The iCub Humanoid Robot:

An open-systems platform for research in cognitive development

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Overview

1. Introduction
2. Design Goals
3. Foundations of Human Development
4. Specific Results
5. Discussion

Introduction

- ➔ designed to support research in the field of cognitive development through autonomous exploration and social interaction.
- ➔ offers rich perceptuo-motor capabilities with many degrees of freedom, a cognitive capacity for learning and development
- ➔ an open systems policy for software/hardware development can have a significantly greater impact on the research.

iCub promises to deliver on all of these, and is freely available as an open source platform.

Introduction

Introduction - Inspiration from Nature

Efficiency - highly task-specific

- automatic systems that are very fast and precise in their operations

Versatility - biological compatibility development

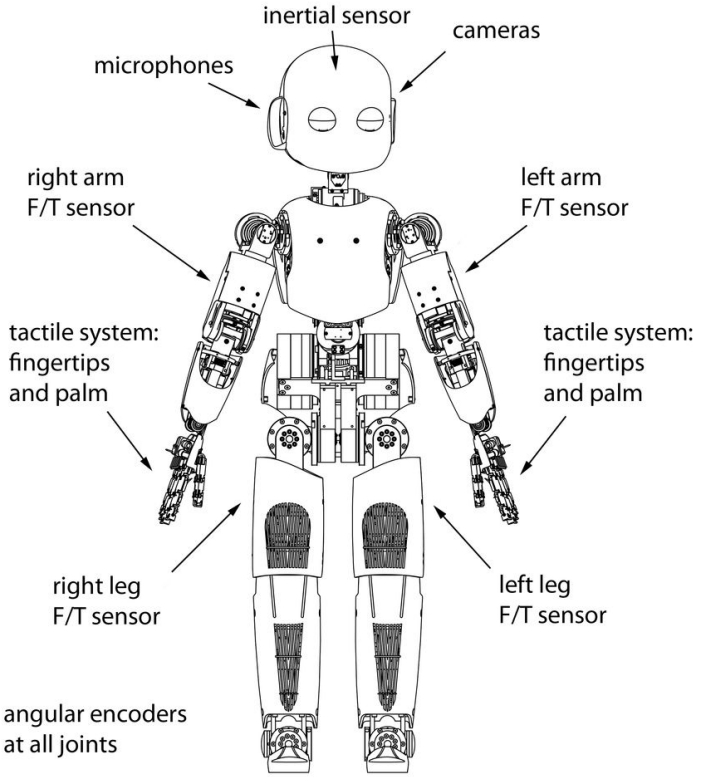
- A biological-like system
  - which takes decisions and acts in the environment
  - adapts and learns how to behave in new situations
  - invents new solutions on the basis of the past experience

Introduction - Humanoid Interaction

- Why mimic biological systems?
  - Learns to interact
    - An interaction is expected to be made up of acting, categorizing, and understanding the environment that it is in.
  - Exhibits exploratory behavior
    - attempts and errors are essential during knowledge acquisition because they increase the field of exploration.

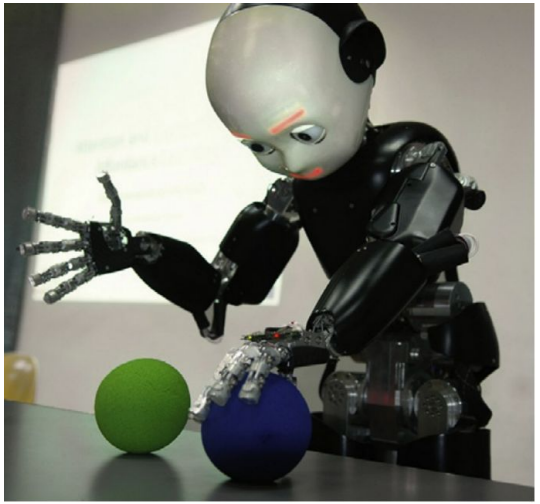
Design Goals

- Cognitive systems could not progress without the following prerequisites:
  - the development of a sound formal understanding of cognition
  - the study of natural cognition and the development of cognition
  - the study of action in humans using neuroscience methods
  - the physical instantiation of these models in a humanoid robot



Design Goals - What Architecture Design?

- The iCub was not designed to contain preprogrammed cognitive skills, but to implement a system that mimics a human infant
- The iCub is able to grasp unknown objects, assemble simple objects with plugs
- Coordinate the use of two hands
    - These skills require visual-haptic object recognition, imitation, and understanding of one and two-hand gestures

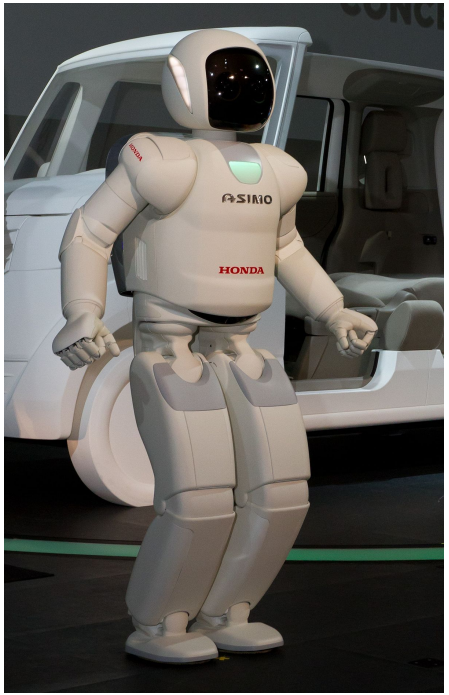


Design Goals - How to Understand Human Development

- Due to the interrelated nature of action, perception, and cognition, they cannot be independently studied on iCub.
- Instead certain experimental scenarios capture facets of these developments.
    - learning to control one's upper and lower body (crawling, bending the torso) to reach for targets
    - learning to reach static and moving targets
    - learning to balance in order to perform stable object manipulations when crawling or sitting.
- The above experiments are far from being completed, but with iCub, the authors believe they have created a basis for solid development in the direction of a biological system.

Design Goals - Physical System

- iCub was designed to maximize degrees of freedom and thus allow for flexible exploration and manipulation of the environment
  - **The lower body (legs) can sit, squat, and crawl,** but they also support bi-pedal walking (not yet implemented when this paper was published)
  - The upper body has 41 DOFs (7 for each arm, 9 for each hand, 6 for the head, 3 for the torso and spine)
  - The sensory system includes binocular vision, touch, binaural audition, and inertial sensors.
- Functionally speaking, iCub can coordinate movement of the eyes and hands to manipulate lightweight objects, crawl on four legs, and sit stably.



Foundations of Human Development

The goal of the iCub team in studying the development of early cognition in humans is to model the relevant aspects of such a process in the iCub robot. This research is strongly driven by studies of developmental psychology and cognitive neuroscience.

Human Development - Studies

- The primary processes that were studied by the iCub team include:
  - the time frame of a developmental process that begins to guide action by internal representations of upcoming events
  - by the knowledge of the rules and regularities of the world
  - by the ability to separate means and end (or cause and effect)

Human Development - iCub approach to cognition

- The next important question is understanding what principles govern the ontogenetic development of biological organisms
  - Developmental psychology and neuroscience tell us that behavior in biological organisms is organized in primitives called actions (not to be confused with movements or reactions)
  - Actions are behaviors initiated by a motivated subject, defined by goals, and guided using prospective information (prediction)
  - Elementary behaviors therefore are not reflexes but actions with goals, where perception and movement are integrated, and are initiated by motivation and guided by prediction.

Human Development - What is relevant?

- What is innate, where do we start from?
- What drives development?
- How is new knowledge incorporated, what are the forces that drive development?

Human Development - What is innate?

- Prestructuring
  - Muscular synergies to lower degrees of freedom
- Core Abilities
  - Abilities to describe perception of objects, geometric relationships, and understanding of people (Spelke 2000)

Human Development - What drives development?

- Newborn motivations are both social and explorative
  - Social motivations allow newborns to learn through social interaction

Human Development - How is new knowledge incorporated?

- The brain
  - Has mapping and formation dynamics baked in
  - Dynamically changes based on interactions with the environment
- The environment
  - Factors in the environment affect how the individual develops

Human Development - Canonical & Mirror Neurons

Canonical

- Active when:
  - Grasping an object
  - Fixating the same object
- Can be thought of as a Gibson Affordance

Mirror

- Active when:
  - When manipulating an object
  - When watching someone else perform the same action on the same object
- Explains mimicry behaviors in humans

Human Development - Sensorimotor Loops

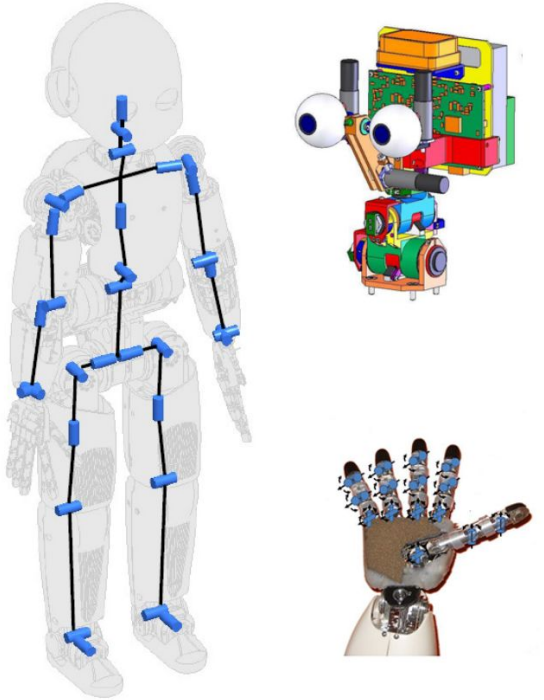
- Required for studying the human motor system
  - Play an essential role in recognition, planning, and understanding intentions (and language)
- Motor resonance phenomenon
  - Indicates that the motor system can actually be activated by passive observation of actions
- TMS pulses vs. H-reflex experiment
  - TMS pulses: evoke motor potentials through magnetic stimulation
  - H-reflex: electrically induced spinal stretch

Specific Results

1. Mechatronics of the iCub
2. Software Architecture
3. Sensorimotor coordination models
4. Object Affordances
5. Imitation and Communication

Specific Results - Mechatronics of iCub

- iCub is a humanoid robot 1 meter tall and weighing 22 kilograms
- It has 53 degrees of freedom, allowing it to crawl and fully explore its environment
- Has a camera for each eye that provides images at a resolution of 640 x 480 pixels



Specific Results - Software Architecture

- YARP (Yet Another Robot Platform): is the software package that drives iCub.
  - Allows for interconnecting sensors, processors, and actuators in the robot
- iCub uses YARP to define input and output ports for its control
  - This system is designed to be modular and easily extensible

Sensorimotor Coordination Models

- iCub depends on the development of sensorimotor coordination and mapping
  - Need to identify the sensory information required for motivated actions
- Two primary research themes
  1. Model how sensorimotor systems evolve from independent mechanisms
  2. Model the role of motor representation as a tool of both action and perception

fMRI Mirror System Experiment

- Functional brain studies showed that the mirror system is more activated when subjects observe a familiar action or sound than an unfamiliar observation
- fMRI experiment looked at whether an efficient mirror system develops in people without any visual experience
    - Found that the system can develop in the absence of sight using other sensory modalities
    - And the results showed that sound can engage the mirror system for actions that have never been learned visually

Human-Infant Gaze Experiment

- Answers whether other people's actions can be understood by projecting them onto one's own action system
- Experiment measured gaze and hand movements of adults and infants
  - Subjects either performed an action or watched the same action being performed
- Findings:
  - For the movement, adults and infants had incredibly similar performance
  - In the observation, infants were more delayed than the adults

Object Affordances

- In this paper, affordances are used by Gibson’s definition
  - All action possibilities on a certain object, based on the actor’s capabilities
  - Whether or not to exploit an affordance is based on goals, values, and interests
- iCub can learn affordances of objects
  - iCub team conducted research on exploratory behaviors and what relevant information is needed

Acquisition of Affordances

- Humans learn affordances throughout their lives
- There are two primary paths to acquiring new affordances:
  - Self-exploration (autonomous learning)
  - Observation (learning from examples)
- Learning by observation requires some base capabilities which are initially acquired by self-exploration

Bayesian Networks

- iCub learns affordances using Bayesian Networks
  - BN's are sets of nodes that describe random variables, sets of directed edges encoding conditional probabilities, and a set of conditional probability distributions

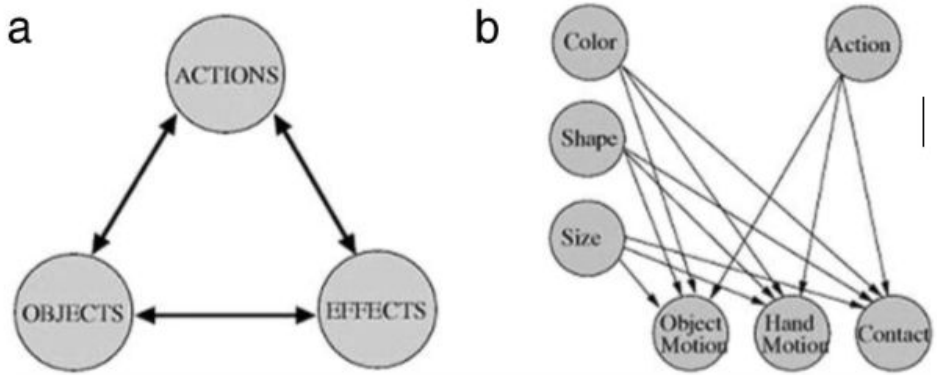
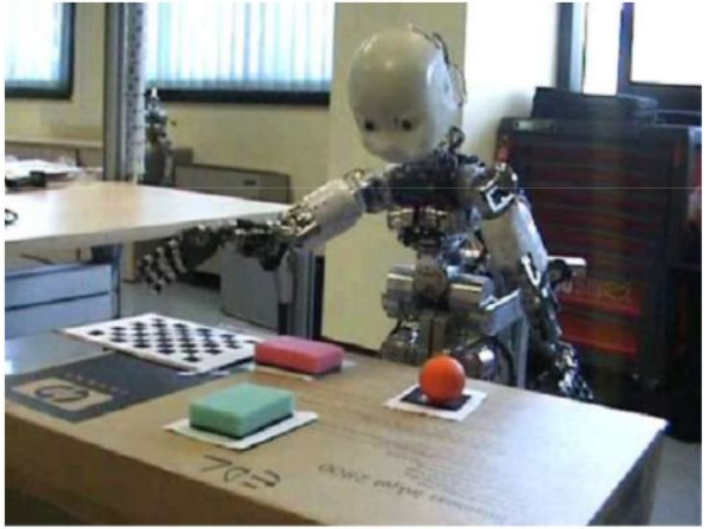


Fig. 3. (a) General affordance scheme relating actions, objects (through their characteristics) and the resulting effects. (b) A particular BN encoding affordances.

Bayesian Networks

A: Action
C: Object Color
Sh: Object Shape
S: Object Size
OV: Object Velocity Profile
HV: Hand Velocity Profile
Di: Hand Object Distance Profile



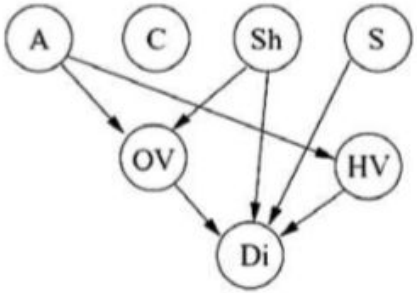


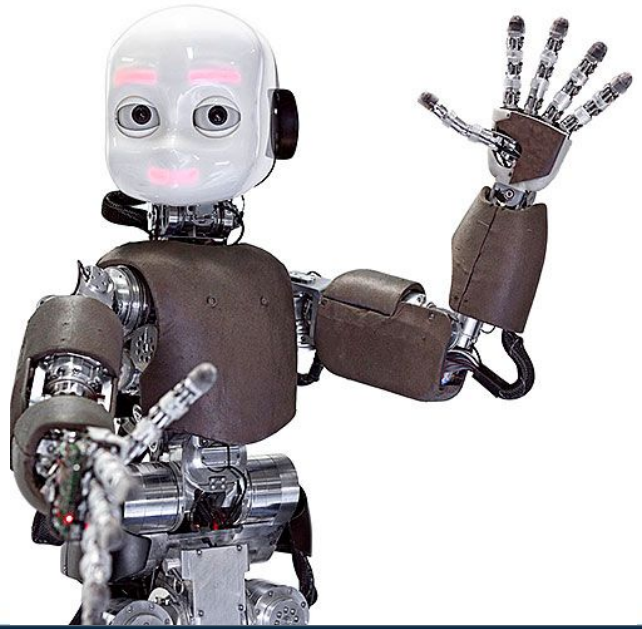
Fig. 5. Learned network. The variables represent *A* action, *C* object colour, *Sh* object shape, *S* object size, *OV* object velocity profile, *HV* hand velocity profile, *Di* hand object distance profile.

Bayesian Networks

https://youtu.be/i8GXuYe2dfY

Conclusion

- iCub is a cognitive humanoid robot pushing the boundaries of research in developmental robotics
- Designed based on a road map of human development, which stressed the role of prediction for skilled movement
- Incorporates a model of sensorimotor control and development to consider actions



Discussion #1 - @74_f4

“Particularly, human babies evolve and become more mobile as they grow. Their cognitive development is a result of them exploring their environment. The concept of objecthood in social environments is attained through exploratory behavior and iCub focuses on this principle as well. A high variability in the environment also serves to improve cognition and exploration skills due to increase in curiosity.”

- How is movement important for the development of human cognition?
- What other factors can be used to motivate curiosity and exploration in a limited environment?

Discussion #2 - @74_f6

- What methods besides Bayesian Networks can be used to model affordances?

https://youtu.be/ghUFweqm7W8