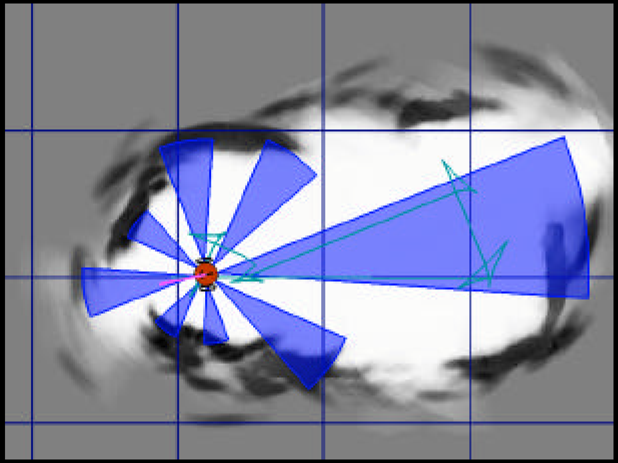
Sonar v. Laser



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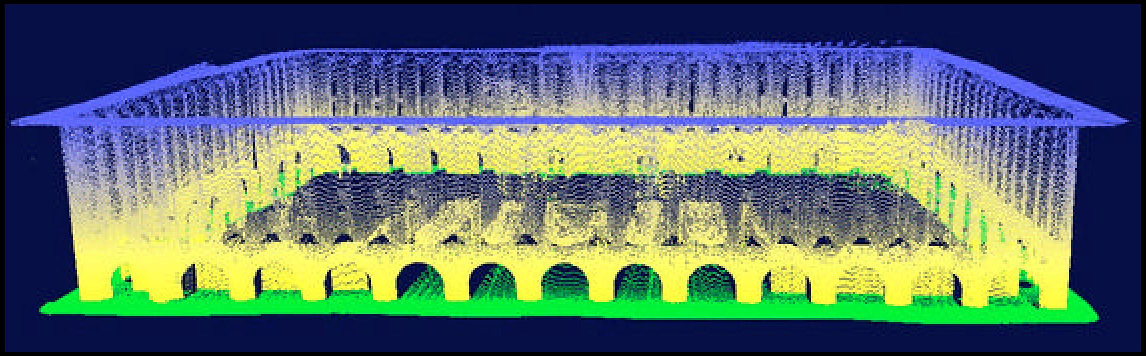
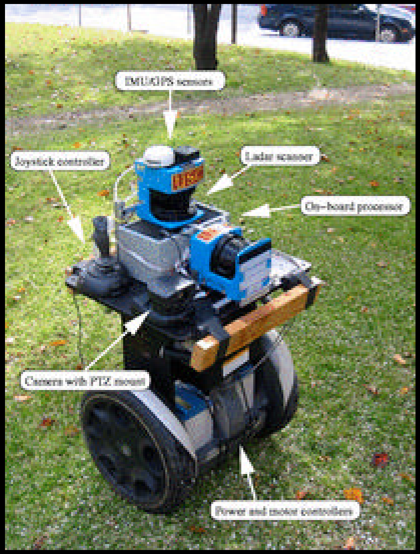
Howard/USC

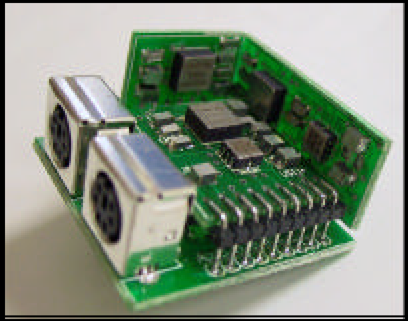


Howard/USC



Howard/USC

Inertial measurement



- Gyroscopes
  - angular velocity
- Accelerometers
  - gravitational vector
- Magnetometers/compass
  - magnetic field vector

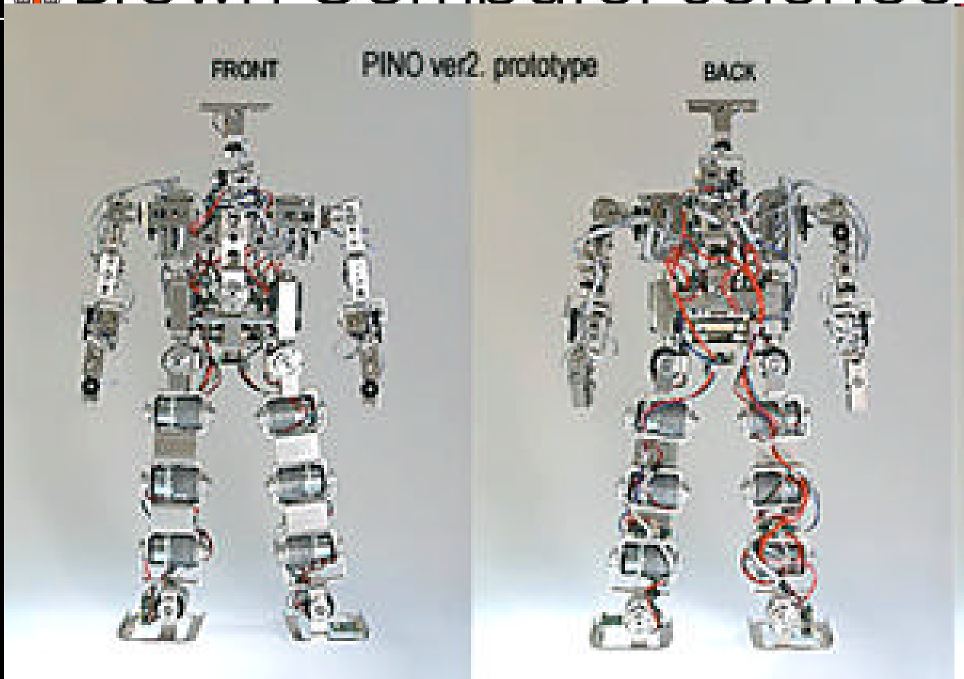
  - Crunch is equipped with an ADXRS150 MEMS rate gyro; gyro drift is zeroed by an ADXL202 MEMS accelerometer. Together they continuously provide an accurate measurement of the robot's pitch.

Crunch/jormungand.net

Actuator Options

- Electro-magnetic
- Hydraulic
- Pneumatic
- Shape memory alloys
- Piezoelectric
- Photoreactive
- Chemical reactive
  - polymer actuators

For more details, refer to "A Survey of Micro-Actuators Technologies for Future Spacecraft Missions" by R. Gilbertson and J. Busch



Pino/ZMP

Gear boxes

- Advantages
  - small torque -> large torque
  - high speed -> low speed
  - light motors and gear boxes
- Disadvantages
  - amplification of rotor inertia
  - friction
  - backlash
  - back-drivability (stiff)

Actuator Options

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- Hydraulic
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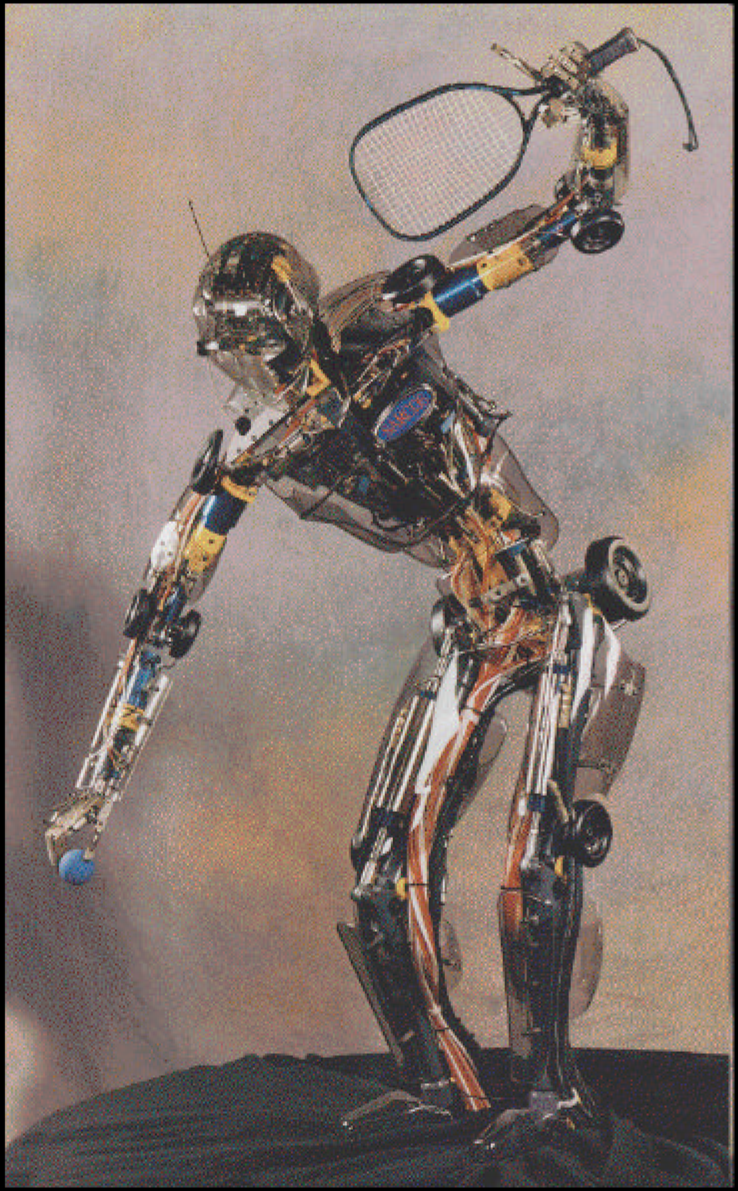

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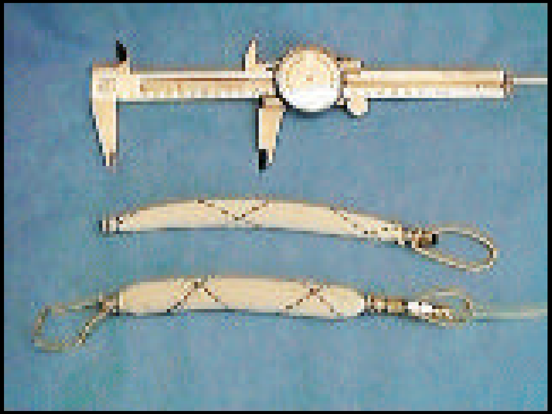
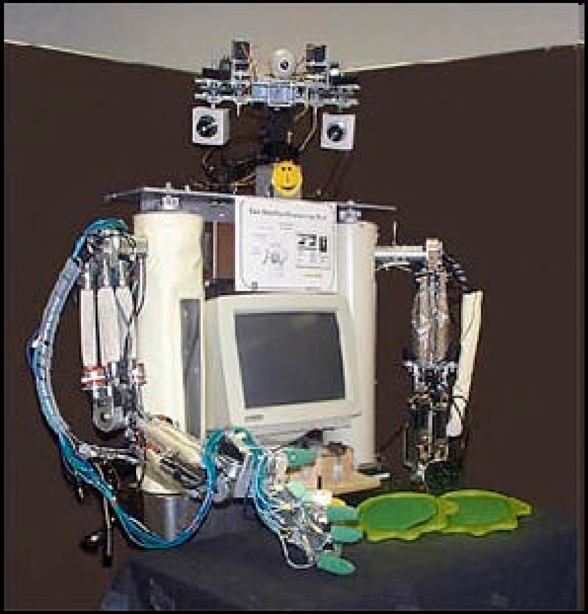


BioRobotics Lab/U. Washington



ISAC/Vanderbilt

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Actuator Options

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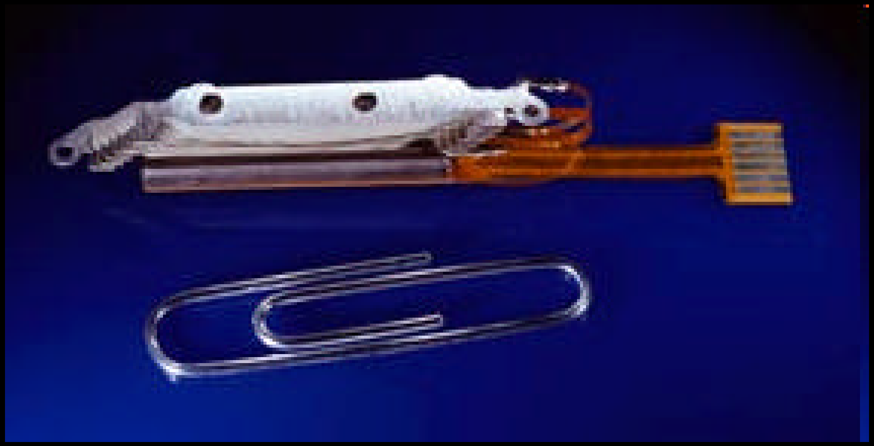
Nanomuscle



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- Polymer actuators

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Kinematics and Physical Dynamics

- Kinematics
  - The branch of mechanics that studies the motion of a body or a system of bodies without consideration given to its mass or the forces acting on it
  - how a robot structure moves without considering physics
- Dynamics
  - The branch of mechanics that is concerned with the effects of forces on the motion of a body or system of bodies, especially of forces that do not originate within the system itself
  - how a robot structure moves with respect to physics

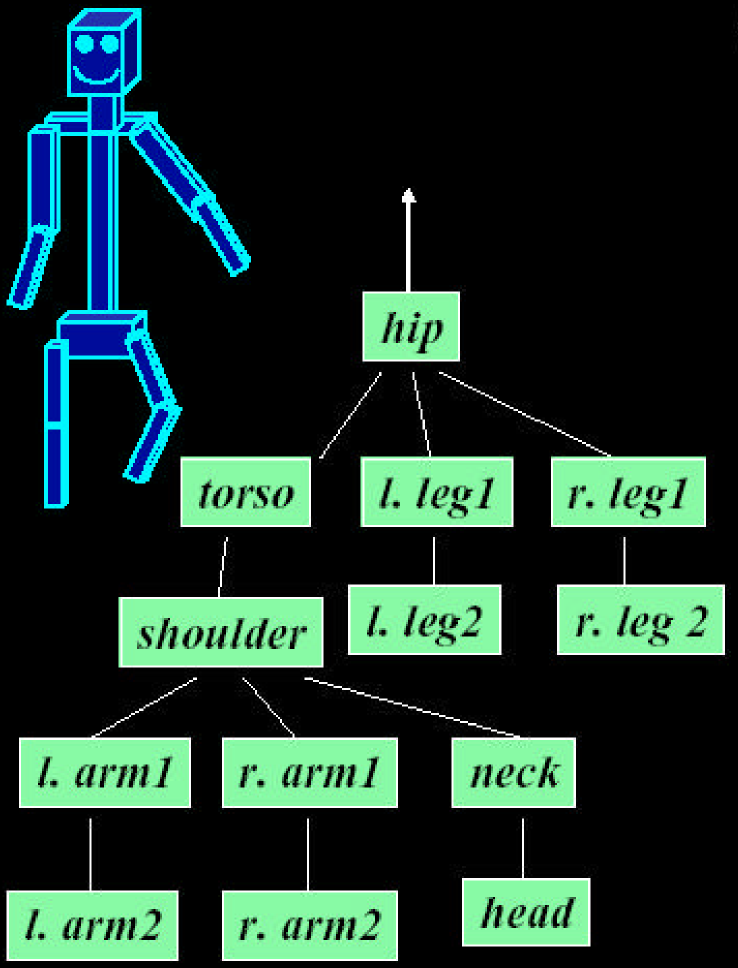
Kinematics

- How could you communicate the pose of your body in a vector?

- How do you specify the configuration of a robot?

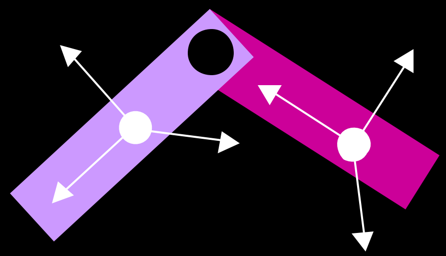
Kinematics

- How could you communicate the pose of your body in a vector?
- How do you specify the configuration of a robot?
- Rigid body transformation
  - translations and rotations
- Hierarchically
  - directed acyclic (tree) structure

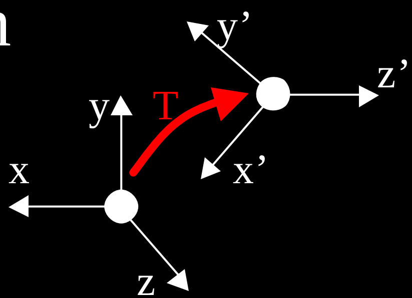


Stolen from nsp

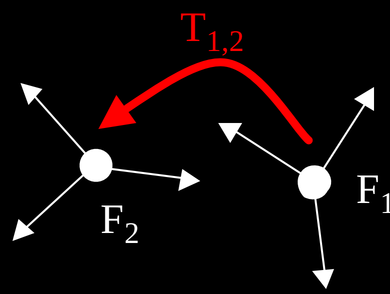
Local coordinates and Rigid body transformation



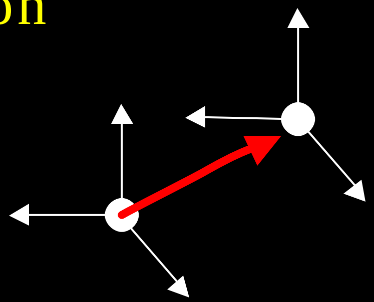
- Each link and parent joint form their own local coordinate system
  - assuming rigid links



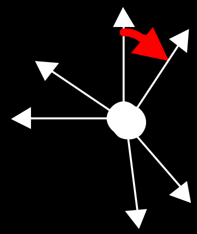
- Coordinate transformation
  - frame change, change of basis
  - relates coordinates of different local frames



- 2 relevant transforms
  - translation



  - rotation



Homogenious coordinates

- Rotation, translation, and other transforms can be performed through matrix multiplication
  - do I need to explain matrix multiplication?
  - translation requires homogenious coordinates
- A 2D point in homogenious coordinates: $\begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$
- Matrices for 2D translation and rotation

$$\begin{bmatrix} 1 & 0 & T_x \\ 0 & 1 & T_y \\ 0 & 0 & 1 \end{bmatrix} \qquad \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 0 \\ \sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

3D transformations

- Translation (D)

$$\begin{bmatrix} 1 & 0 & 0 & Tx \\ 0 & 1 & 0 & Ty \\ 0 & 0 & 1 & Tz \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

- Rotation about x (Rx), y (Ry), and z (Rz) axes

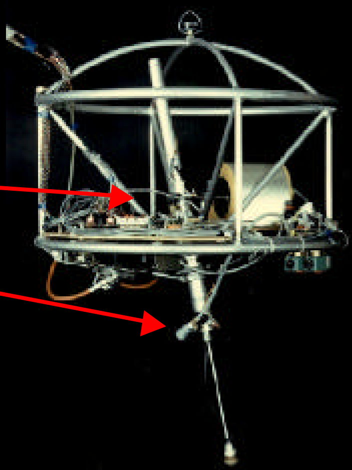
$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \begin{bmatrix} \cos\theta & 0 & \sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \begin{bmatrix} \cos\theta & -\sin\theta & 0 & 0 \\ \sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Composing transformations

- Transformations can be combined through multiplication
- A three axis rotation can be formed through individual rotations about each axis
  - $R = R_x R_y R_z$
- A change in coordinate systems is performed through a rotation followed by a translation
  - $T = DR$

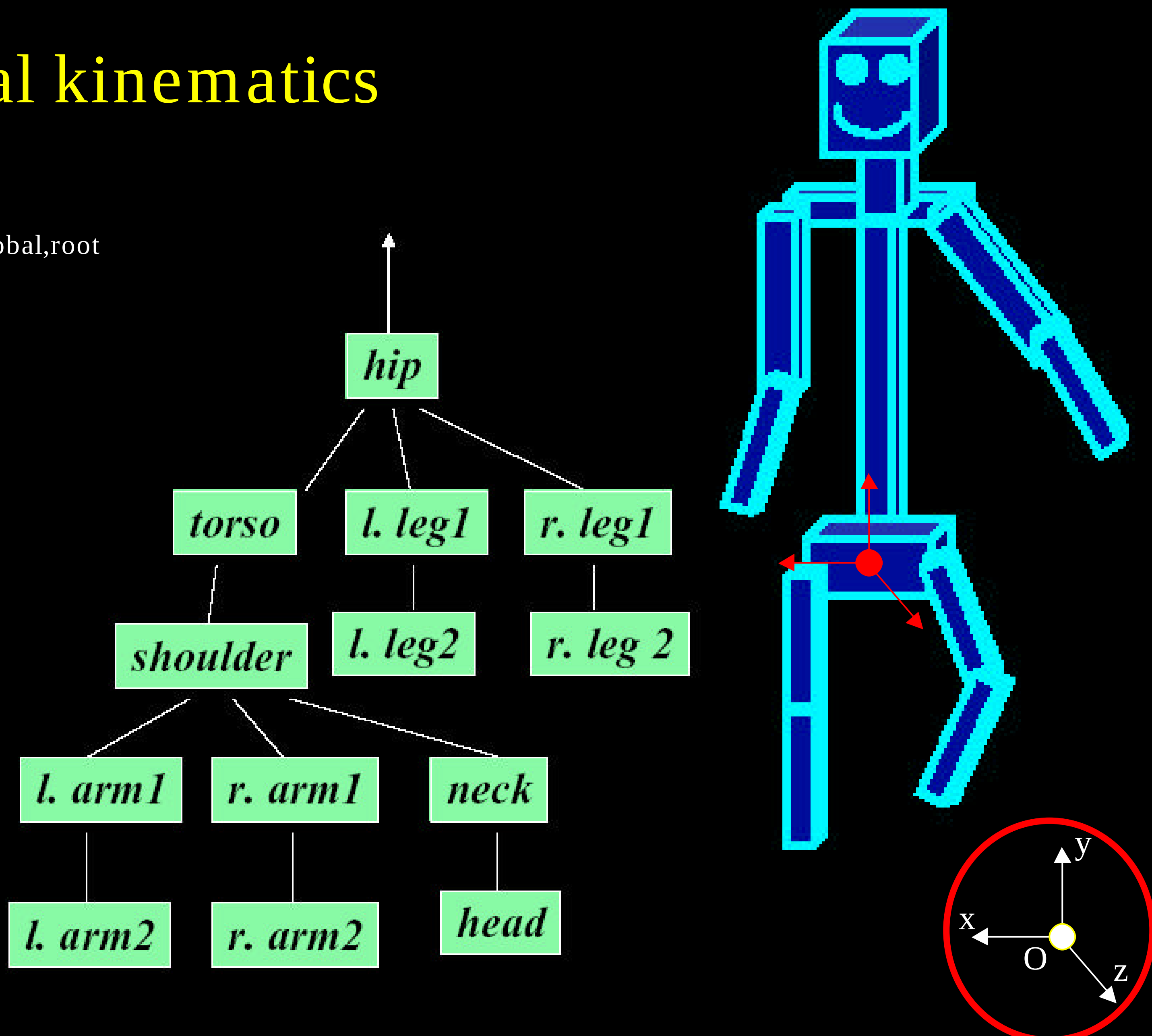
Articulated kinematics

- Given 3D transforms, we know how to relate two local coordinate frames
- How do we use these transforms to build articulated kinematic systems?
- Types of joints
  - Revolute: rotational
  - Prismatic: translational



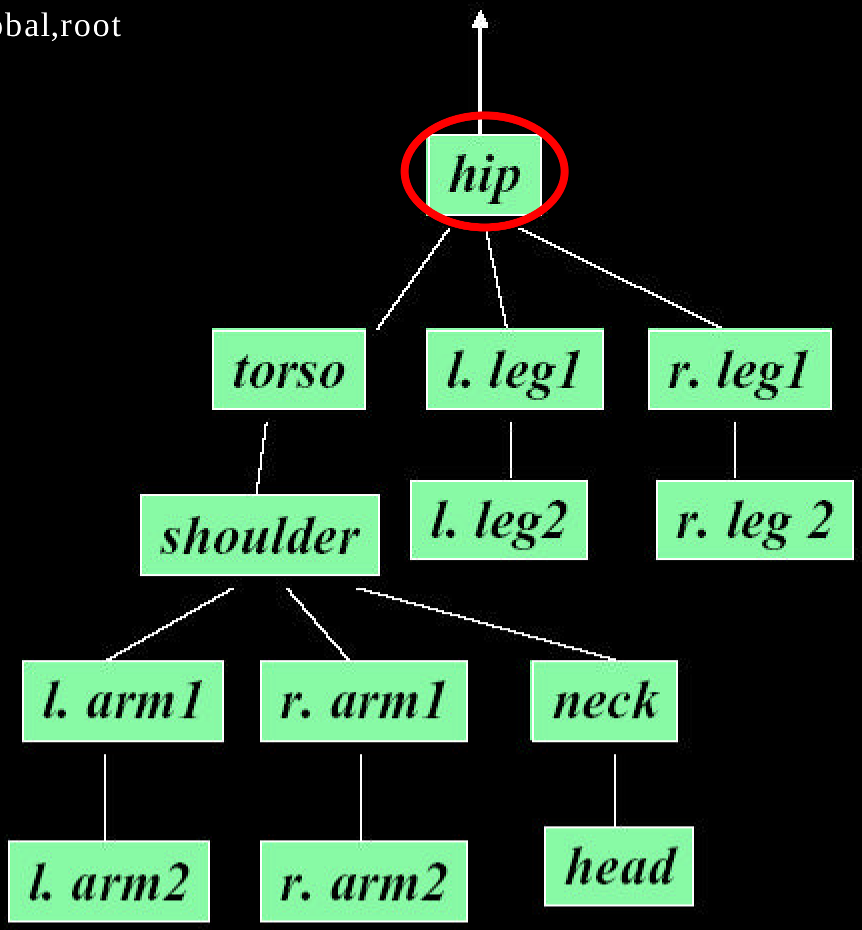
Hierarchical kinematics

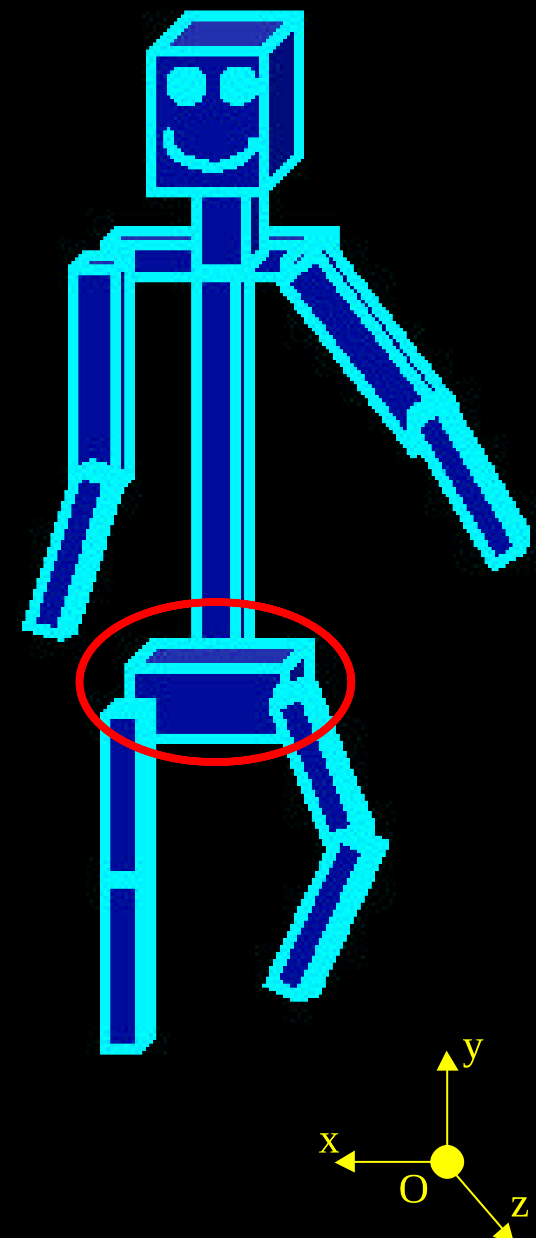
- Global coodinates $T_{global,root}$
  - absolute root



Hierarchical kinematics

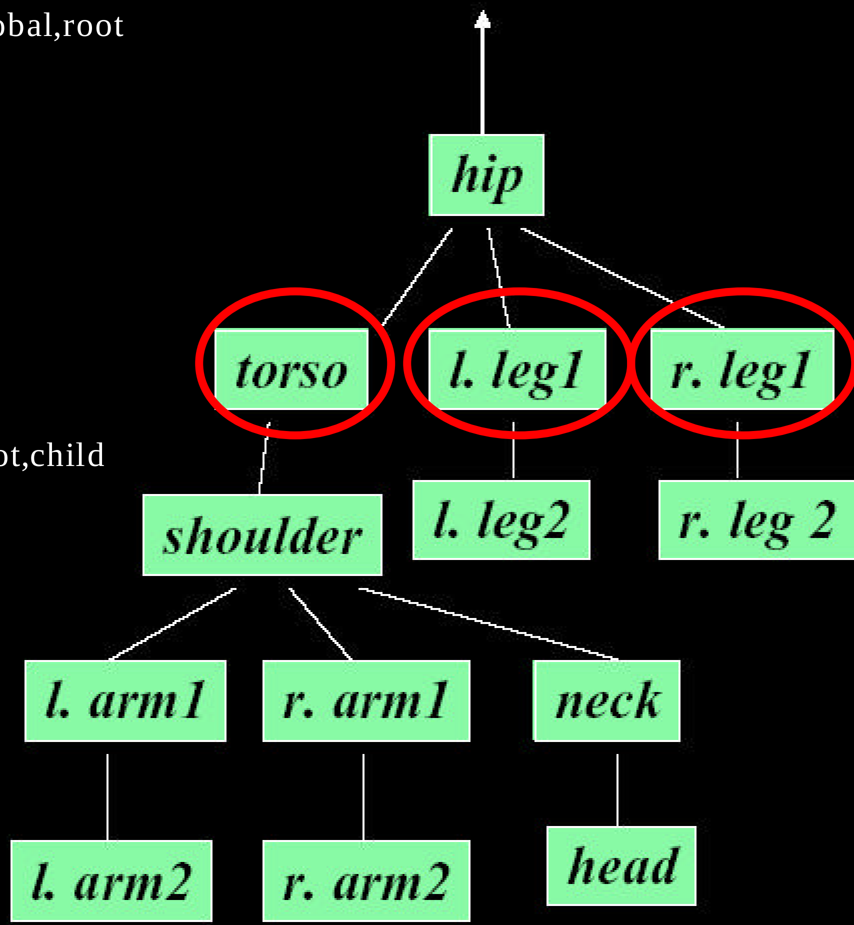
- Global coodinates $T_{global,root}$
  - absolute root
- Body root

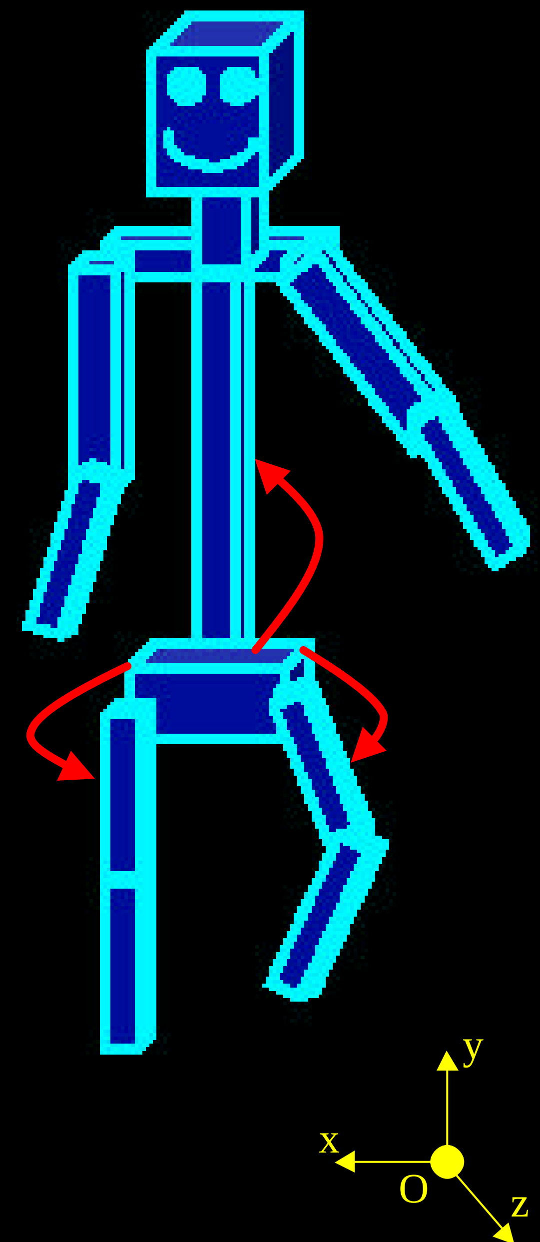




Hierarchical kinematics

- Global coodinates $T_{global,root}$
  - absolute root
- Body root
- 1st level children $T_{root,child}$





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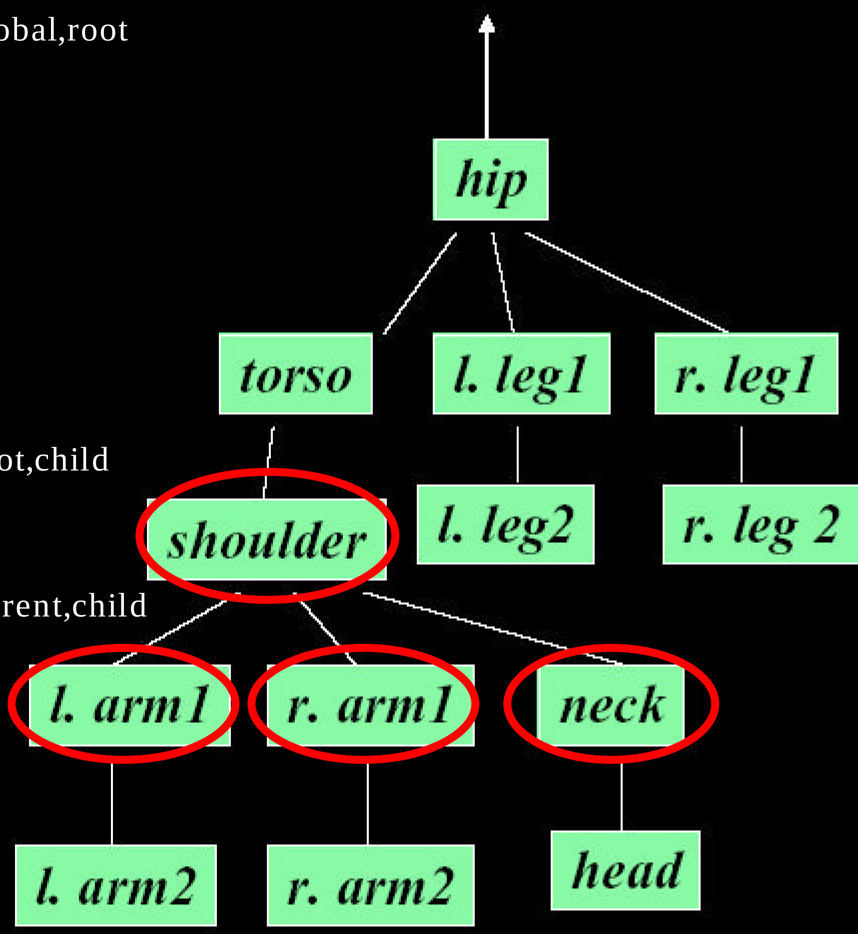
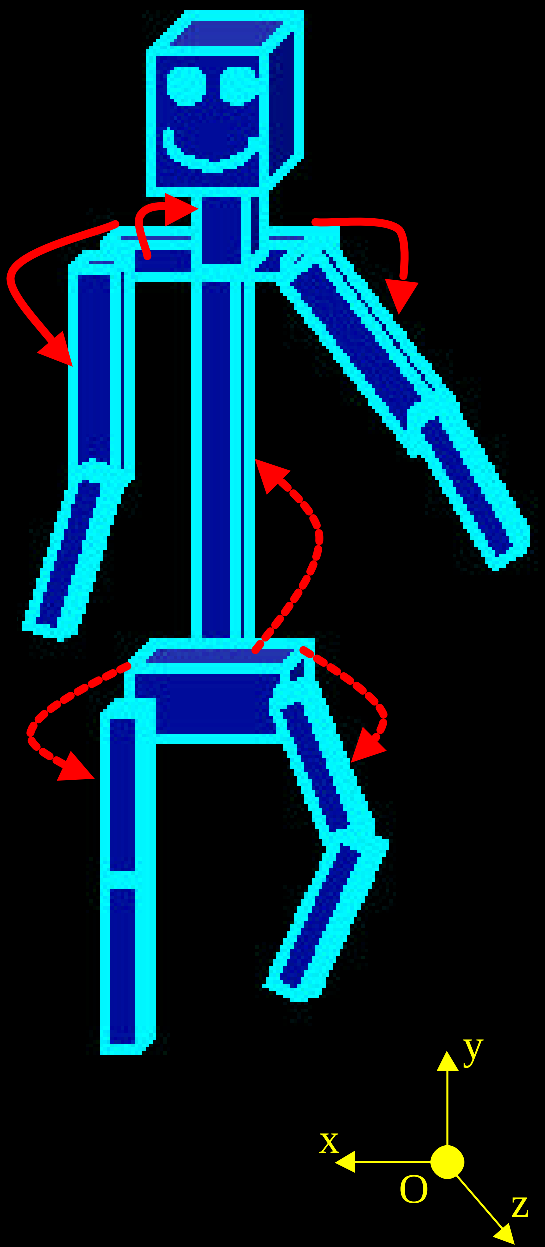
Hierarchical kinematics

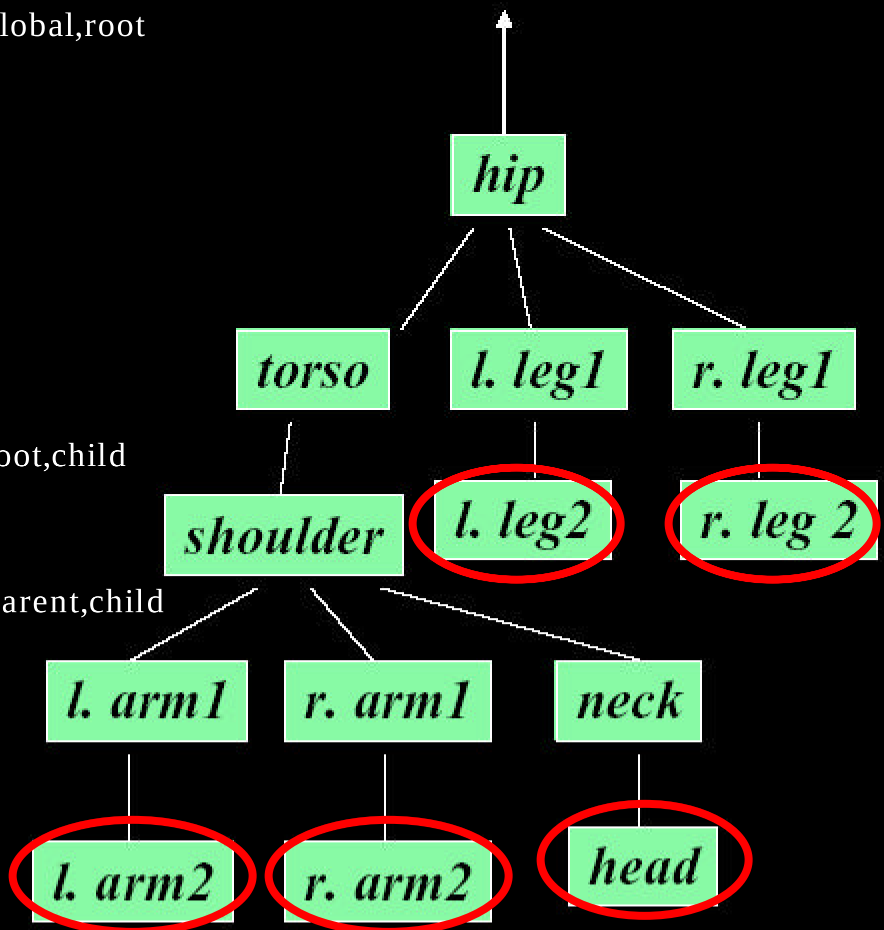
- Global coodinates $T_{global,root}$
  - absolute root
- Body root
- 1st level children $T_{root,child}$
- Nth level children $T_{parent,child}$

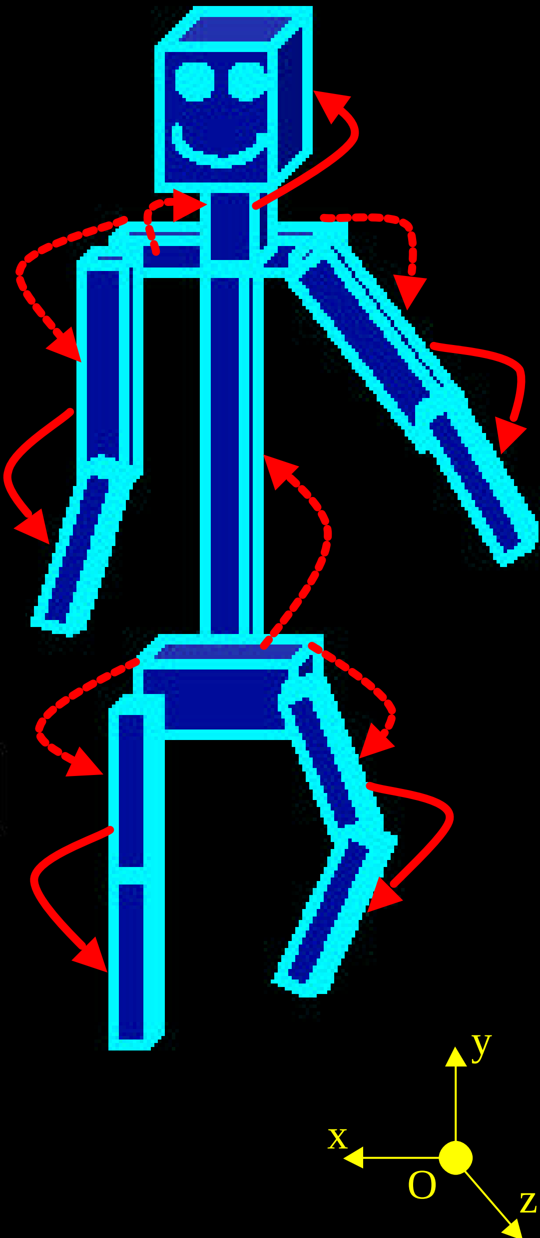




Hierarchical kinematics

- Global coodinates $T_{global,root}$
  - absolute root
- Body root
- 1st level children $T_{root,child}$
- Nth level children $T_{parent,child}$
- Leaf bodies $T_{parent,leaf}$



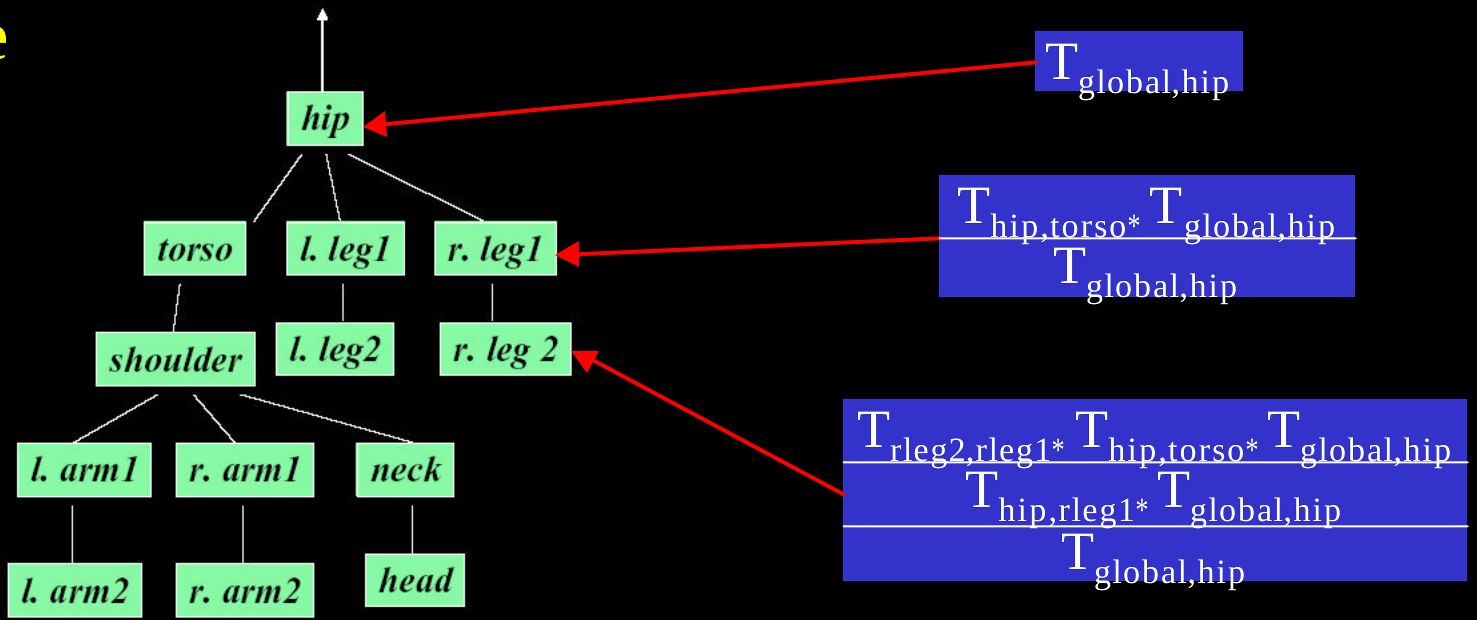


Hierarchical kinematic representations

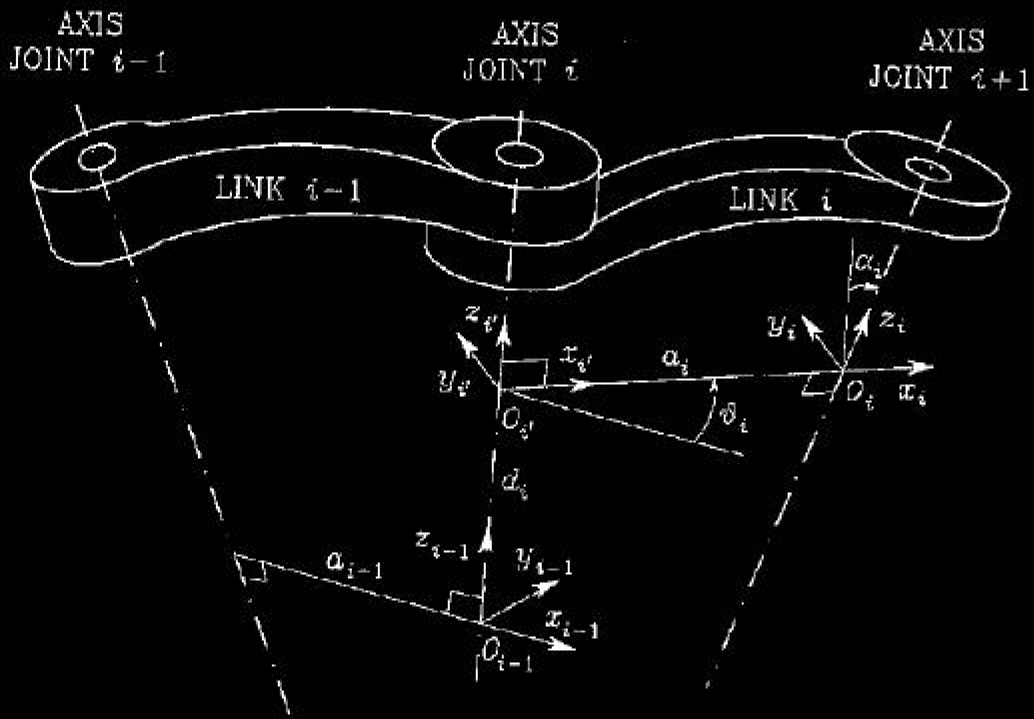
- Hierarchical kinematic representations define the configuration space of the robot
  - a robot configuration is specified by a vector containing all of the robot's degrees-of-freedom (DOFs)
  - think of a D-dimensional space where each DOF is an axis
- Recursive notations for hierarchical kinematics
  - Matrix stack
  - Denavit-Hartenberg notation

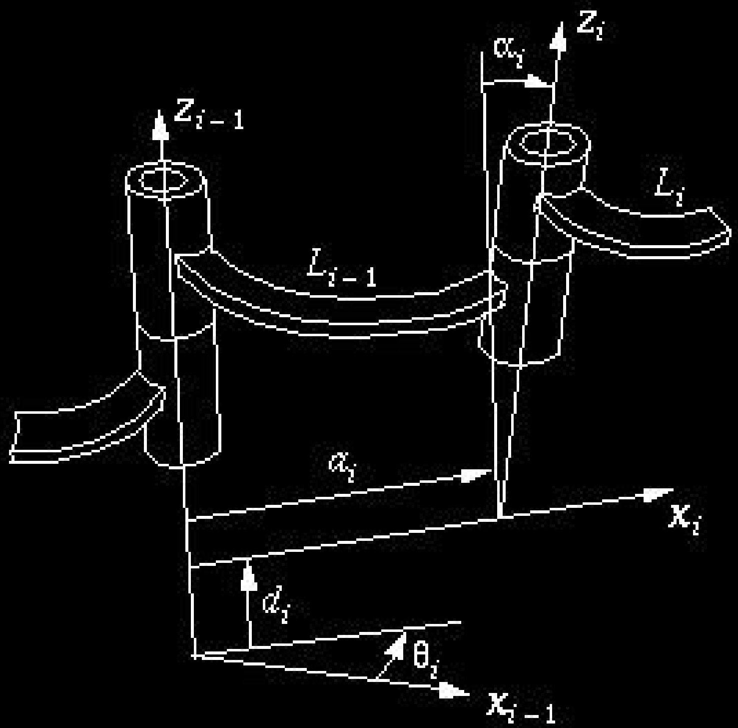
Kinematic matrix stack

- Maintain global transformation into current local coordinates at the top of a stack
- Push transformation onto stack when entering a local frame
- Pop transformation from stack when leaving a local frame



Denavit-Hartenberg notation





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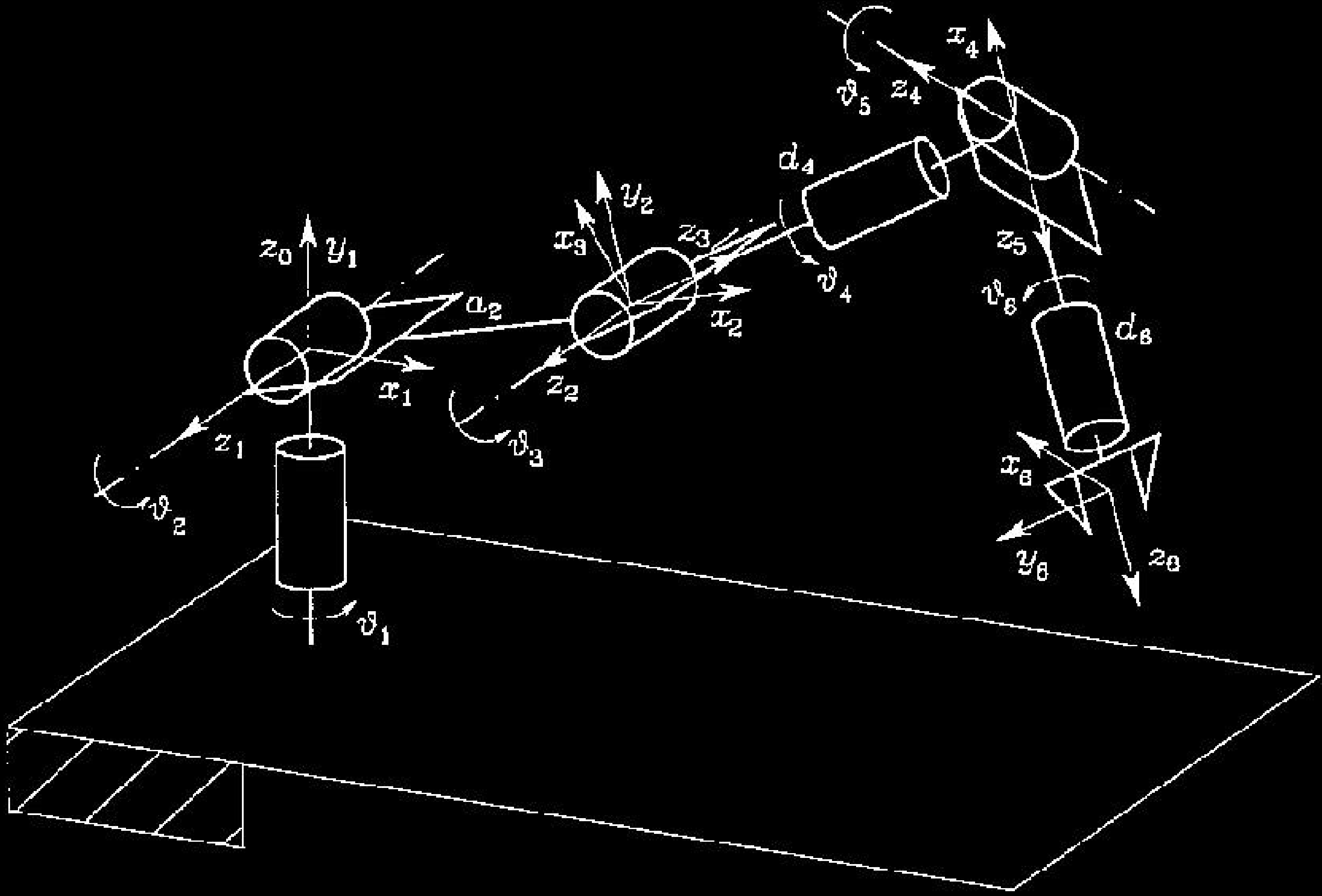
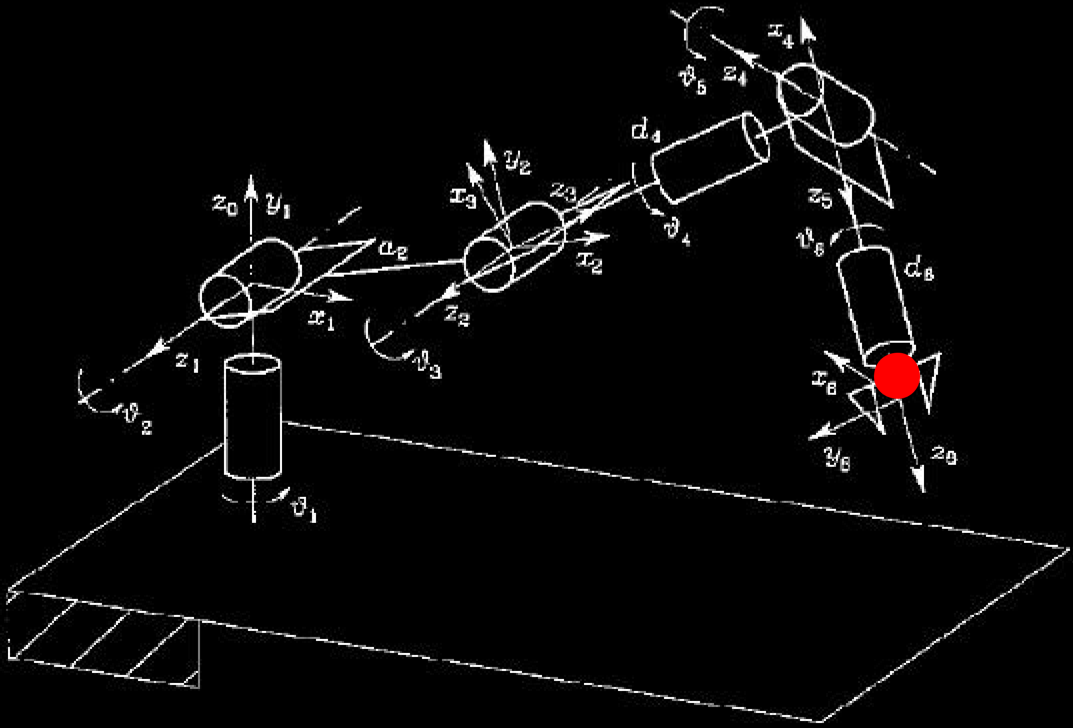
Denavit-Hartenberg notation (hierarchical view)



Brown Computer Science

Forward and inverse kinematics

- Forward kinematics
  - computing endeffector position (x) from robot configuration (Theta)
- Inverse kinematics
  - computing robot configuration (Theta) from endeffector position (x)
  - no unique solution
  - heuristics



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