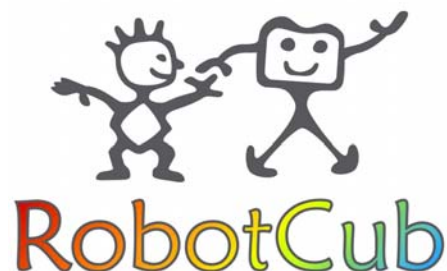


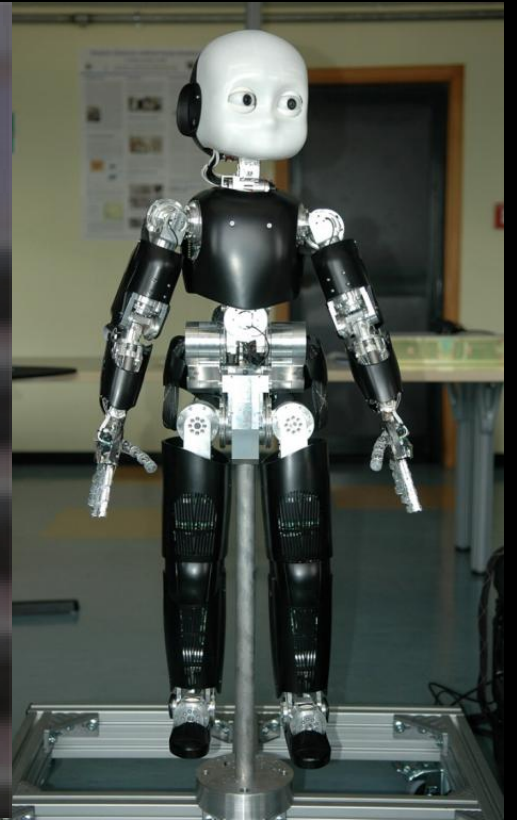
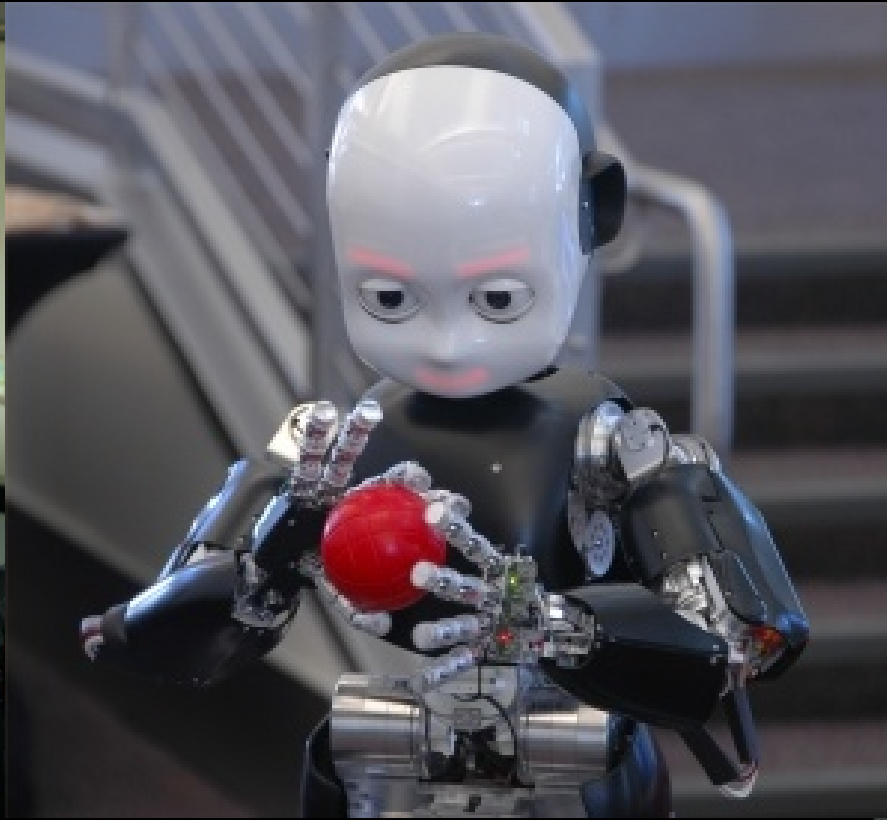
Cognitive Development and The iCub Humanoid Robot

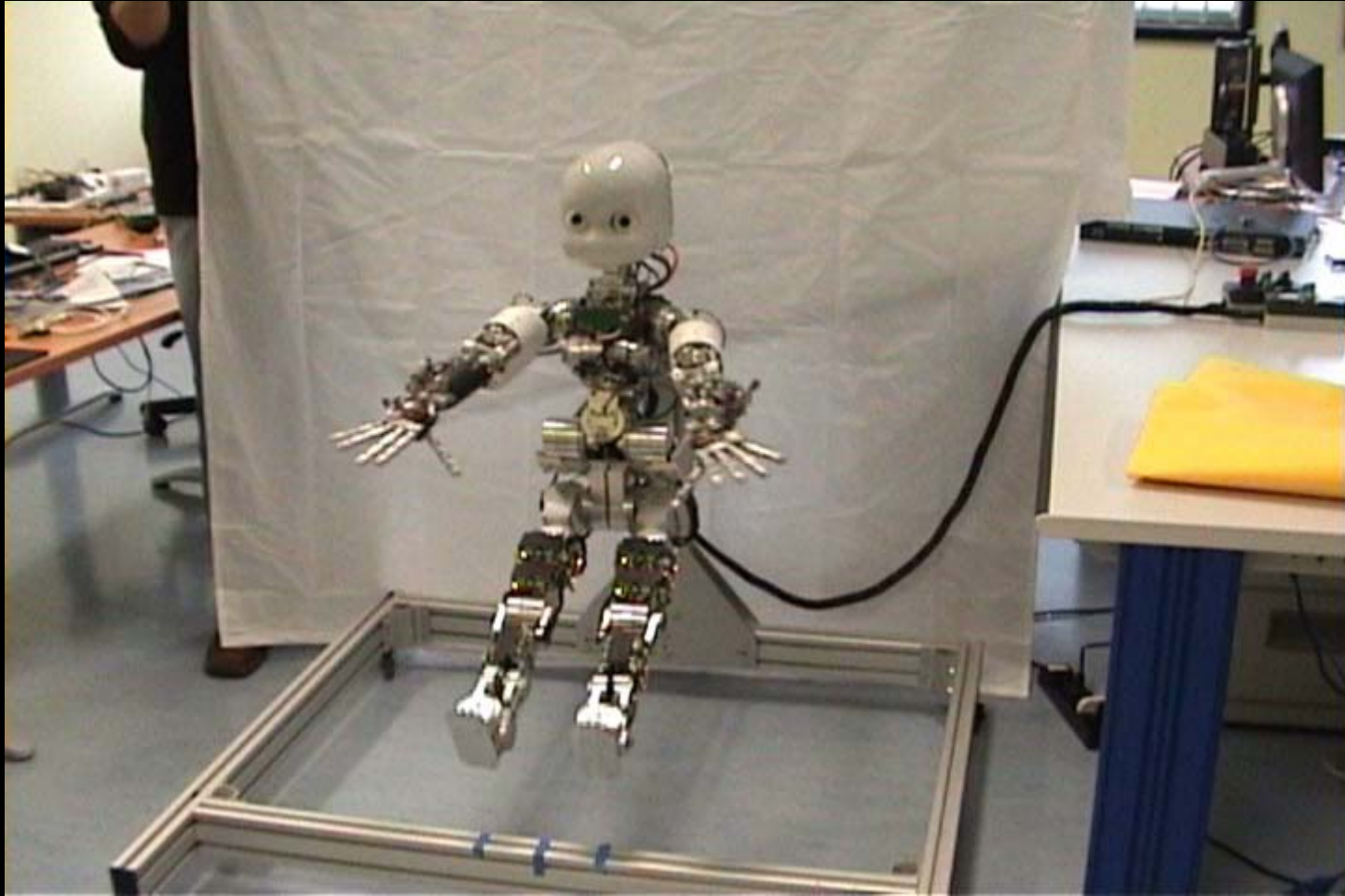


Second EUCogII Members Conference
"Development of Cognition in Artificial Agents"

Zürich
29 January 2010

iCub





Giulio Sandini, IIT & U. Genoa
Giorgio Metta, IIT & U. Genoa
Lorenzo Natale, IIT & U. Genoa
Francesco Nori, IIT & U. Genoa
Paul Fitzpatrick, IIT & U. Genoa
Francesco Orabona, IIT & U. Genoa
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Andrey Olynyyck, U. Ferrara
Livio Finos, U. Ferrara
Giovanni Ottoboni, U. Ferrara
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Kerstin Rosander, U. Uppsala
Olga Kochukova, U. Uppsala
Helena Gronqvist, U. Uppsala



Universität Zürich



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Giulio Sandini
Giorgio Metta

Cecilia Laschi
Paolo Dario

Rolf Pfeifer

Claes von Hofsten

Luciano Fadiga



U. Hertfordshire	IST - Lisbon	U. Sheffield/IIT	EPFL	Telerobot S.r.l.
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Kerstin Dautenhahn
Chrystopher L. Nehaniv

José Santos-Victor
Alexandre Bernardino

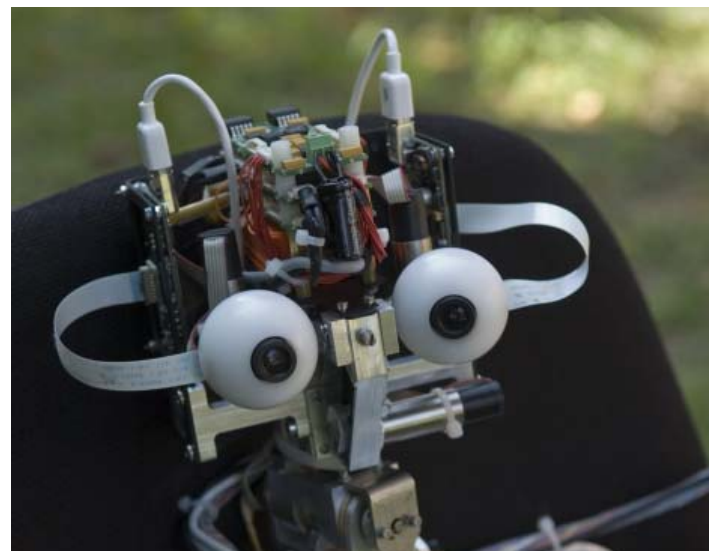
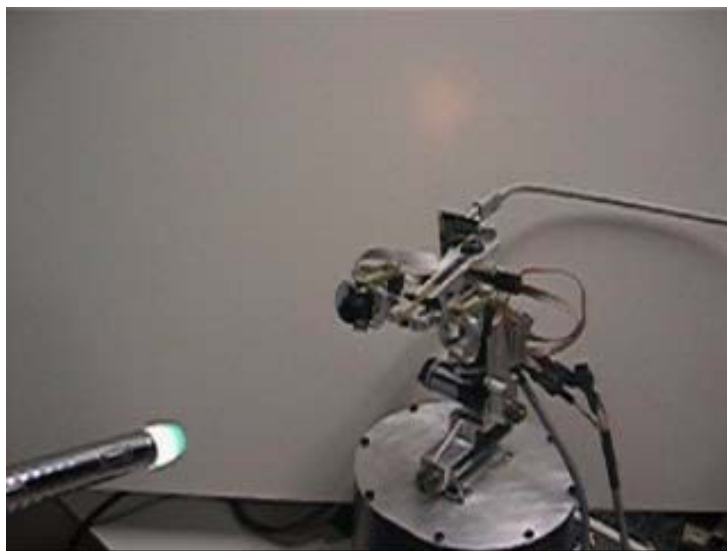
Darwin Caldwell
Nikos Tsagarakis

Aude Billard
Auke Ijspeert

Francesco Becchi

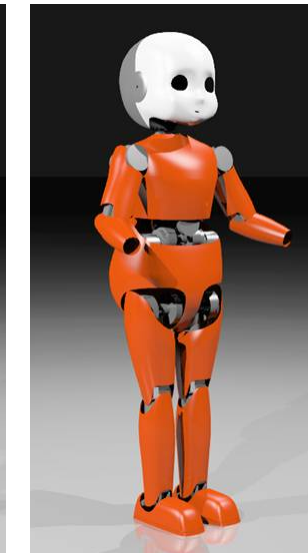
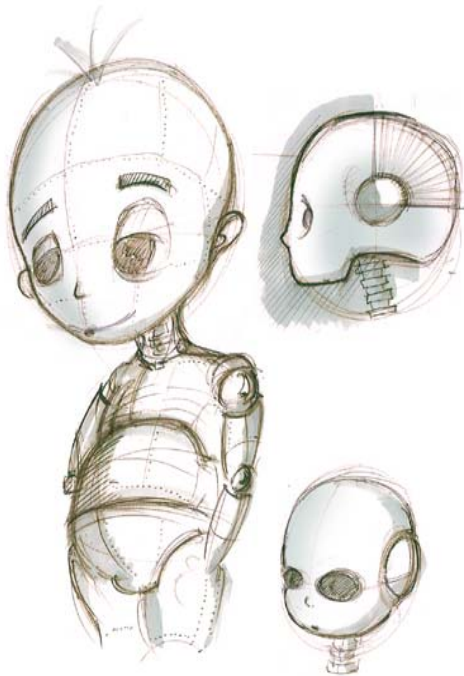
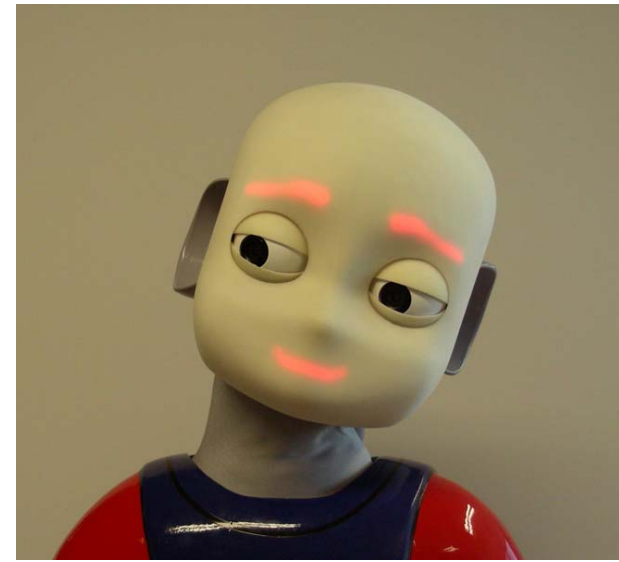
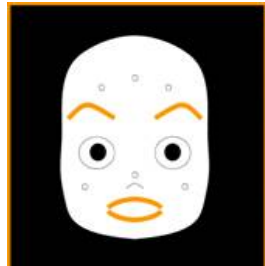
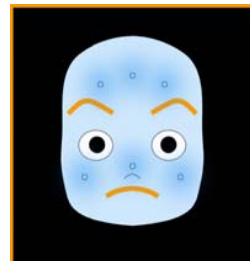
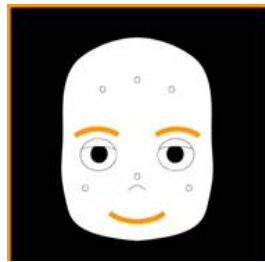
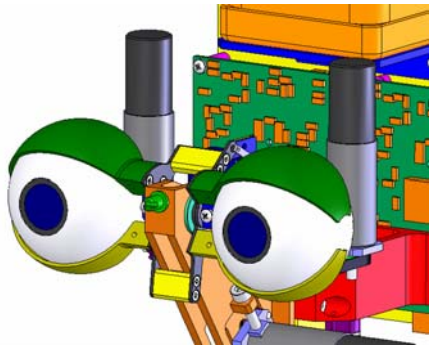
Head Design

(IST)

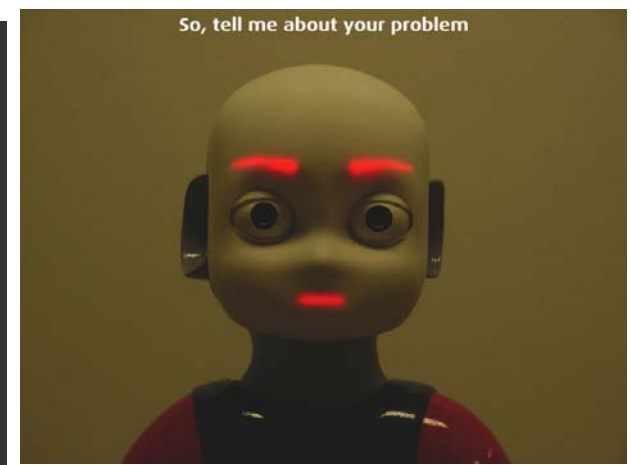
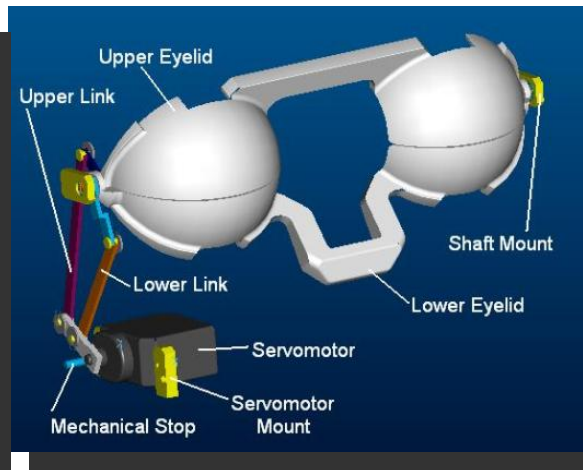
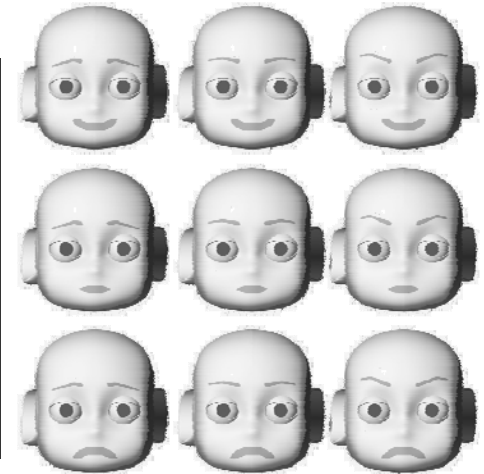
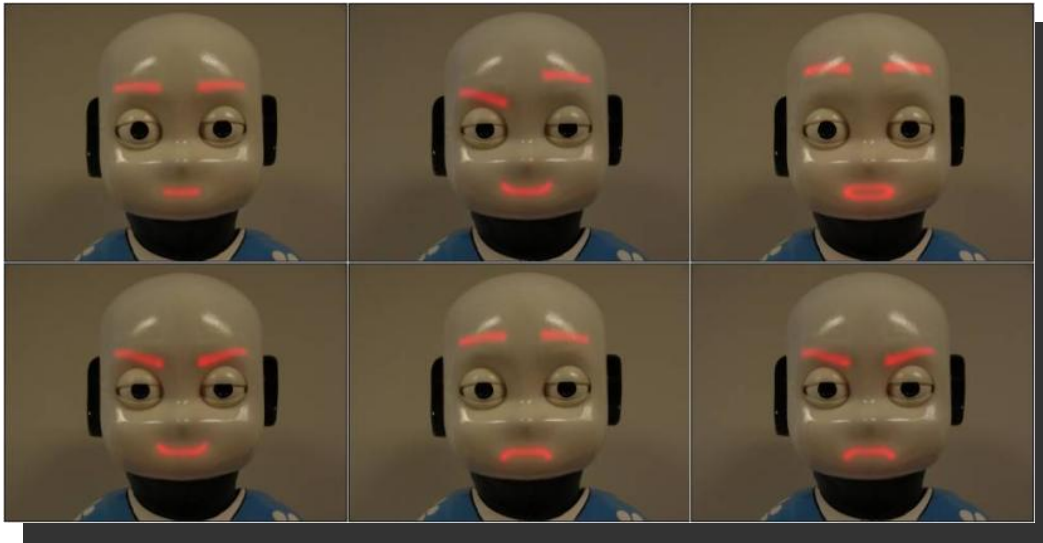


Face/Cover Design

(IST)



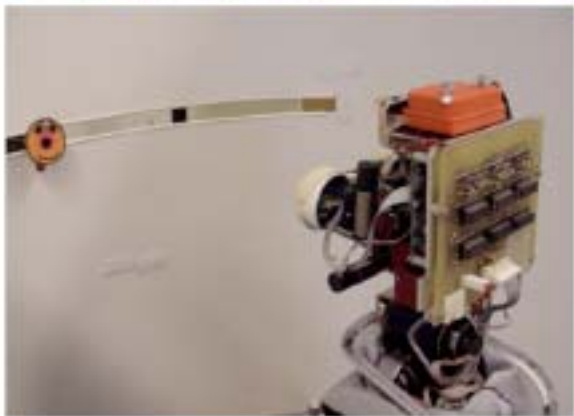
Facial Expressions (IST)



Smooth Pursuit

(U. Uppsala, IST, SSSA)

Perception and anticipation of the upcoming motion



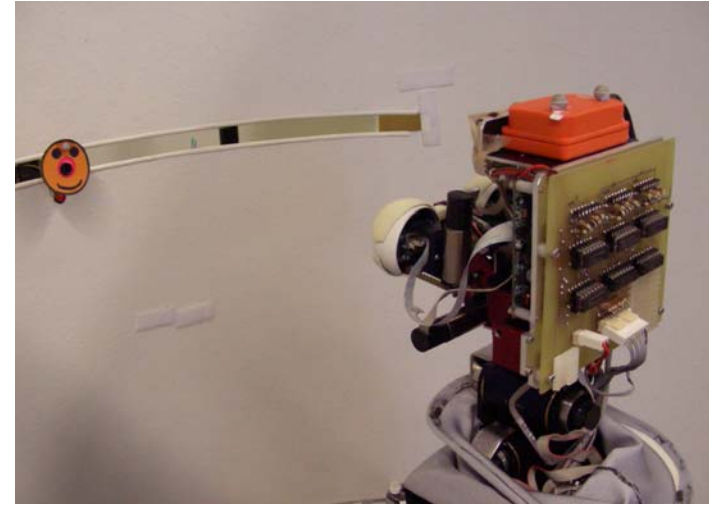
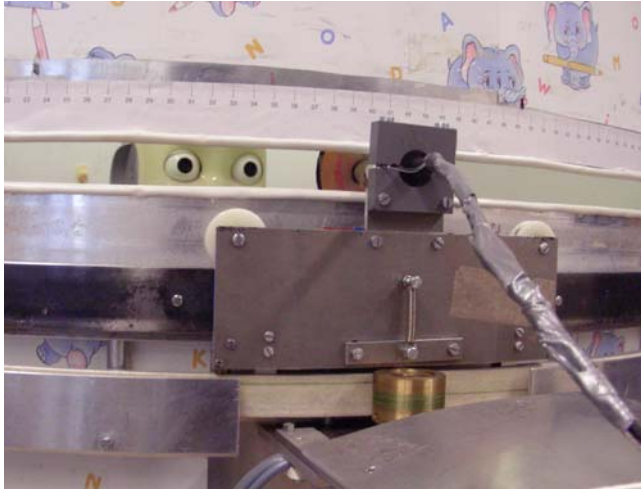
4-week-old



9-week-old

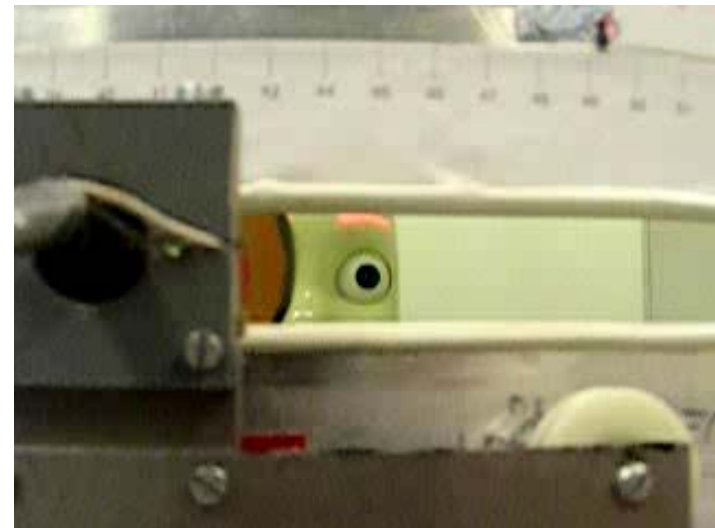
Smooth Pursuit

(U. Uppsala, IST)



“Uppsala drum” – where we can rotate the base and/or the target

Manuel Lopes, Alexandre Bernardino, José Santos-Victor, Claes von Hofsten and Kerstin Rosander.
Biomimetic Eye-Neck Coordination. IEEE - International Conference on Development and Learning, Shanghai, China, 2009.



Predictive tracking with temporarily-occluded objects

(U. Uppsala, U. Zürich, SSSA)

4-month-old children move gaze ahead of time to the place where they expect the object to appear



9-week-old lag= 740 ms



17-week-old lag = 15 ms



Smooth Pursuit

"Infant" Gaze (U. Uppsala & IST)



Attention

- Posner task (IST & U. Ferrara)



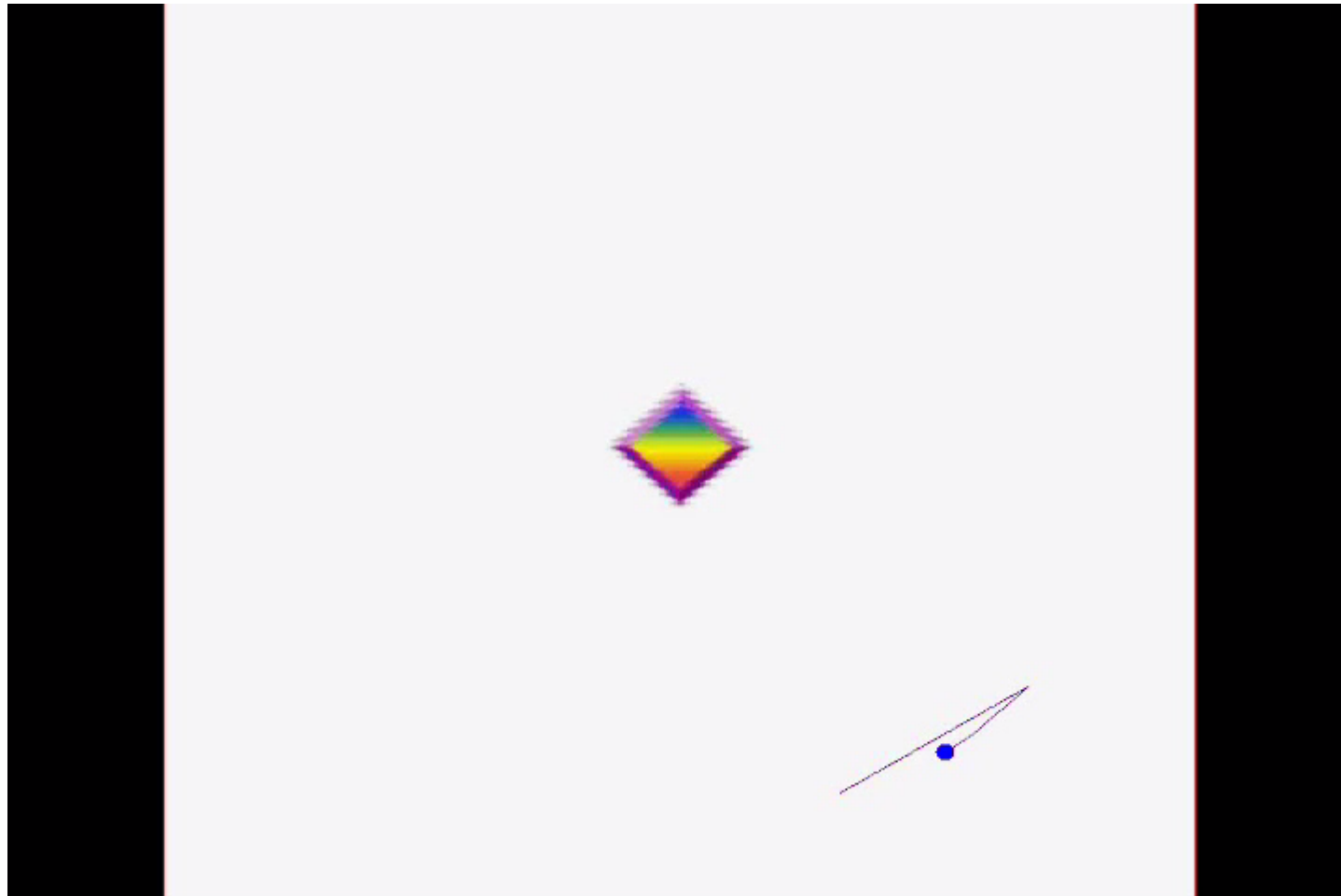
Attention

- Infant Gaze (U. Uppsala)



Attention

- Infant Gaze (U. Uppsala)



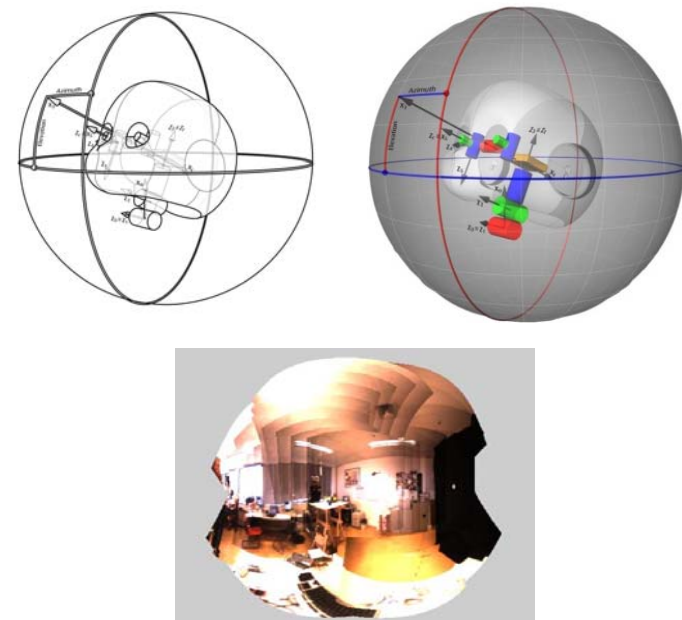
Attention

Multi-Modal Bottom-Up Attention System (IST & UZH)

Saliency



Egocentric



Multimodal Saliency-Based Bottom-Up Attention A Framework for the Humanoid Robot iCub, Jonas Ruesch, et al. ICRA 2008.

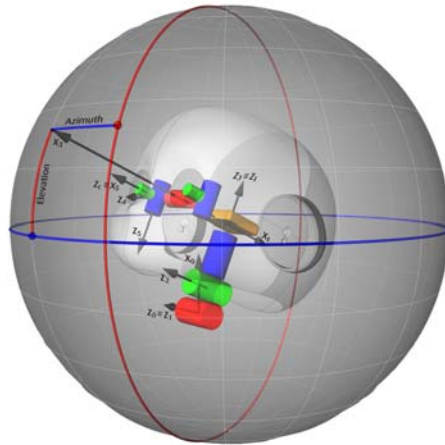
Attention

- Top-down (IST)
- Representation and detection familiar objects
- Learning triggered by depth (proximity based) segmentation

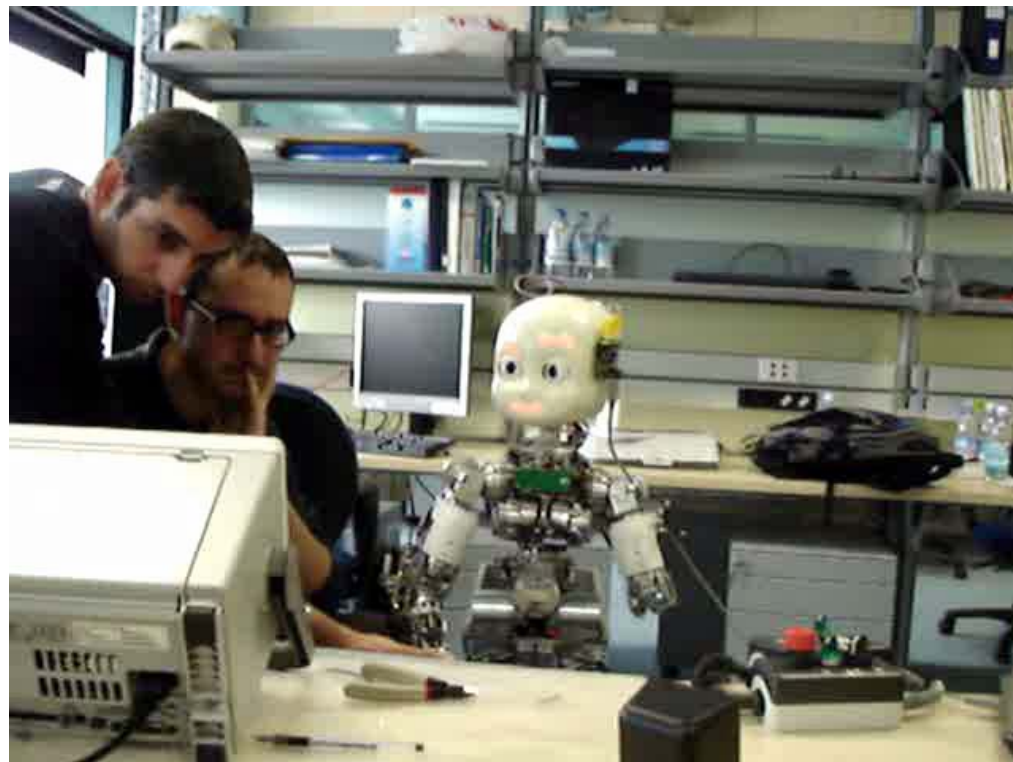


From Pixels to Objects: Enabling a spatial model for humanoid social robots. Dario Figueira, *et al.* ICRA'09

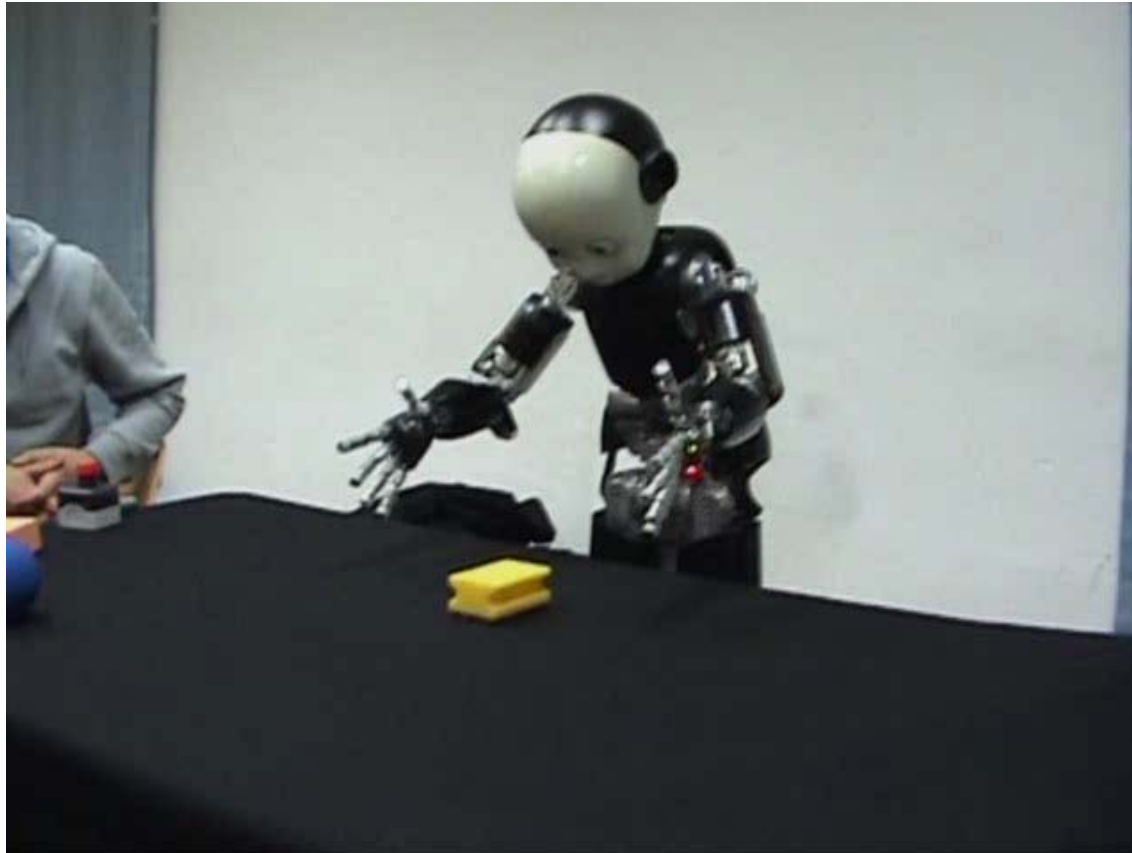
Attention



(IST & UZH)

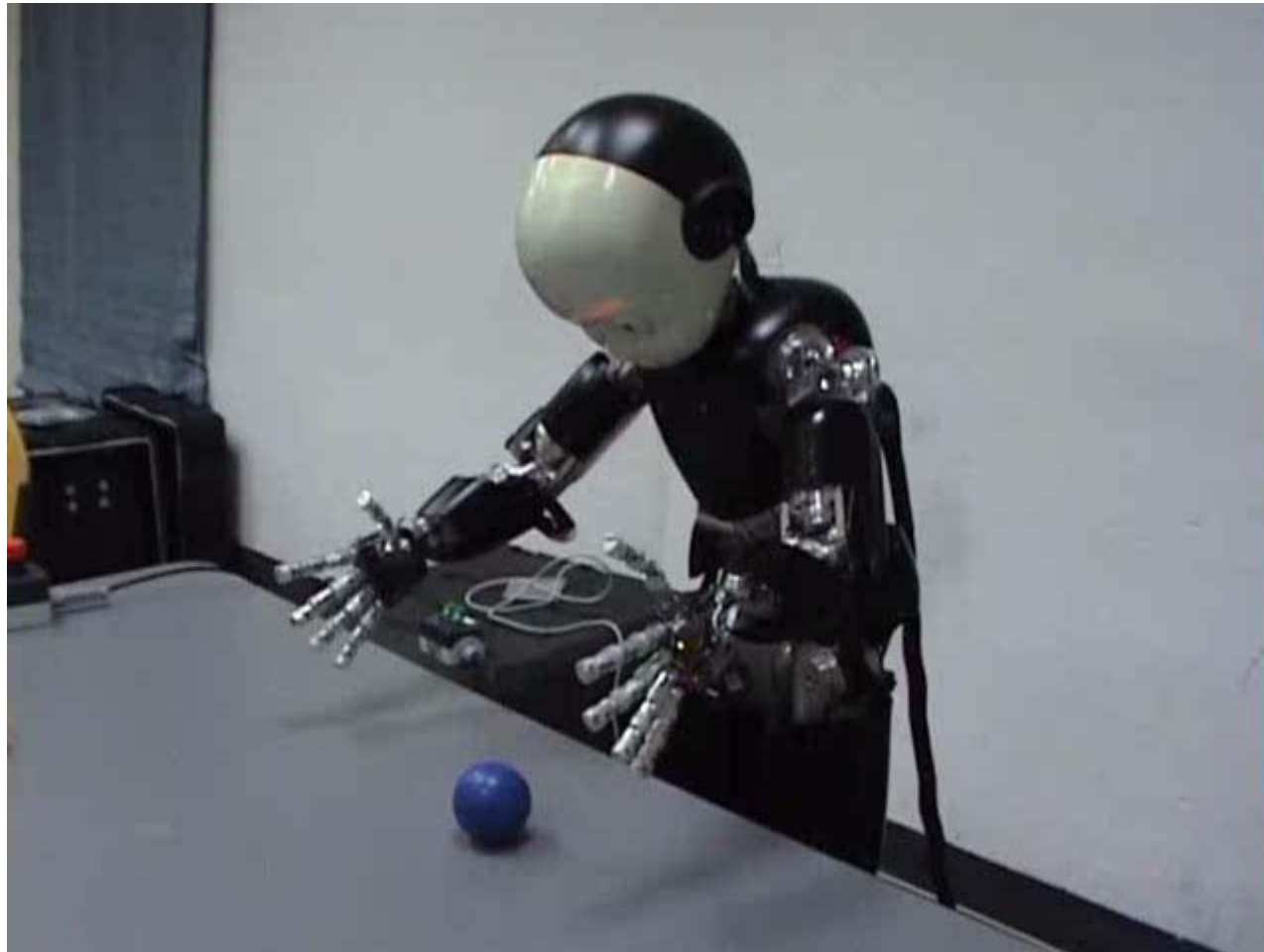


Reaching and Grasping



(U. Genoa, IIT, IST)

Reaching and Grasping



(U. Genoa, IIT, IST)

Crawling

Kinematic studies of crawling children as they crawled, went from sitting to crawling, and crawling to sitting (U. Uppsala, EPFL)



Crawling to sitting

Crawling

Kinematic studies of crawling children as they crawled, went from sitting to crawling, and crawling to sitting (U. Uppsala, EPFL)

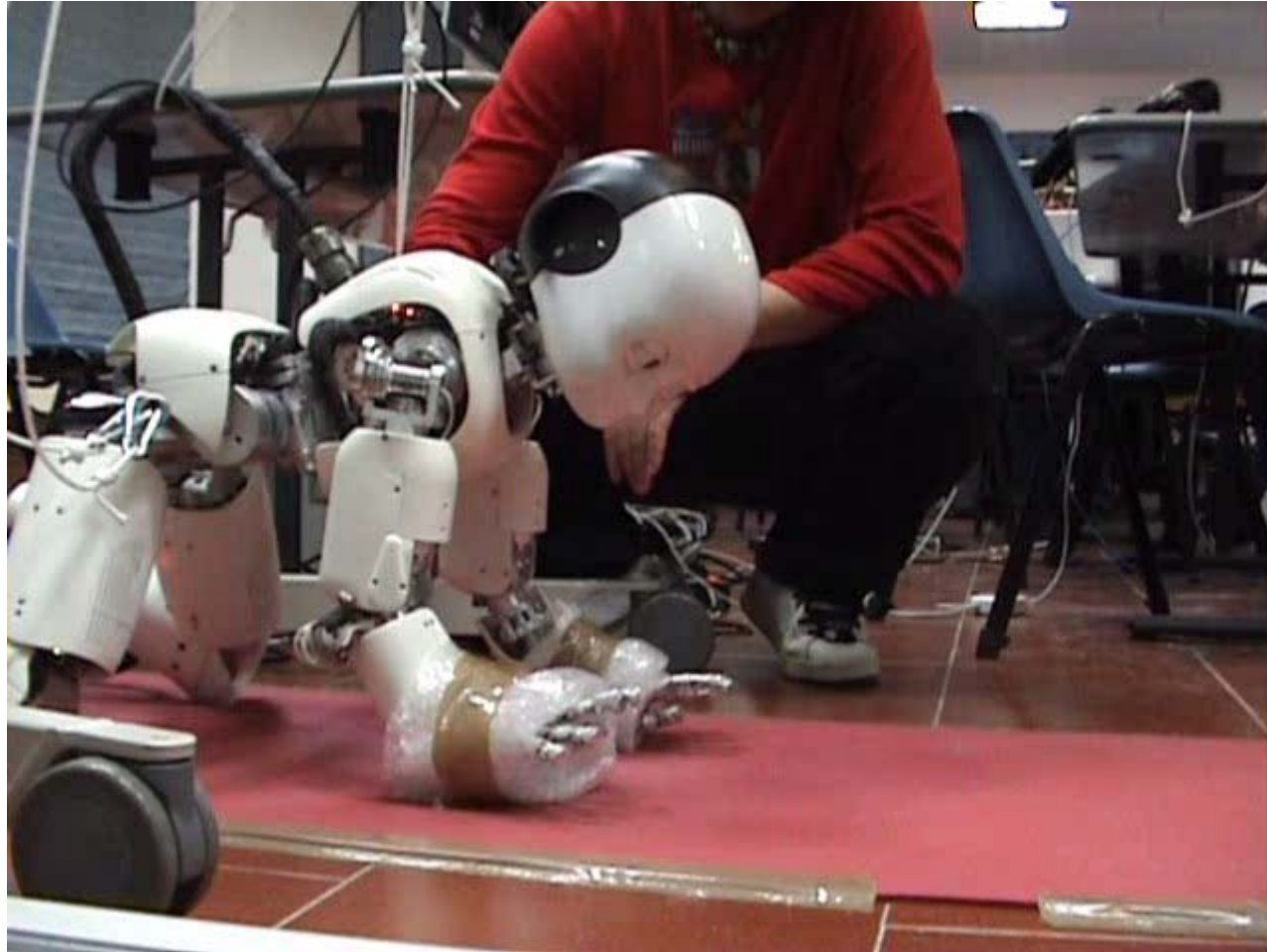


Crawling with one hand occupied

Crawling

Kinematic studies of crawling children as they crawled, went from sitting to crawling, and crawling to sitting (U. Uppsala, EPFL)





(U. Uppsala, EPFL)



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Manual

This is a tentative table of contents for what should be in the iCub manual. Please do not edit these pages at this point.

Contents [v]

- led
- lowerbody
- cabling
- mechanics
- electric
- legs
- torso
- bo
- dr
- mc4
- mcp
- DC104
- serial_dsp
- tools
- ball
- upperbody
- cabling
- mechanics
- elbow
- forearm
- bo

search

Go Search

toolbox

- What links here
- Related changes
- Upload file
- Special pages
- Printable version
- Permanent link

ICL is available, shell

For help, press F1

Wiki

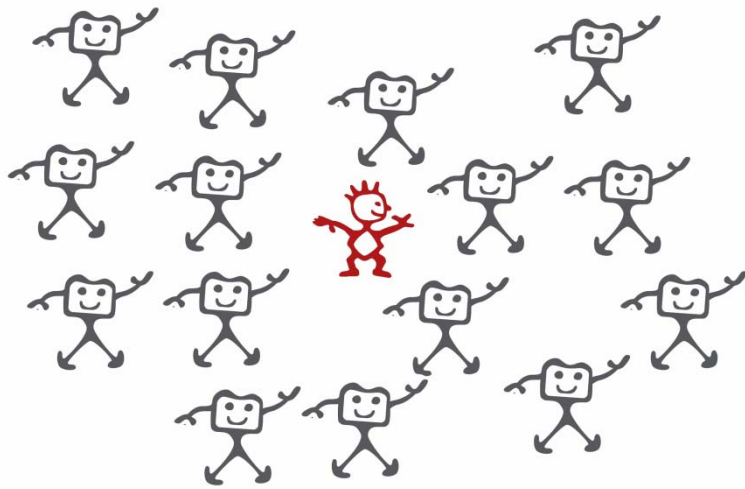
Software

Hardware

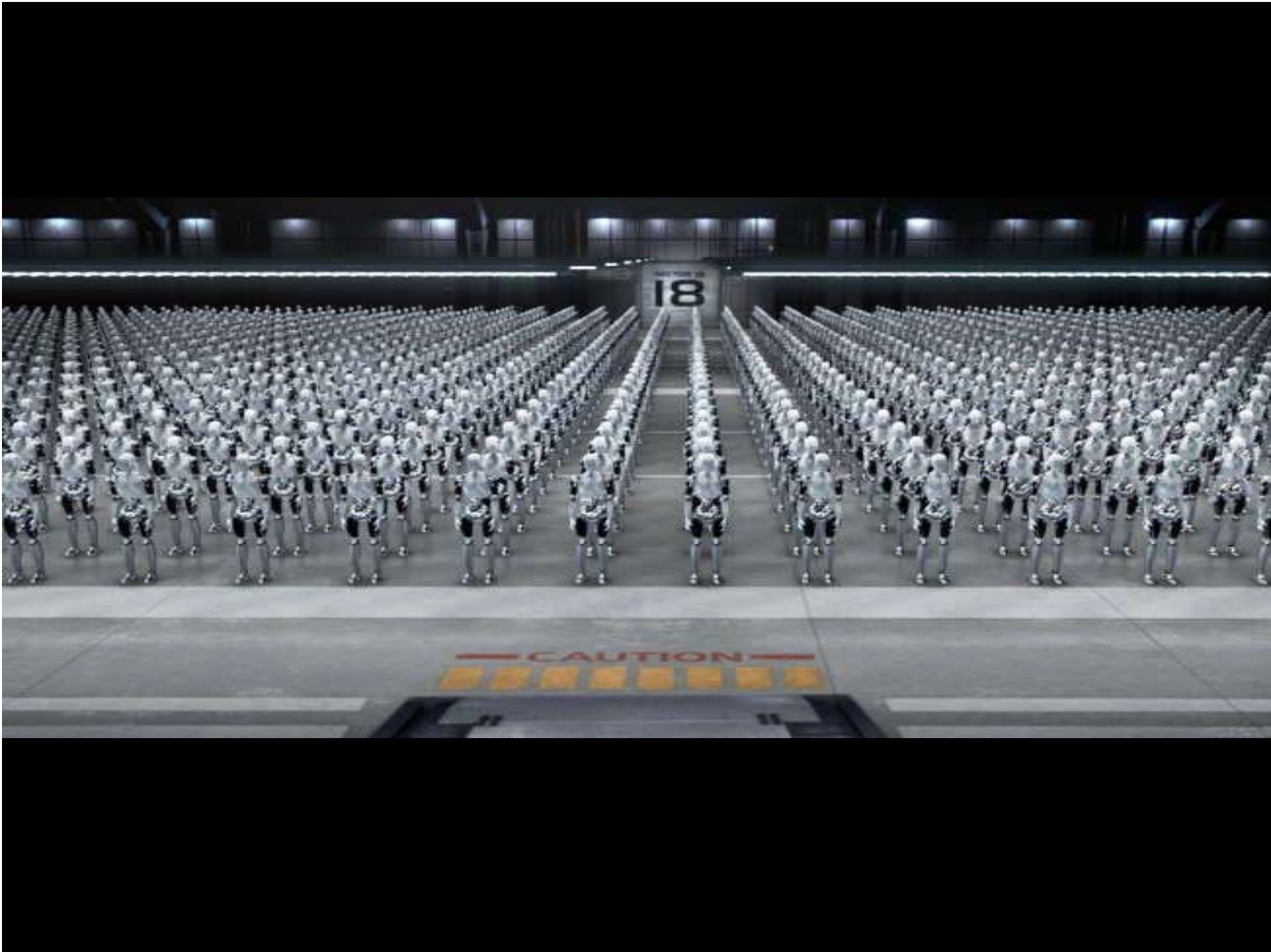
Drawings

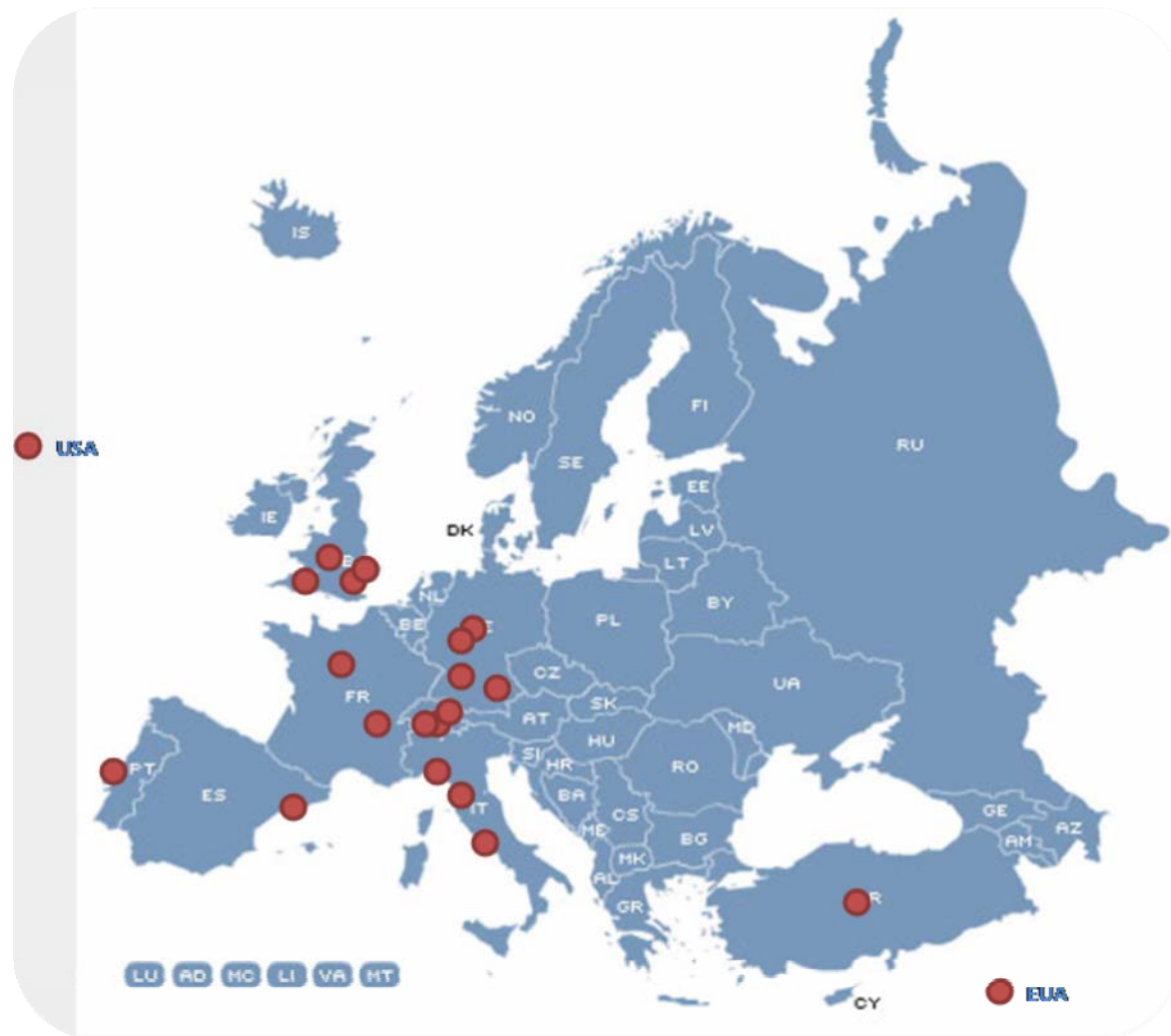
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2	2	USB to CAN Bus Interface	COMMERCIAL	AP	FICD	297	691	To be used for testing, not in the final design (replaced by 10)
3	3	TRIPLE WIRE CABLE 4 x 0.15 (3mm)	COMMERCIAL	CA	Ramat	181	271.5	OK
4	4	CABLE 3x17 FOPICPER NOT IN PAPER	COMMERCIAL	CA	Ramat	66	99	OK for testing, not used if 10 is in the final assembly (used 10)
5	5	BELL cover (small)	COMMERCIAL	CA	Micro-design	280	280	
6	6	SLP control card	COMMERCIAL	CA	Micro-design	333	333	
7	7	DC CONTROLLER CARD	COMMERCIAL	CA	Micro-design	240	240	
8	8	DC CONTROLLER POWER SUPPLY	COMMERCIAL	CA	Micro-design	333	333	
9	9	ORACLE MINI OBJECT TWO (2.0/4.0)	COMMERCIAL	CA	Micro-design	333	333	
10	10	POWER SUPPLY 1.8V	COMMERCIAL	CA	Micro-design	333	333	
11	11	POWER SUPPLY 3.3V	COMMERCIAL	CA	Micro-design	333	333	
12	12	HARMONIC DRIVE DEARDESH 100 L	COMMERCIAL	CA	Micro-design	333	333	
13	13	HARMONIC DRIVE DEARDESH 100 L	COMMERCIAL	CA	Micro-design	333	333	
14	14	DEARDESH COOLING COOLING UNIT 1.0	COMMERCIAL	CA	Micro-design	333	333	
15	15	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
16	16	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
17	17	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
18	18	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
19	19	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
20	20	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
21	21	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
22	22	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
23	23	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
24	24	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
25	25	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
26	26	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
27	27	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
28	28	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
29	29	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
30	30	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
31	31	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
32	32	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
33	33	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
34	34	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
35	35	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
36	36	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
37	37	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
38	38	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
39	39	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
40	40	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
41	41	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
42	42	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
43	43	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
44	44	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
45	45	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
46	46	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
47	47	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
48	48	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
49	49	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	
50	50	COOLING SYSTEM 1.0	COMMERCIAL	CA	Micro-design	333	333	

iCub production

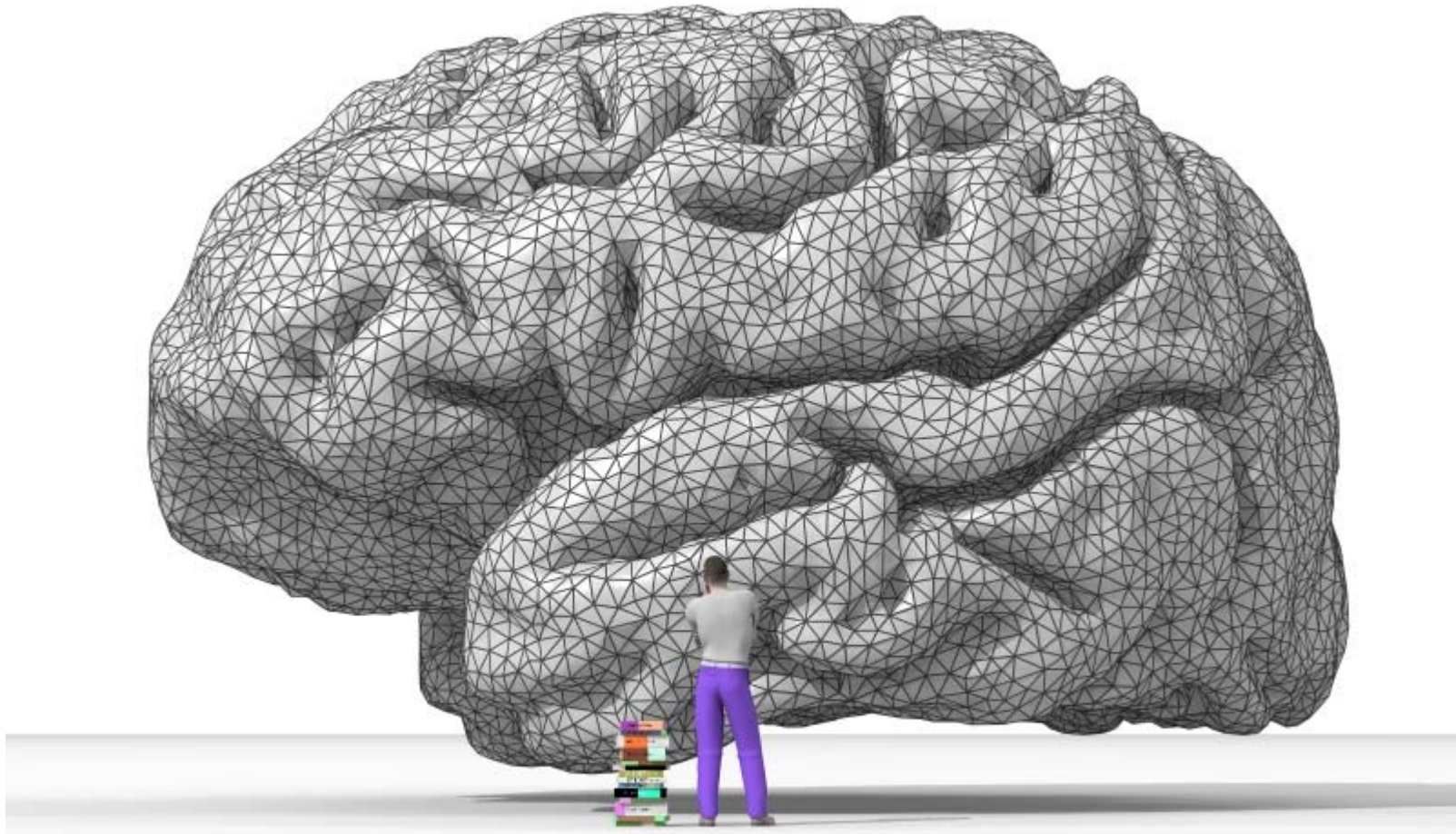


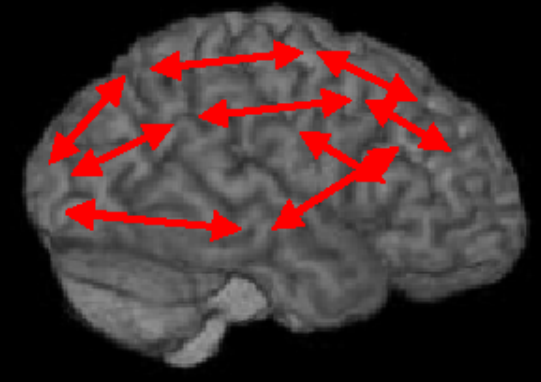
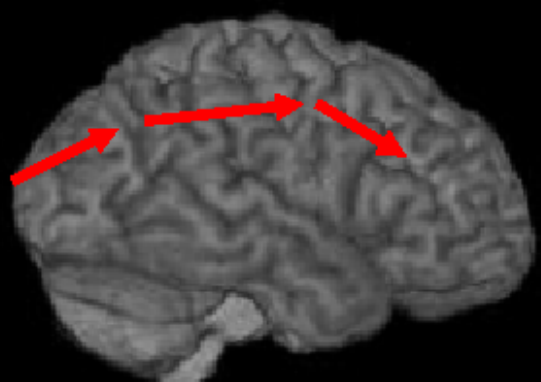
15 iCubs completed and 5 more in production







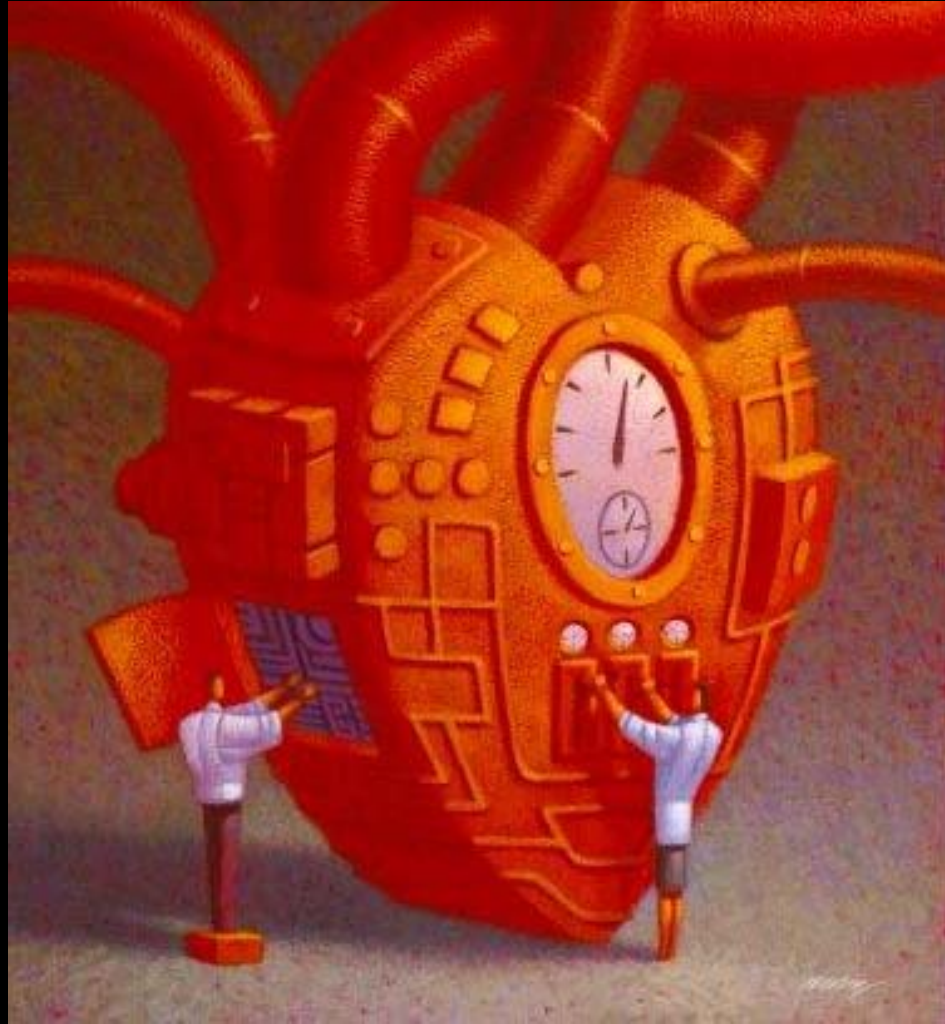


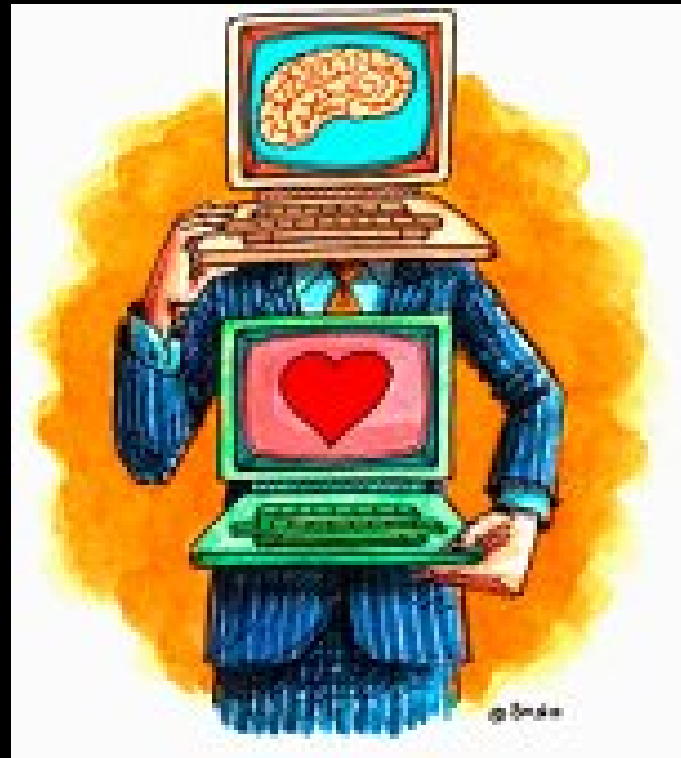




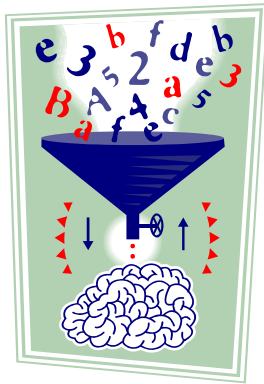


Mind as Motion, Port & Van Gelder





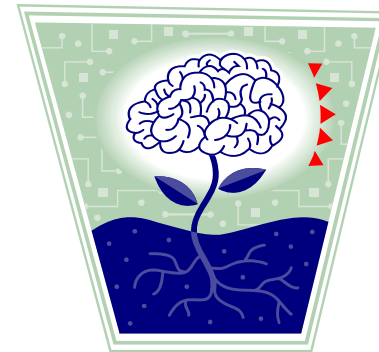
GOFAI



Functionalist & Dualist

Mechanisms are independent of the instantiation

Cognitive Systems



Emergent, Embodied, & Enactive

Embodiment plays a constitutive role in the process of cognition





Breaking the 'here-and-now barrier'



Breaking the 'prior knowledge barrier'



The fire-hose of experience



Cognition: guide actions

- Missing information
 - Uncertain information
 - LATE information
-
- Adapt (make sense of the world)
 - Anticipate (predict what might happen)

Cognitive systems

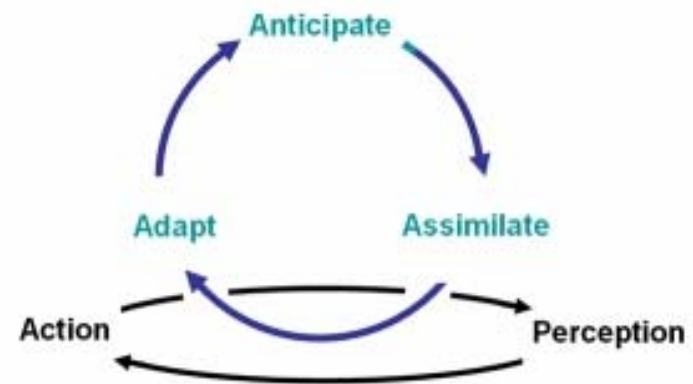
- Anticipate
- Assimilate
- Adapt



Learn & develop



- Predict future events when selecting actions
- Learn from what actually happens
- Modify subsequent predictions
- Autonomously



- What makes an action the right one to choose?
- What type of behaviour does cognition enable?
- What motivates cognition?
- How is perception guided?
- How are actions selected?
- What makes cognition possible?
- Cognitive skills can improve, but what do you need to get started?
- What drives the developmental process?

Embodiment

Meaning
(inter-agent epistemology)

Development

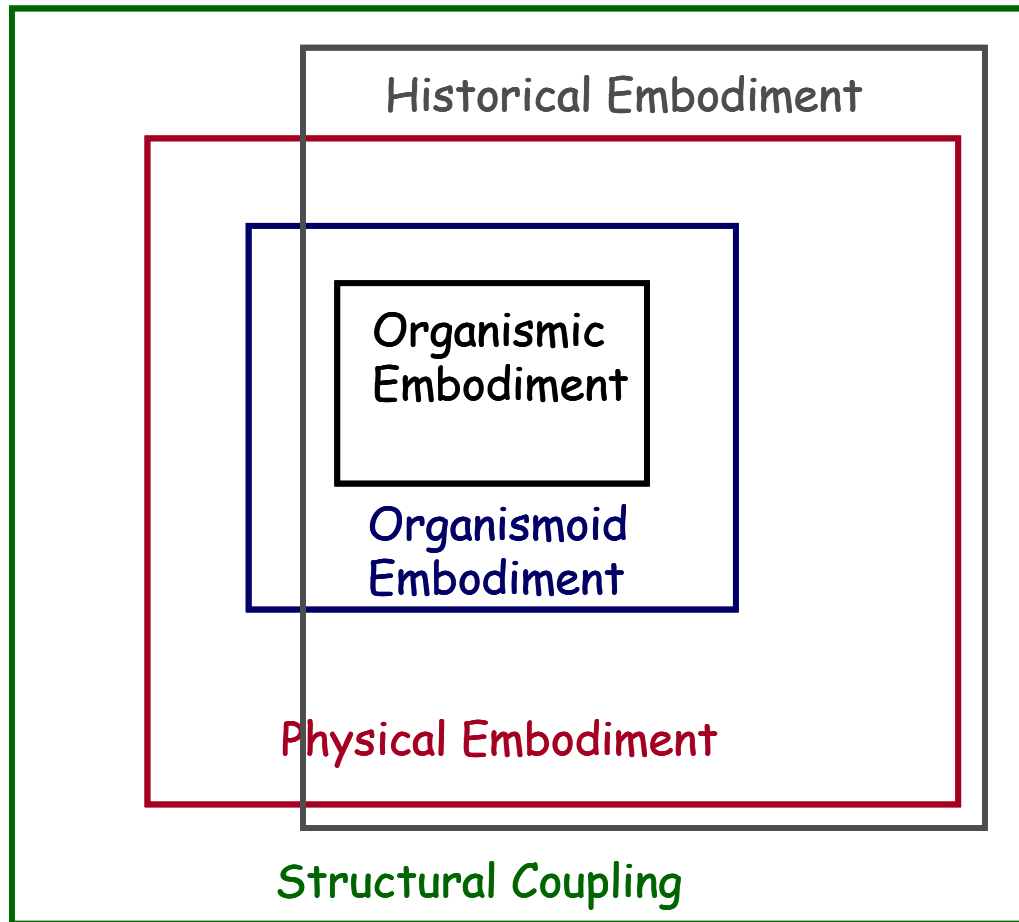
Meaning emerges through shared consensual
experience mediated by interaction



Bond of Union
M. C. Escher, 1956

Types of Embodiment

Why Humanoid Robotics is Special



Shared epistemology \Rightarrow
compatible embodiment

From: T. Ziemke, 2003

The problem of disparate embodiment & interaction histories





The problem of disparate embodiment & interaction histories



Development

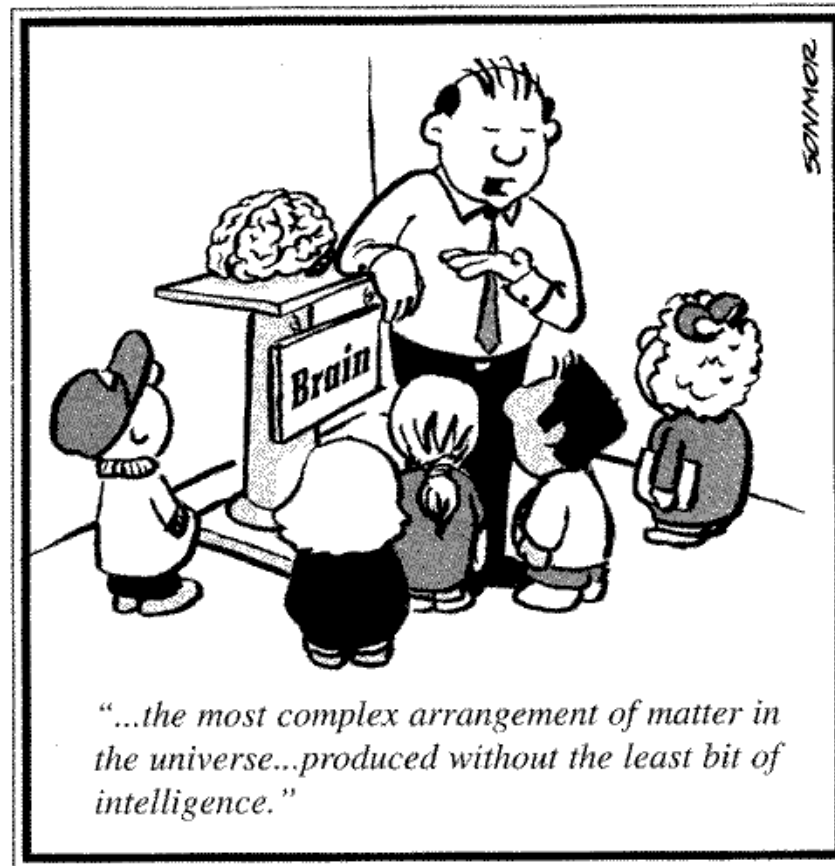
Progressive ontogenetic acquisition of anticipatory capabilities

- Cognition cannot short-circuit ontogeny
- Necessarily the product of a process of embodied development
- Initially dealing with immediate events 
- Increasingly acquiring a predictive capability 

Cognition and perception are functionally-dependent on the richness of the action interface

Luc Steels:

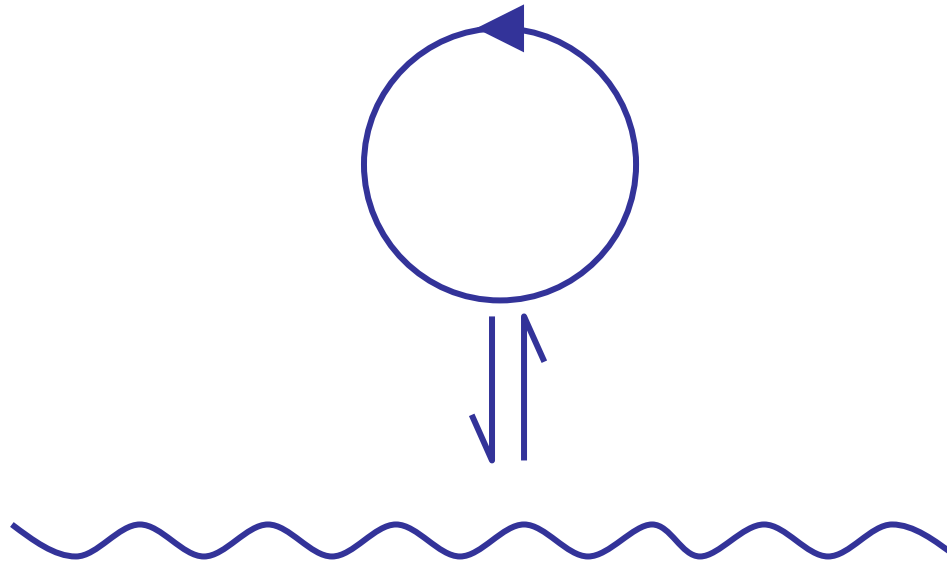
1. AI through design
2. AI through statistical machine learning
3. **Self-generated AI**
(AI by orchestrating the processes that generate it)



Self-Generated AI ... HOW?

Phylogeny
(Cognitive Architecture)

Ontogenesis
(Learning & Development + Motivations)

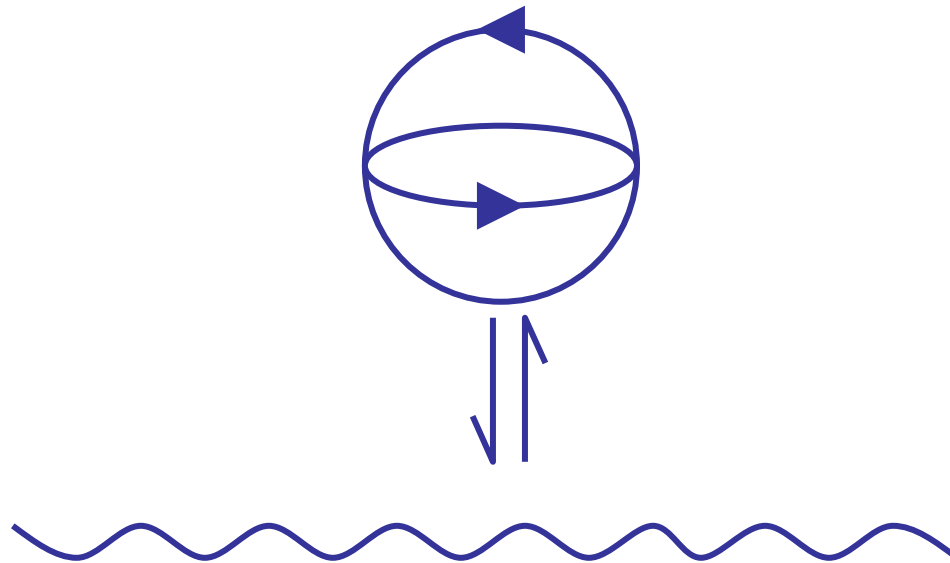


Co-Determination / Structural Coupling

BUT ... simple coupling between sensor and motor surfaces

Perturbation is only effected by the environment

[Note: this ideogram and similar ones to follow were introduced in Maturana and Varela 1987]



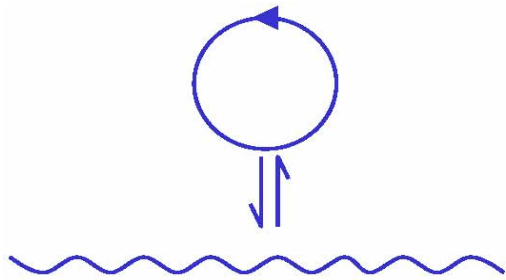
Cognitive system: operationally-closed system with a nervous system

Nervous system facilitates a highly-plastic mapping between sensor and motor surfaces

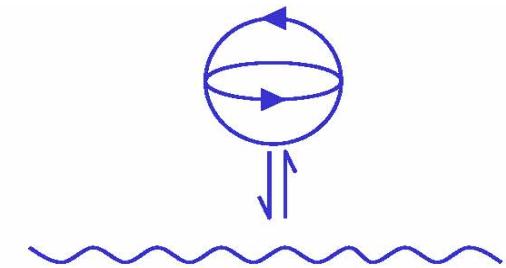
Perturbation by both environment and system (of receptors & NS)

"Development is the result of a process with two foci, one in the central nervous system and one in the subject's dynamic interactions with the environment"

Claes von Hofsten



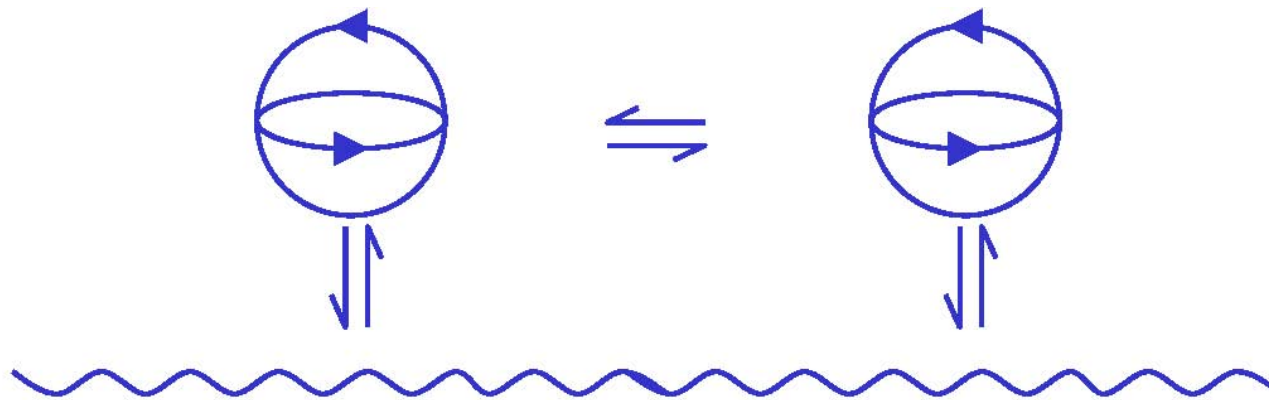
→ t



→ t

Anticipation / Planning / Deliberation / Prediction

INTERACTION



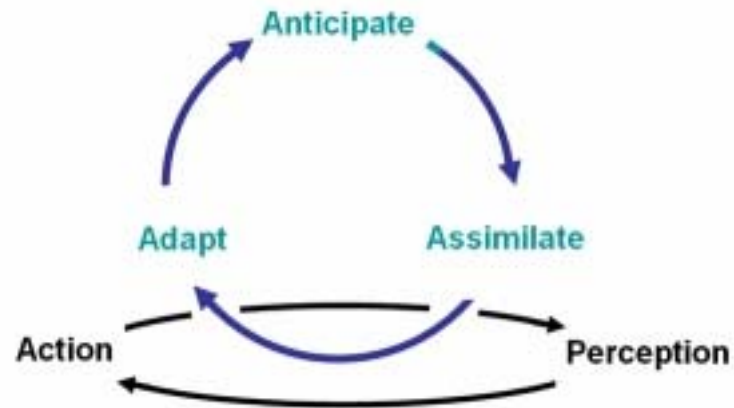
A shared activity in which the actions of each agent
Influence the actions of the other agents in the same interaction
Resulting in a mutually-constructed pattern of shared behaviour
[Ogden et al.]

COGNITION & SENSE-MAKING

Is a process whereby the issues that are important for the continued existence of the cognitive entity are brought forth: co-determined by the entity as it interacts with the environment in which it is embedded

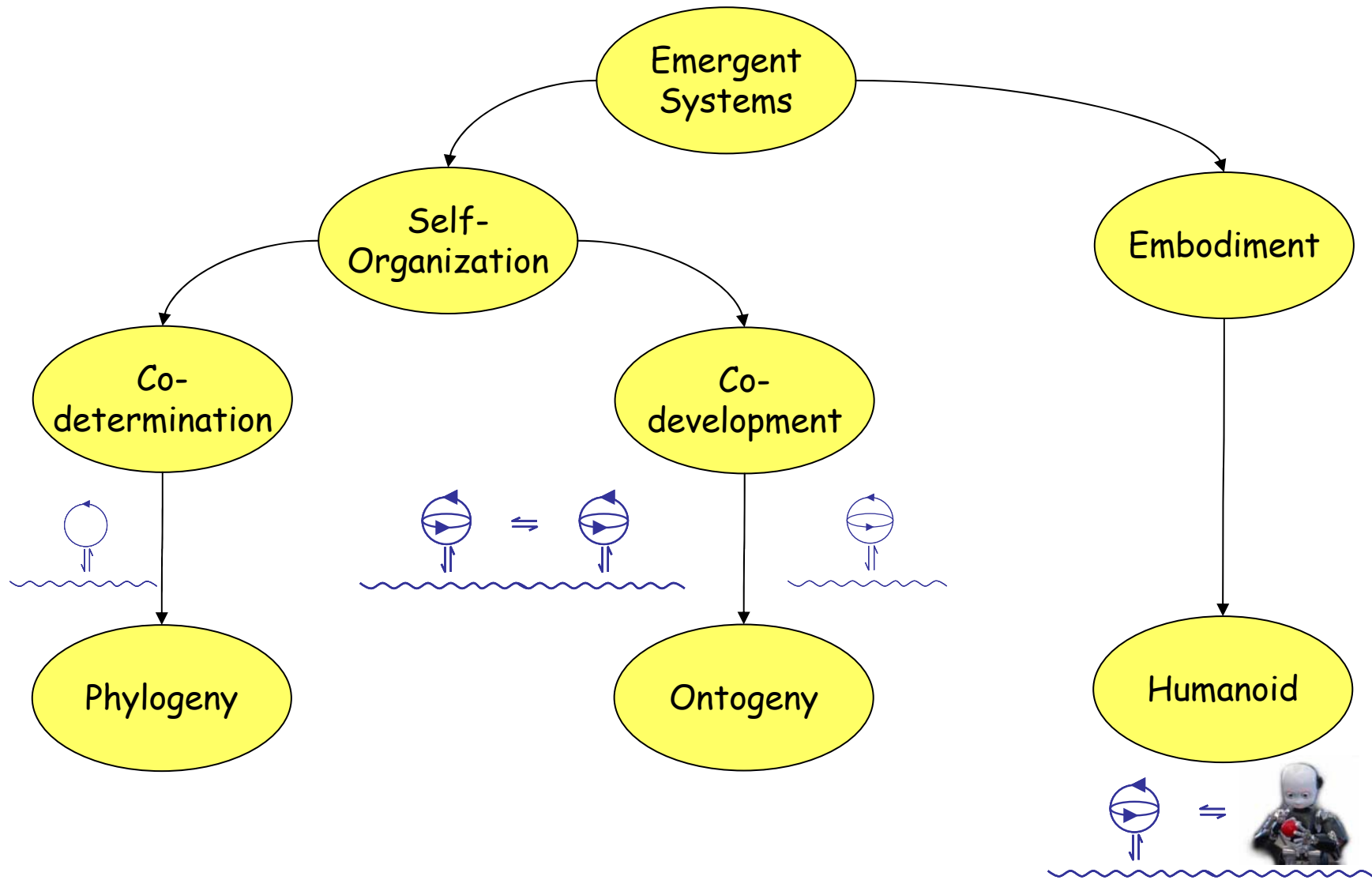
PERCEPTION, ACTION, and COGNITION

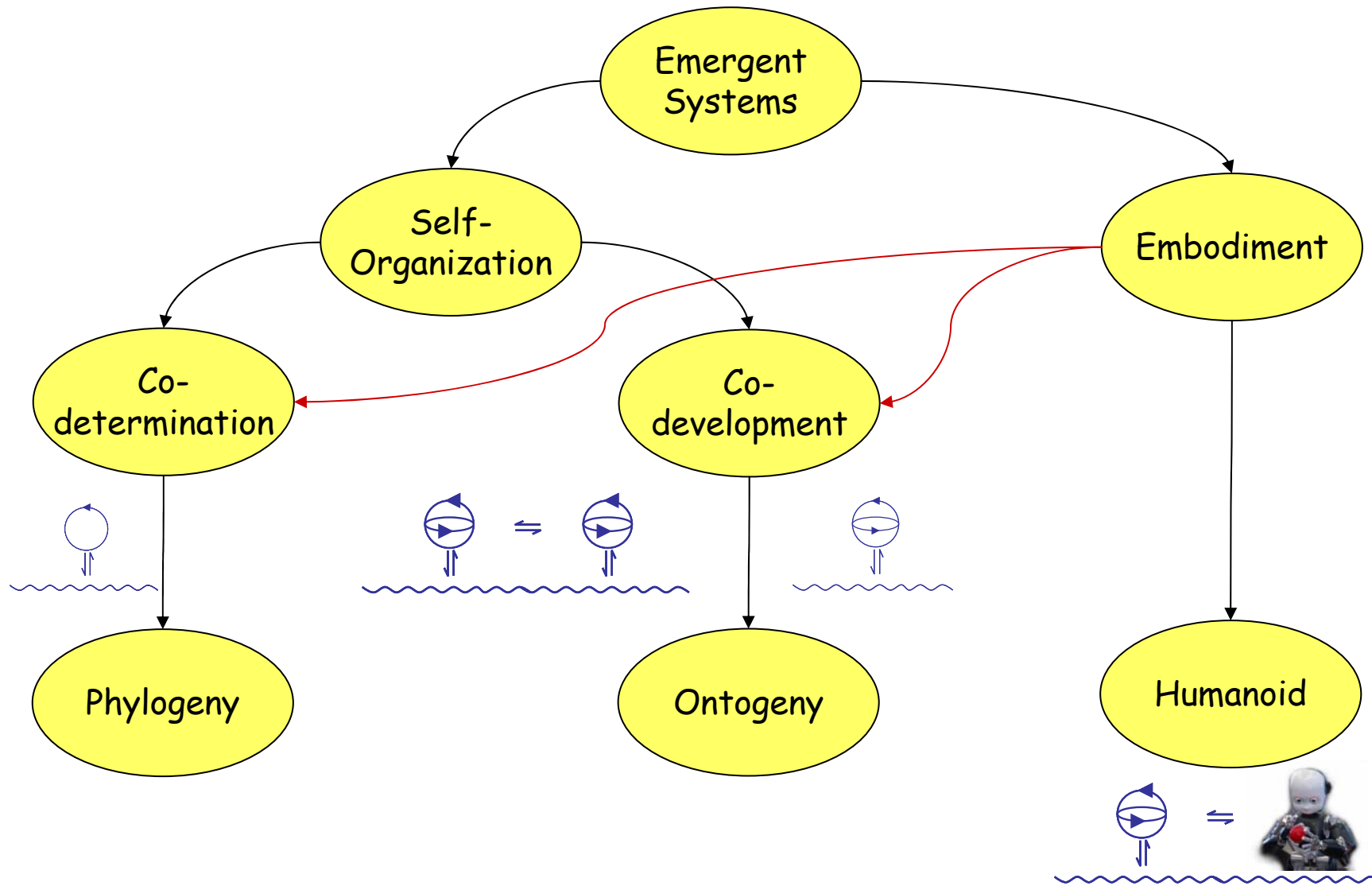
form a single process of self-organization
in the specific context of environmental perturbations
of the system



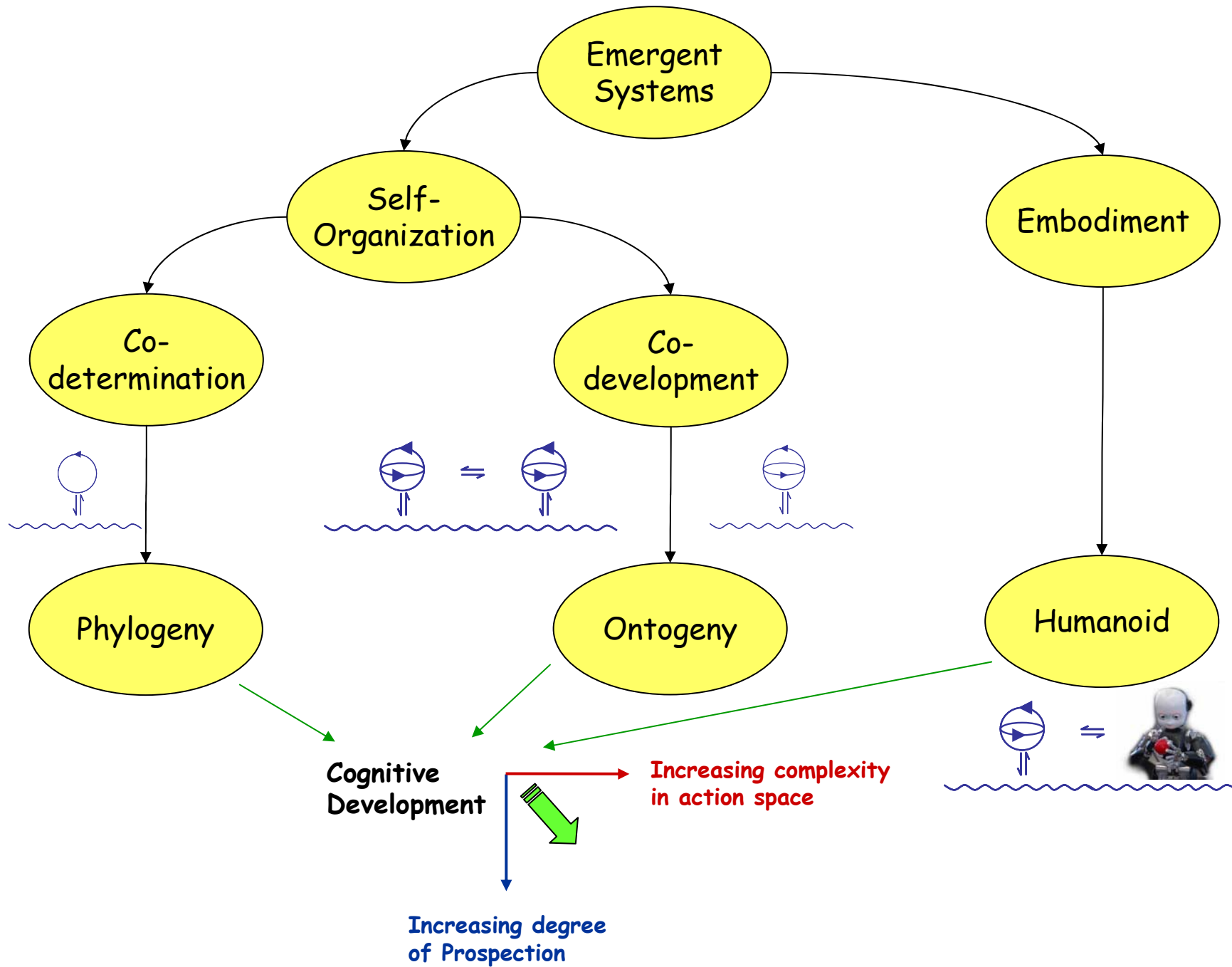
THE SPACE OF PERCEPTUAL POSSIBILITIES

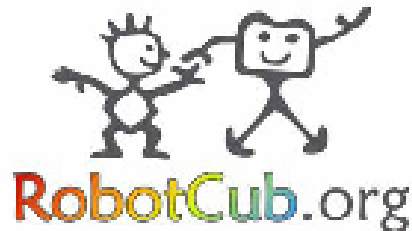
Is predicated not on an objective environment,
but on the space of possible actions
that the system can engage in whilst still
maintaining the consistency of its coupling with the environment





Morphology is a constitutive component of both co-determination and co-development
 Consequently, a plastic morphology is important: the embodiment shouldn't be static





ROBotic Open-architecture Technology for
Cognition, Understanding, and Behavior



Project No. 004370

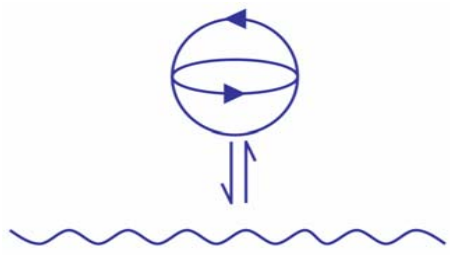
RobotCub

Development of a Cognitive Humanoid Cub

Instrument: Integrated Project
Thematic Priority: IST – Cognitive Systems

**D2.1 A Roadmap for the Development of Cognitive
Capabilities in Humanoid Robots**

Due Date: 01/12/2009
Submission date: 30/12/2009



Cognitive Architecture
The iCub Phylogeny

Model Generation

Network of cooperating/competing circuits

Each with own limited encodings

Self-modification

Learning: to tune phylogenetic skills

Development: change system dynamics new action spaces

Exploratory motives

Novel regularities in the world

Potential of own actions

Social motives

agent interaction: mutually-constructed patterns of behaviour

Learning

Unsupervised

Supervised

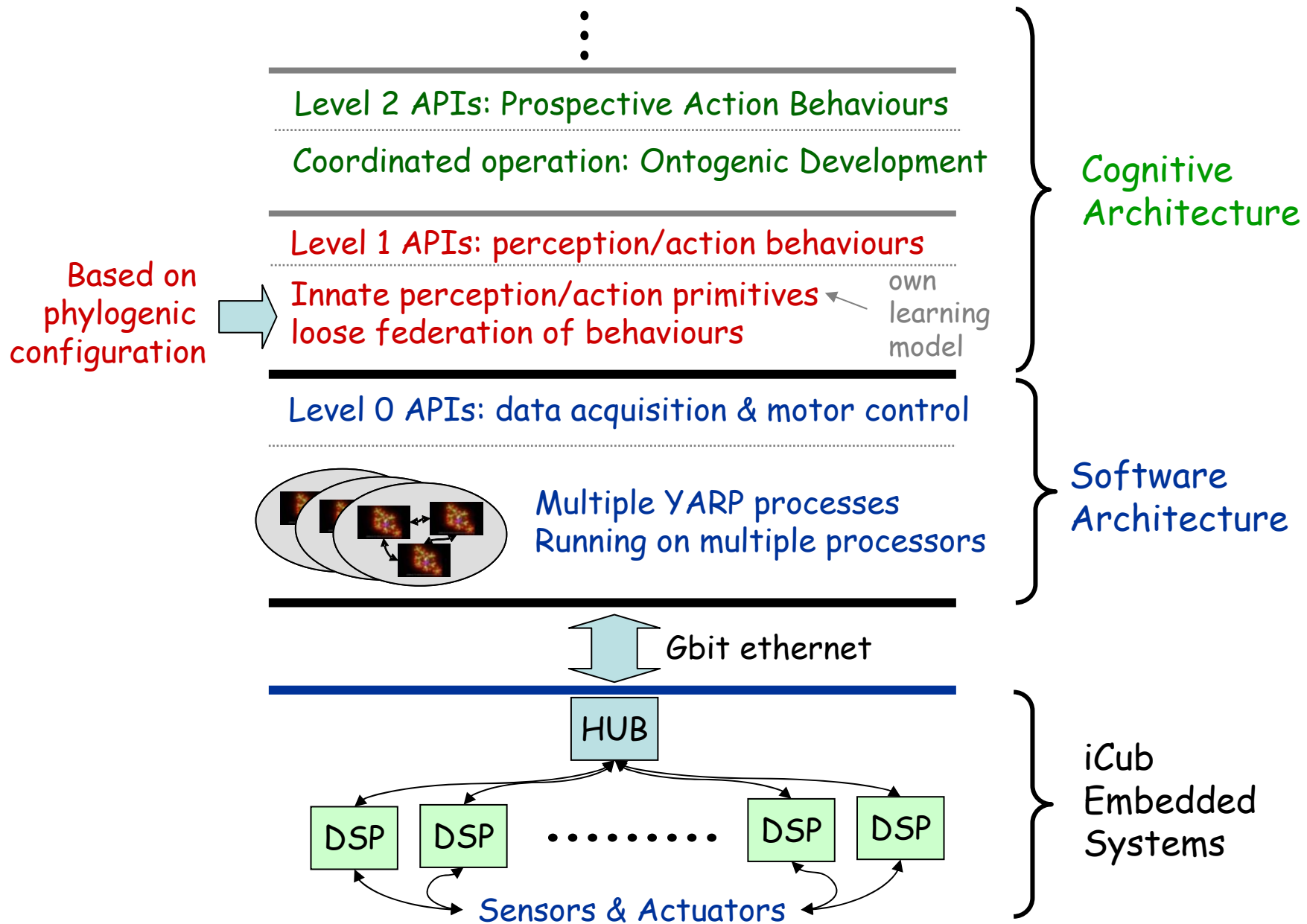
Reinforcement

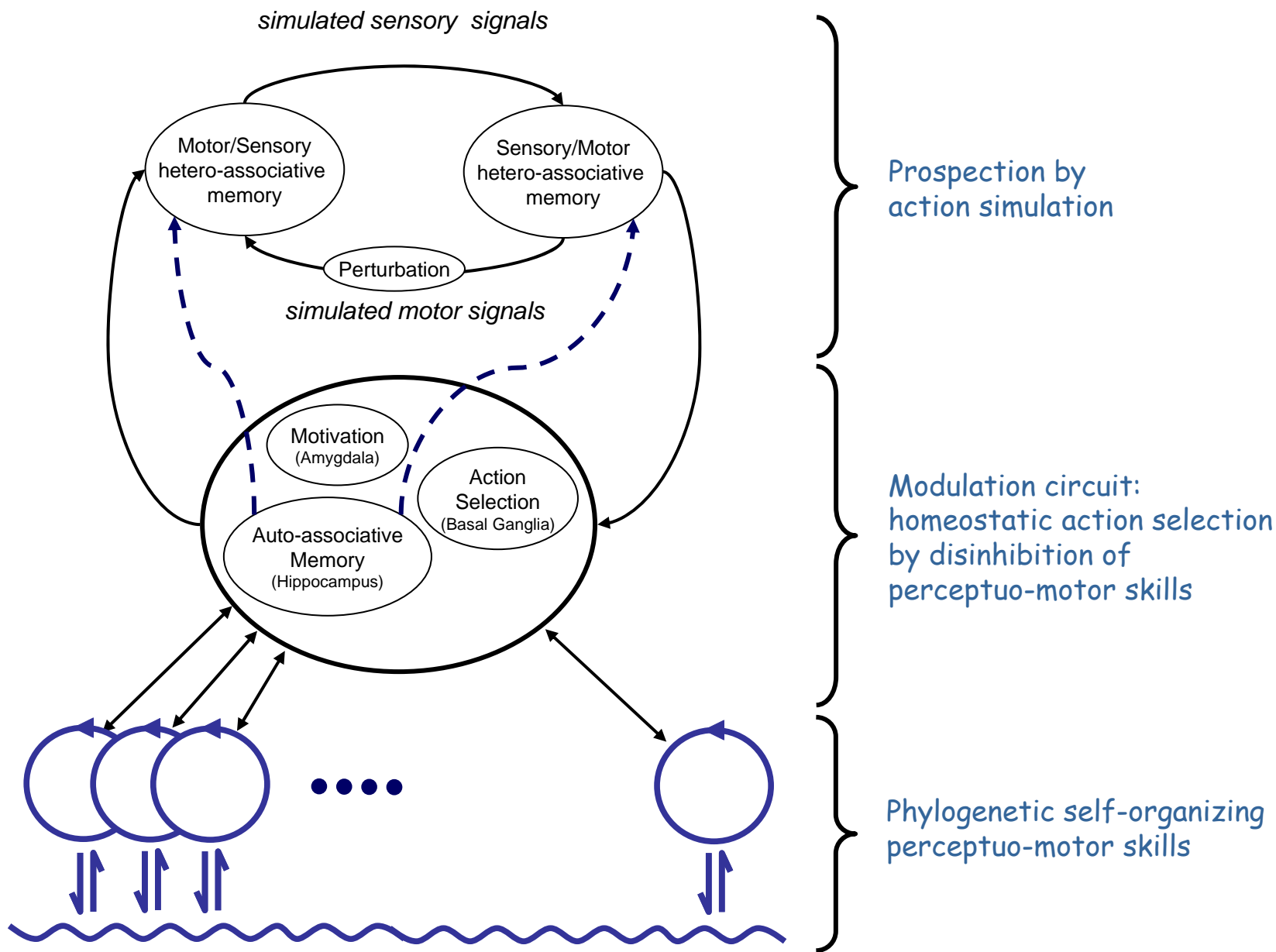
Mechanism to rehearse hypothetical scenarios

Moderate actual behaviour

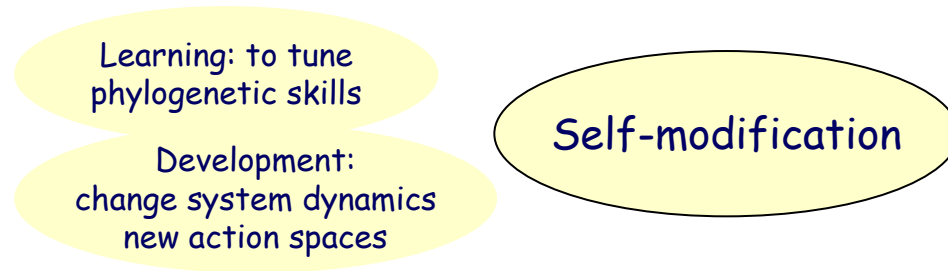
Embodiment

Action-Perception Couplings





Key Issue: Development



- Improve the predictive performance
- Increase the space of viable actions

Key Issue: Internal Simulation

Three purposes of internal simulation:

1. Prediction: future events

Moderate
actual behaviour

Mechanism to rehearse
hypothetical scenarios

2. Reconstruction: explaining observed events
(imagining a causal chain leading to that event)

3. Imagination: internal simulation as a way of imagining
new ideas

Key Issue: Exogenous and Endogenous

Exogenous: curiosity

Sensori-motor learning

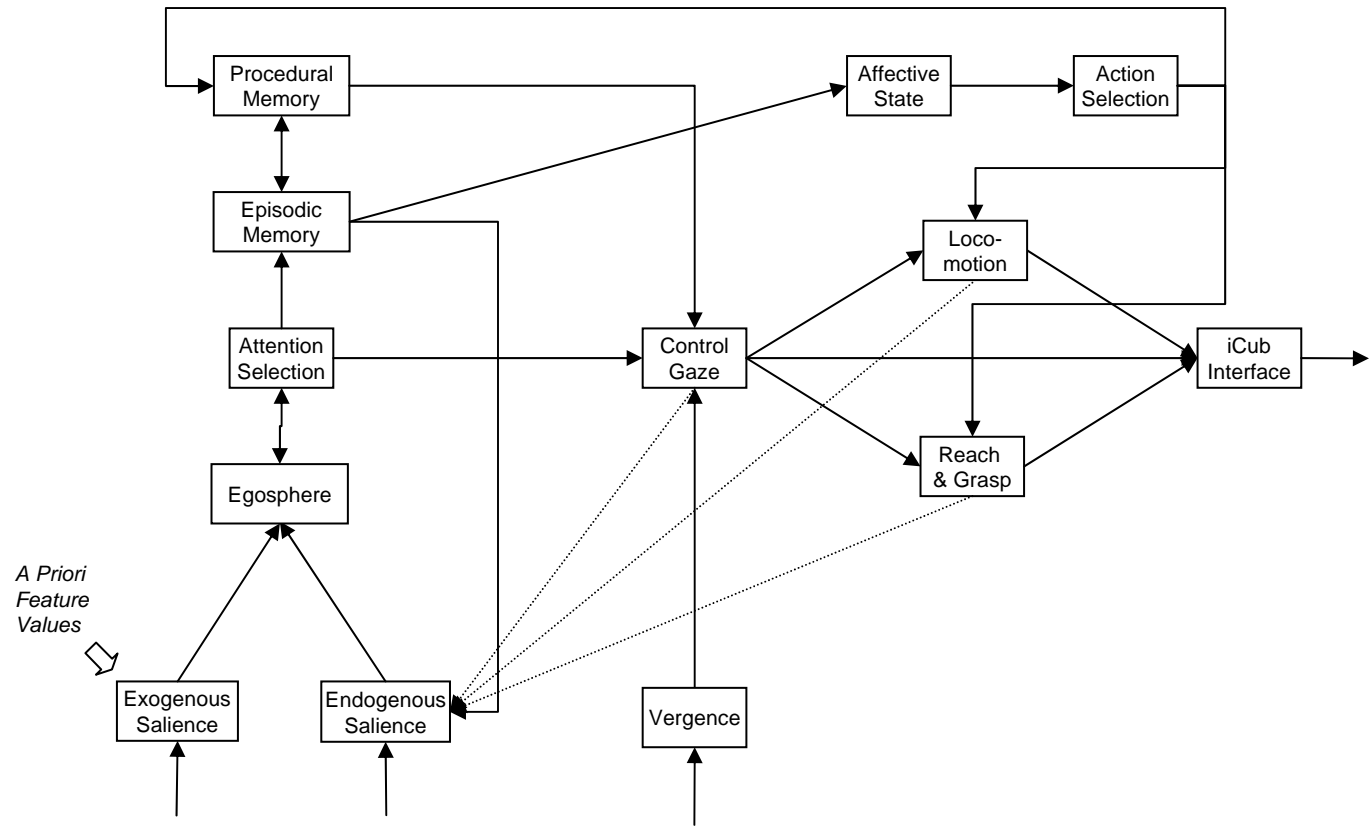
Novel regularities in the world

Potential of own actions

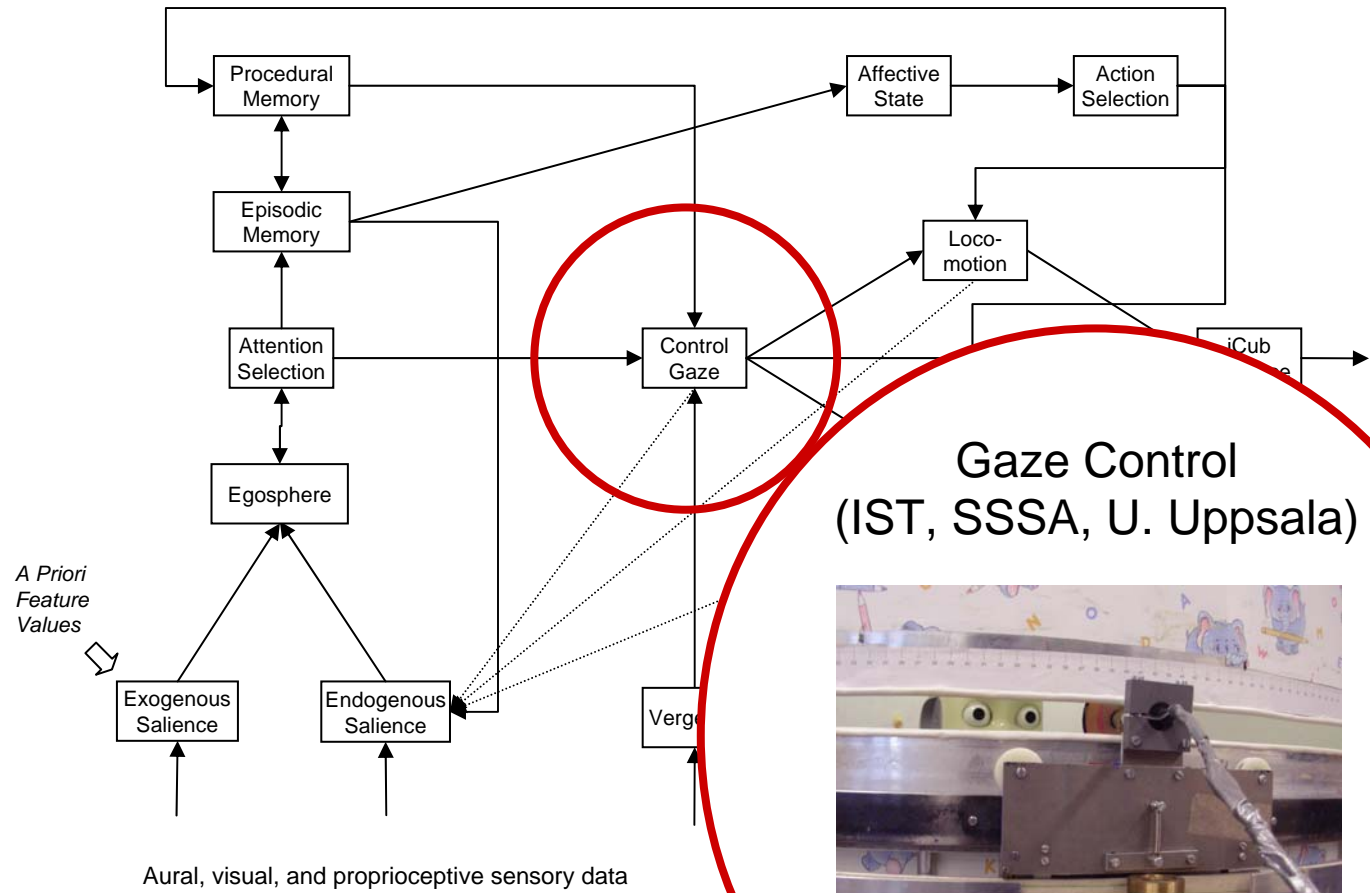
Exploratory motives

Endogenous: experimentation

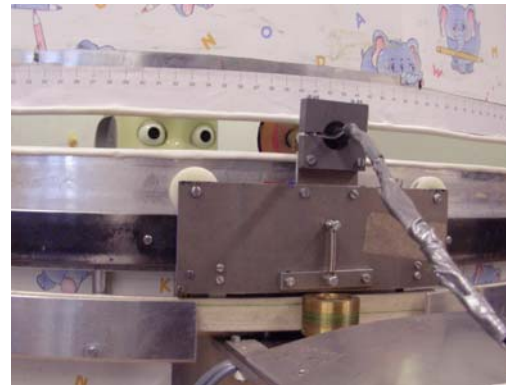
Experience-based *generative* development & operation

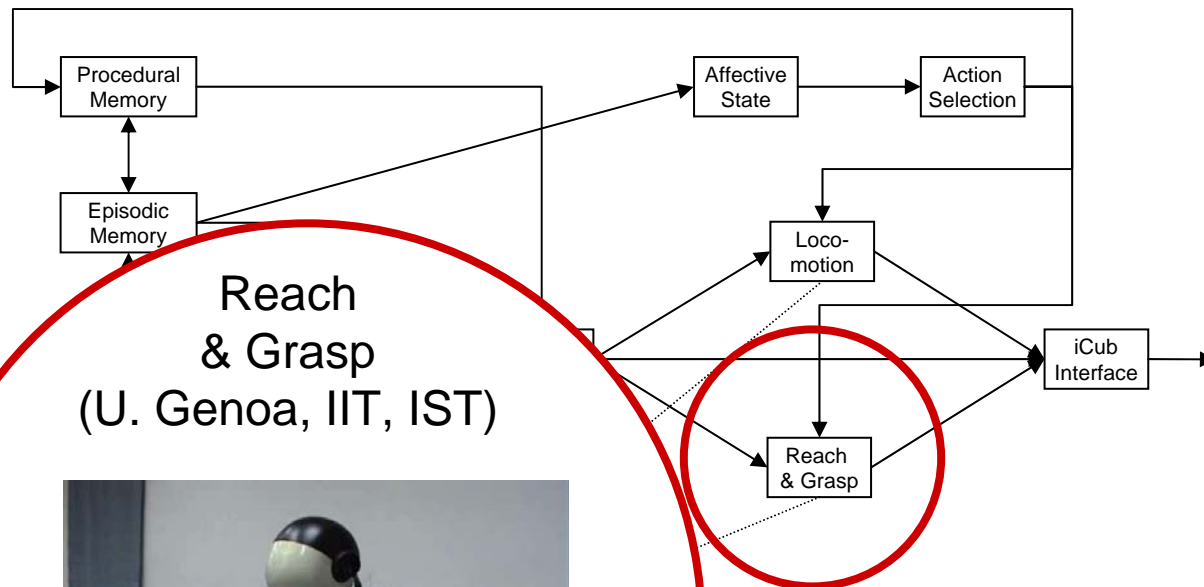


Aural, visual, and proprioceptive sensory data

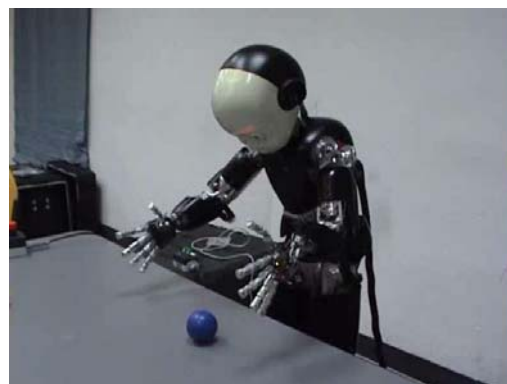


Gaze Control (IST, SSSA, U. Uppsala)

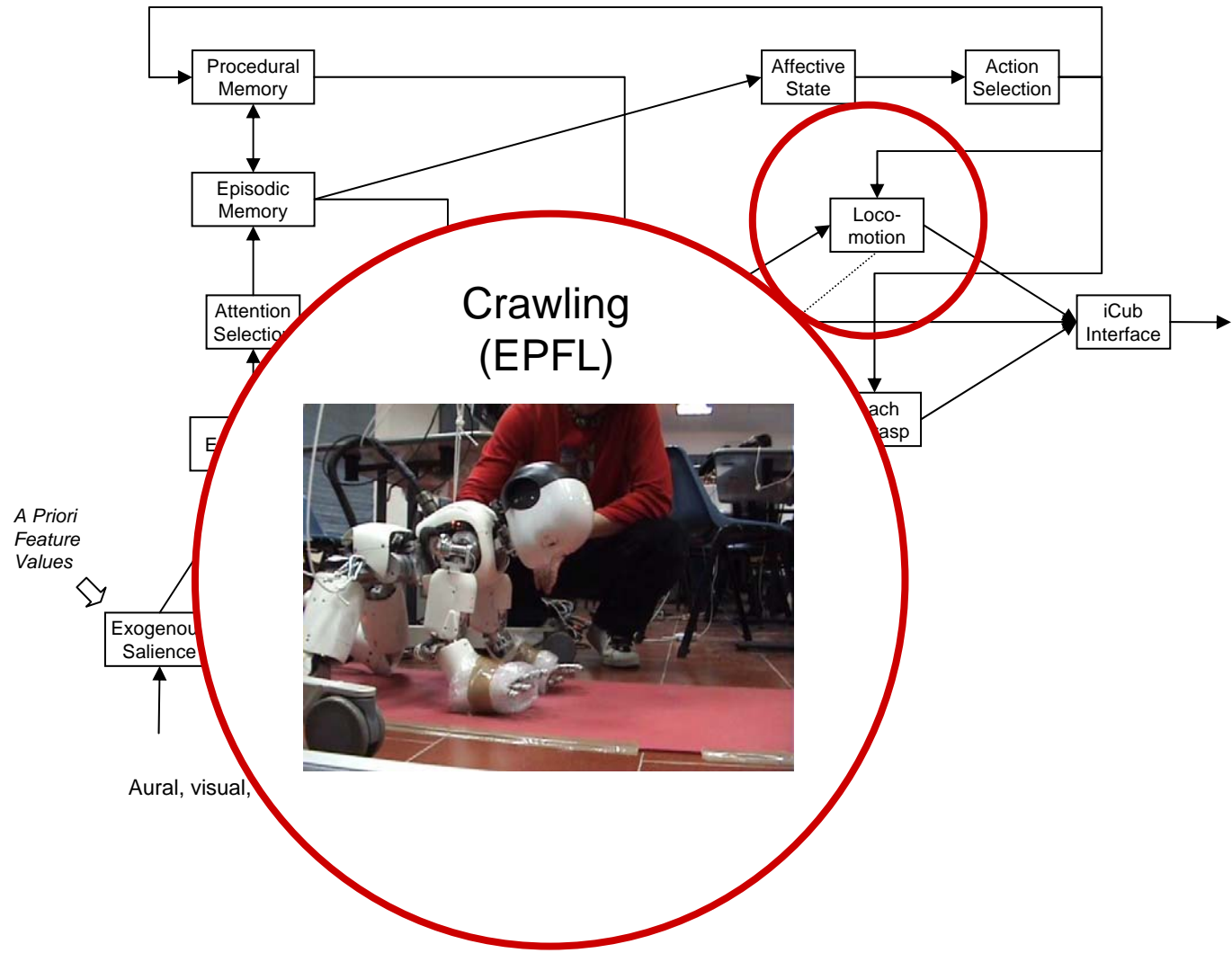




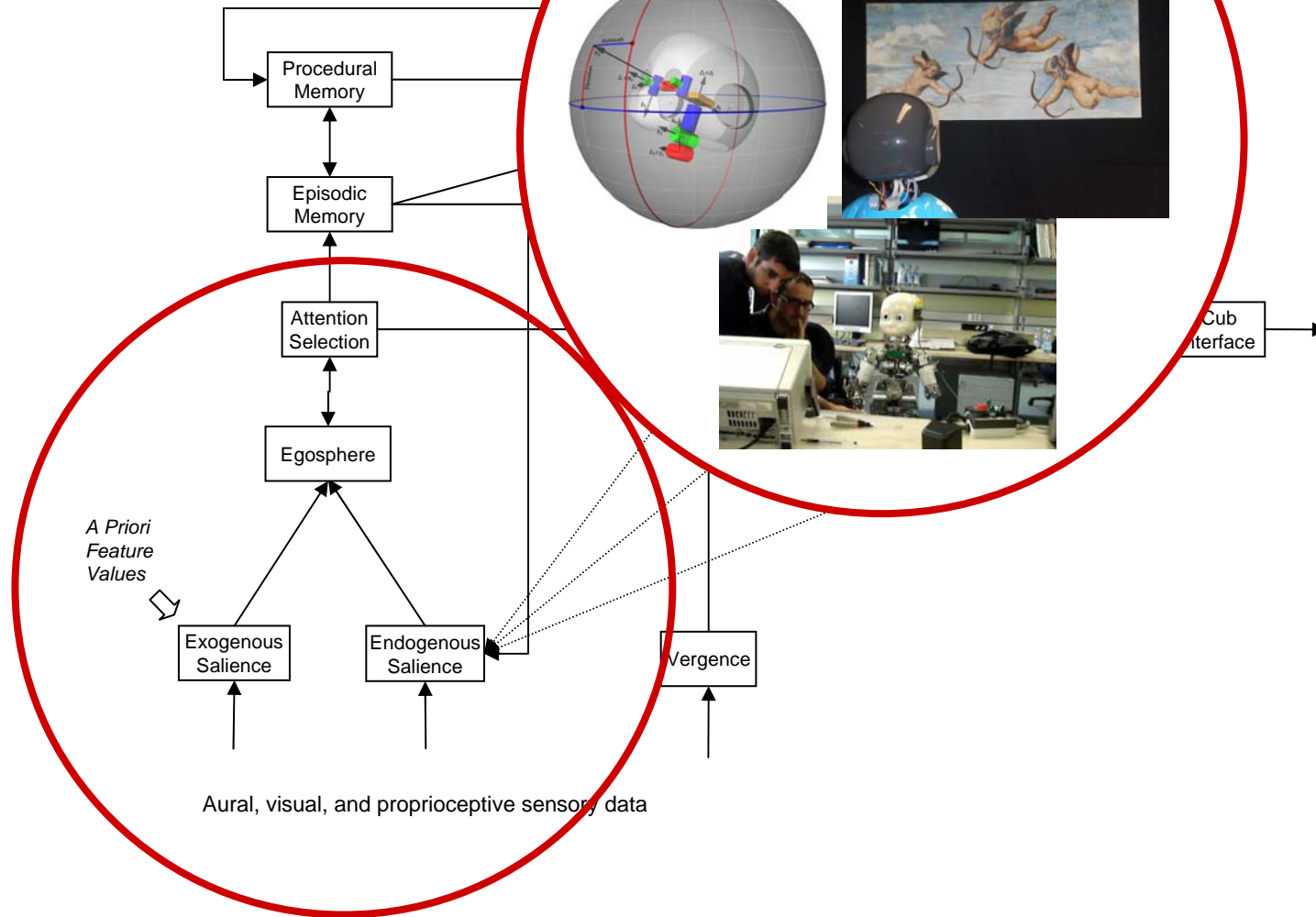
Reach
& Grasp
(U. Genoa, IIT, IST)

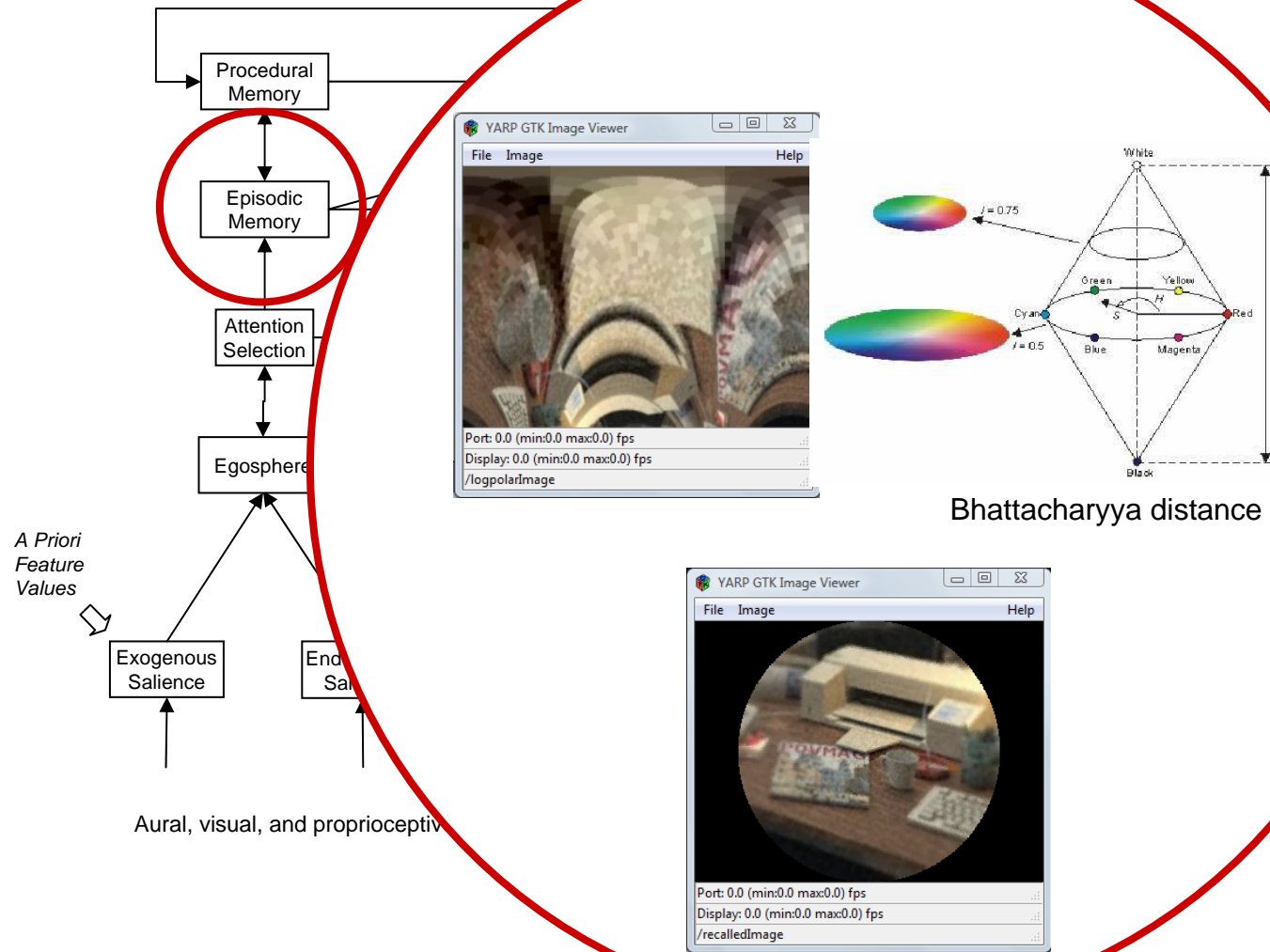


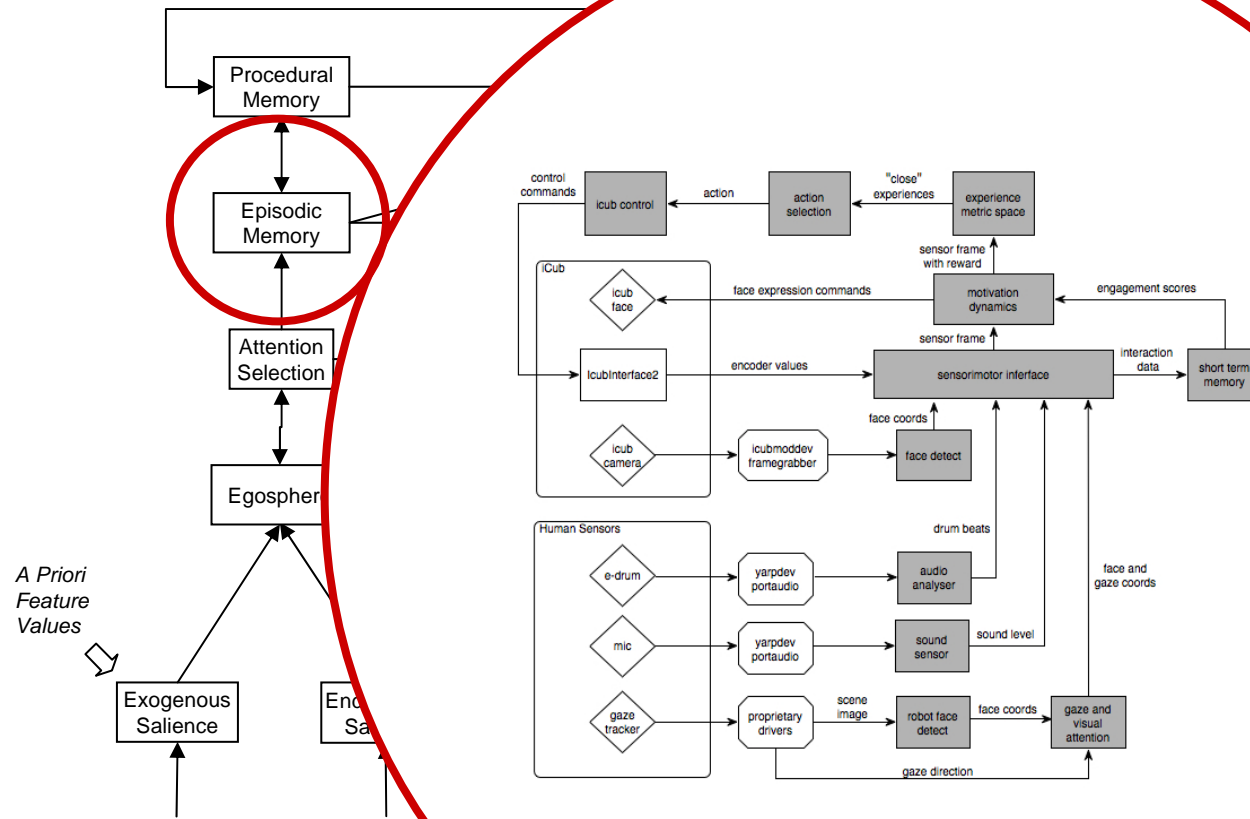
A Pri
Featu
Valu



Attention Sub-system (IST)

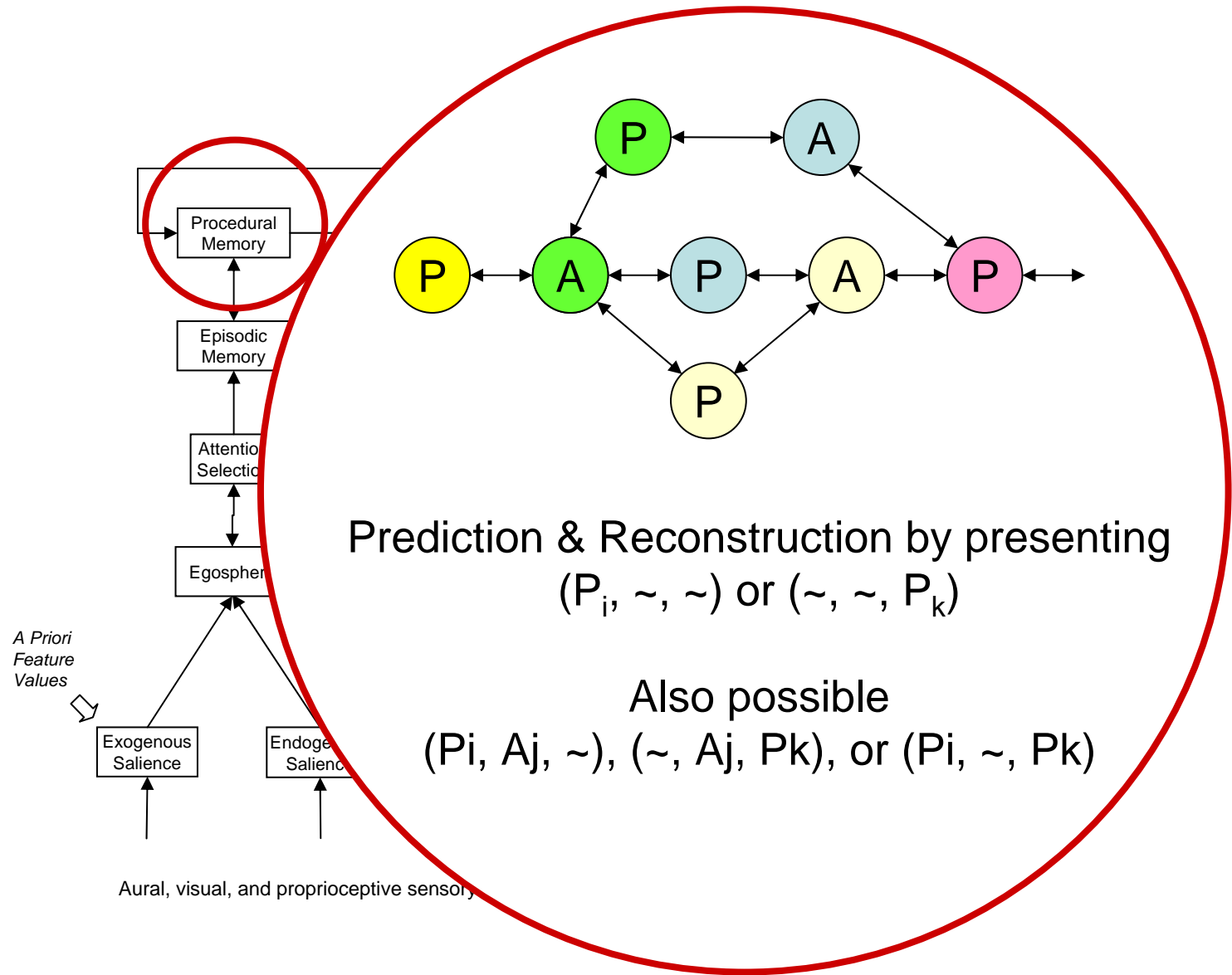




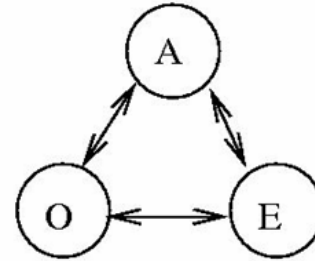
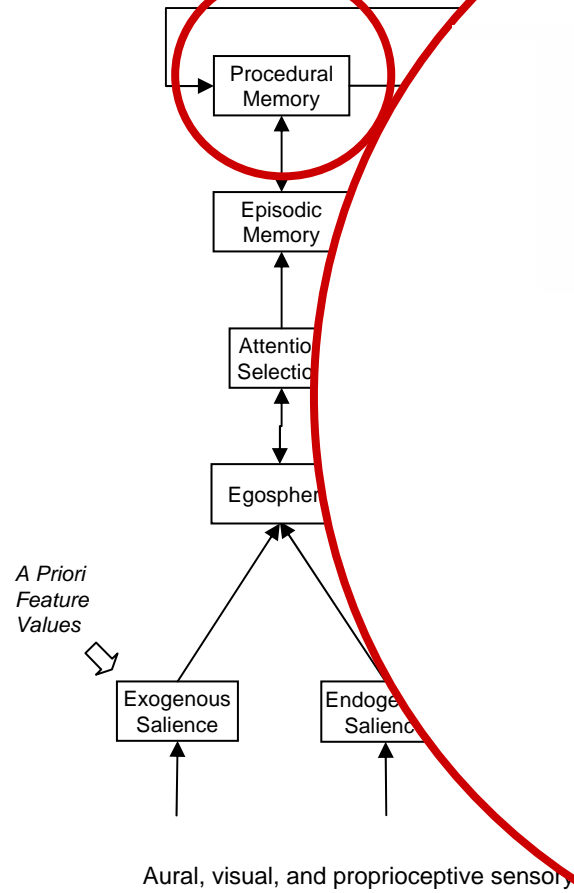


Aural, visual, and proprioceptive

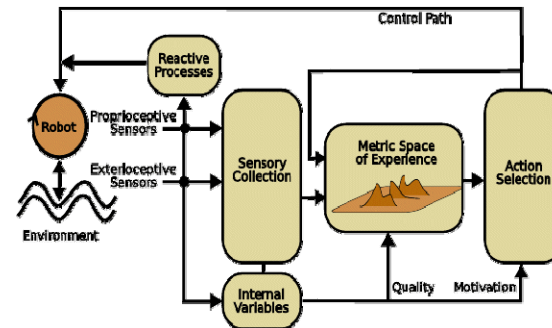
Alternative work on episodic memory at the University of Hertfordshire



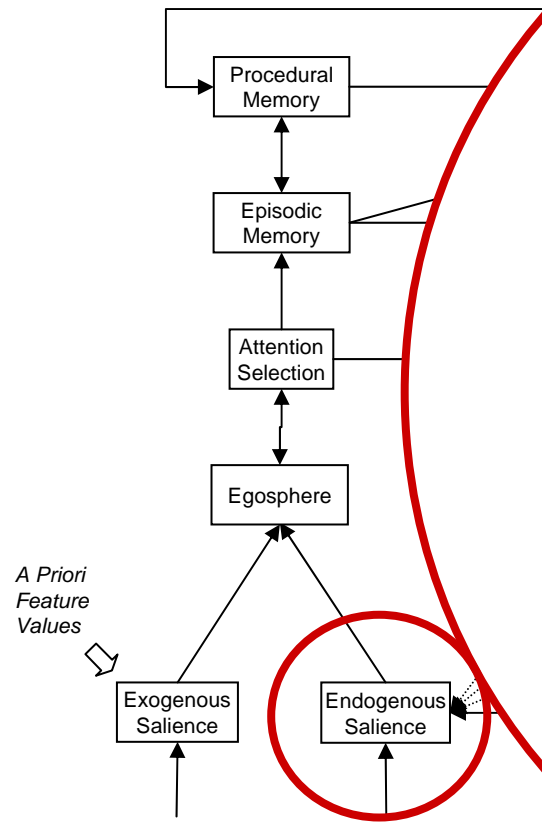
Learning affordances at IST



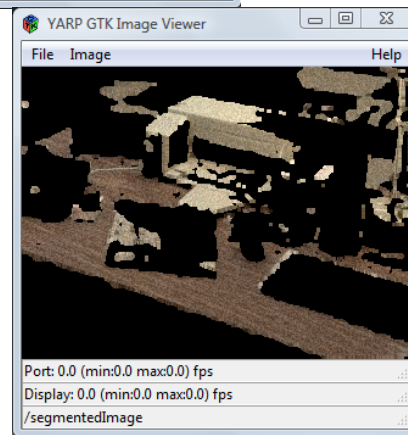
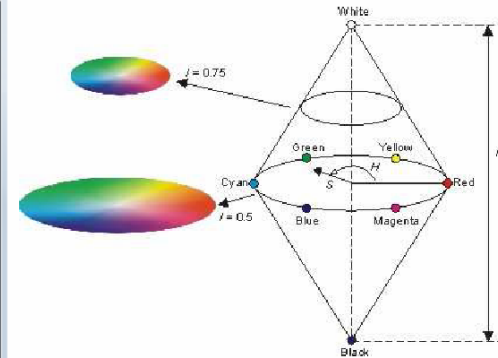
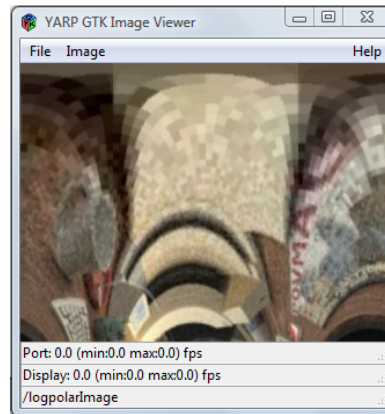
Input	Output
A,E	-> O
O,A	-> E
O,E	-> A



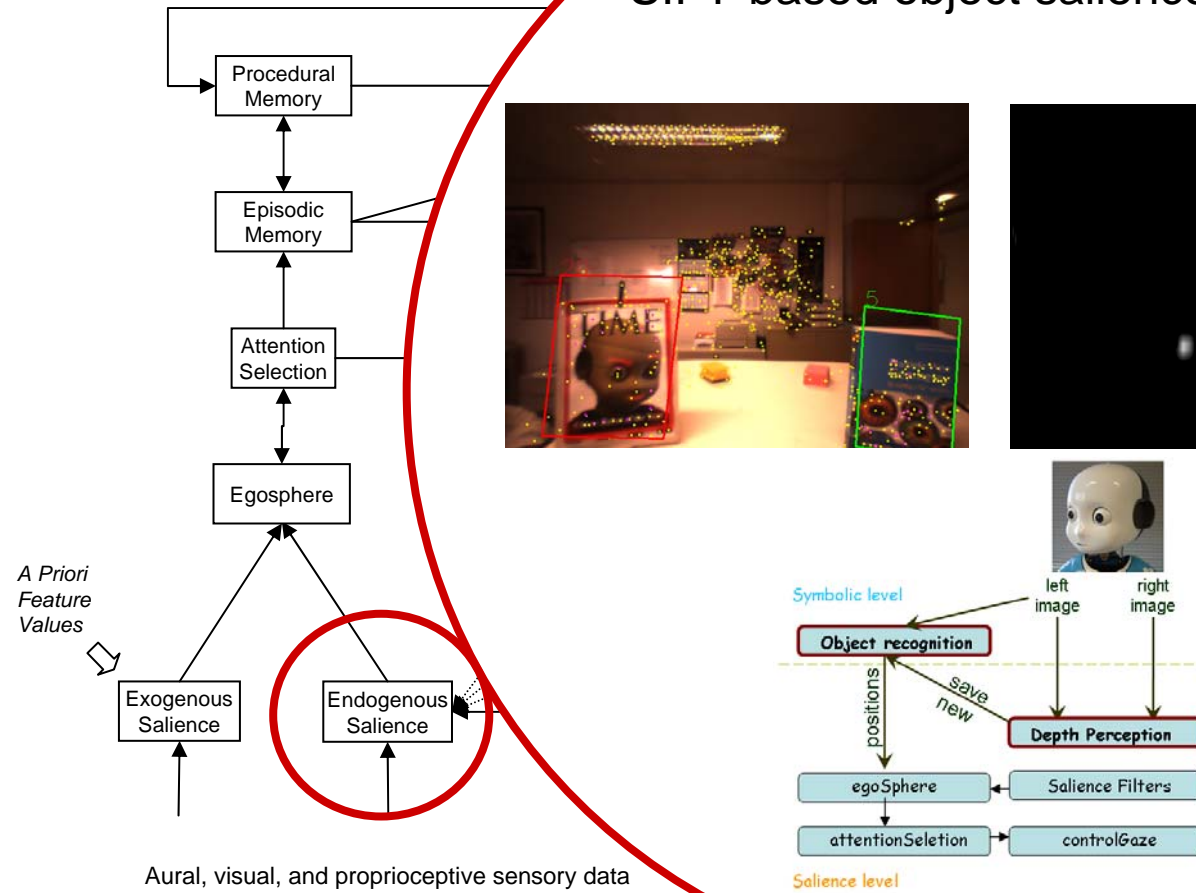
Interaction Histories at the University of Hertfordshire



Aural, visual, and proprioceptive sensory data



SIFT-based object salience at IST

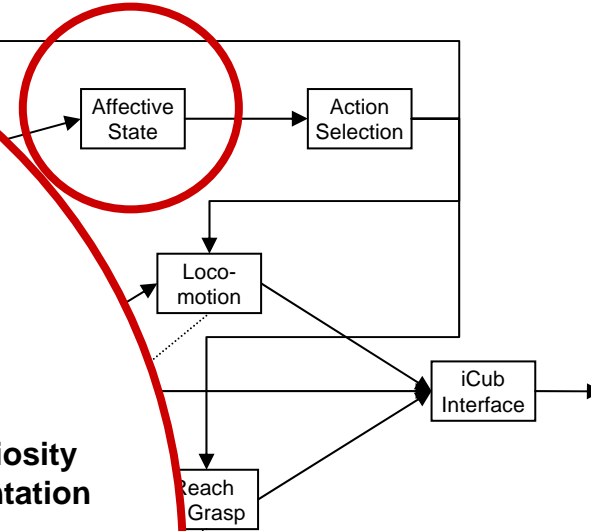


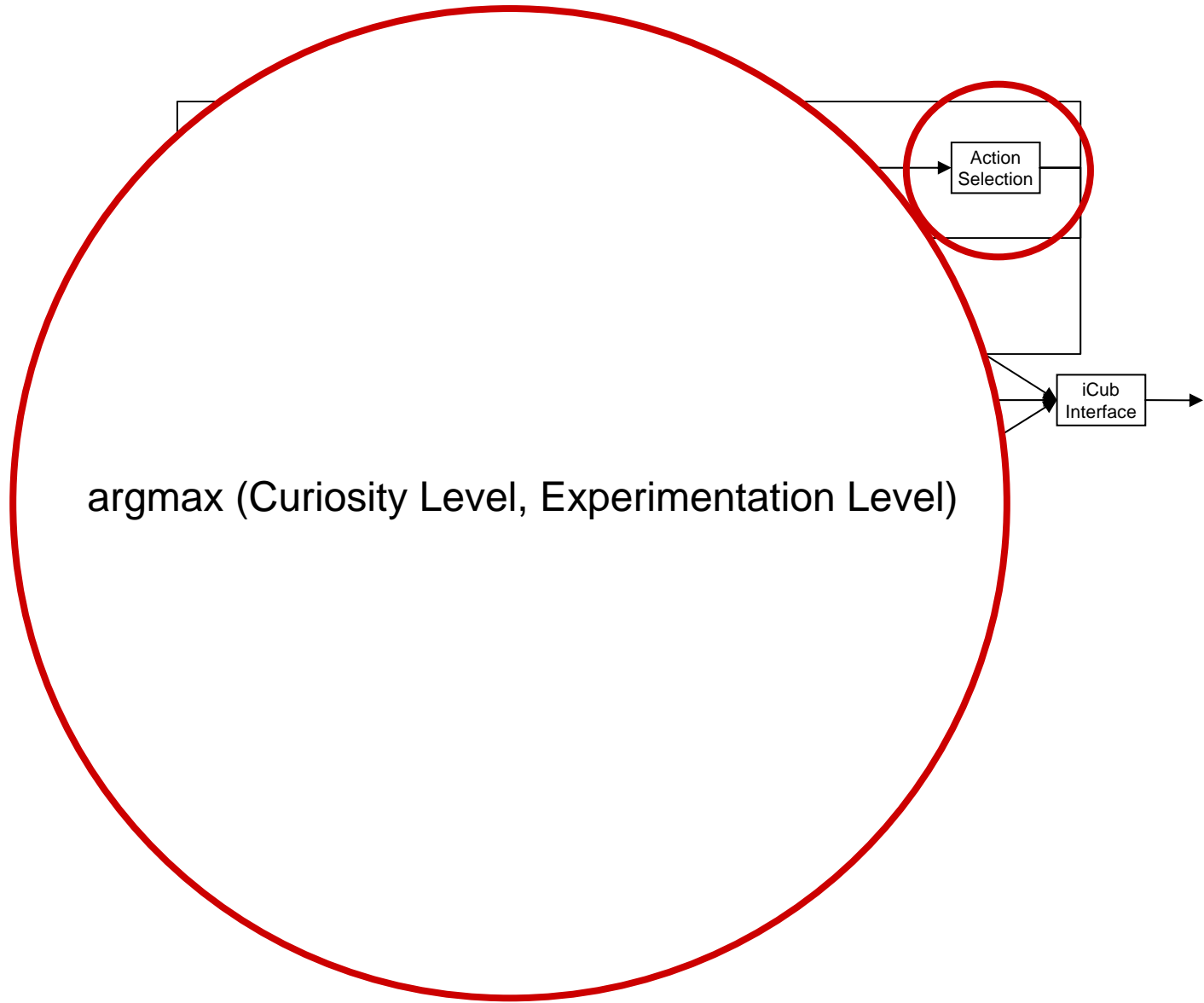
Curiosity & Experimentation

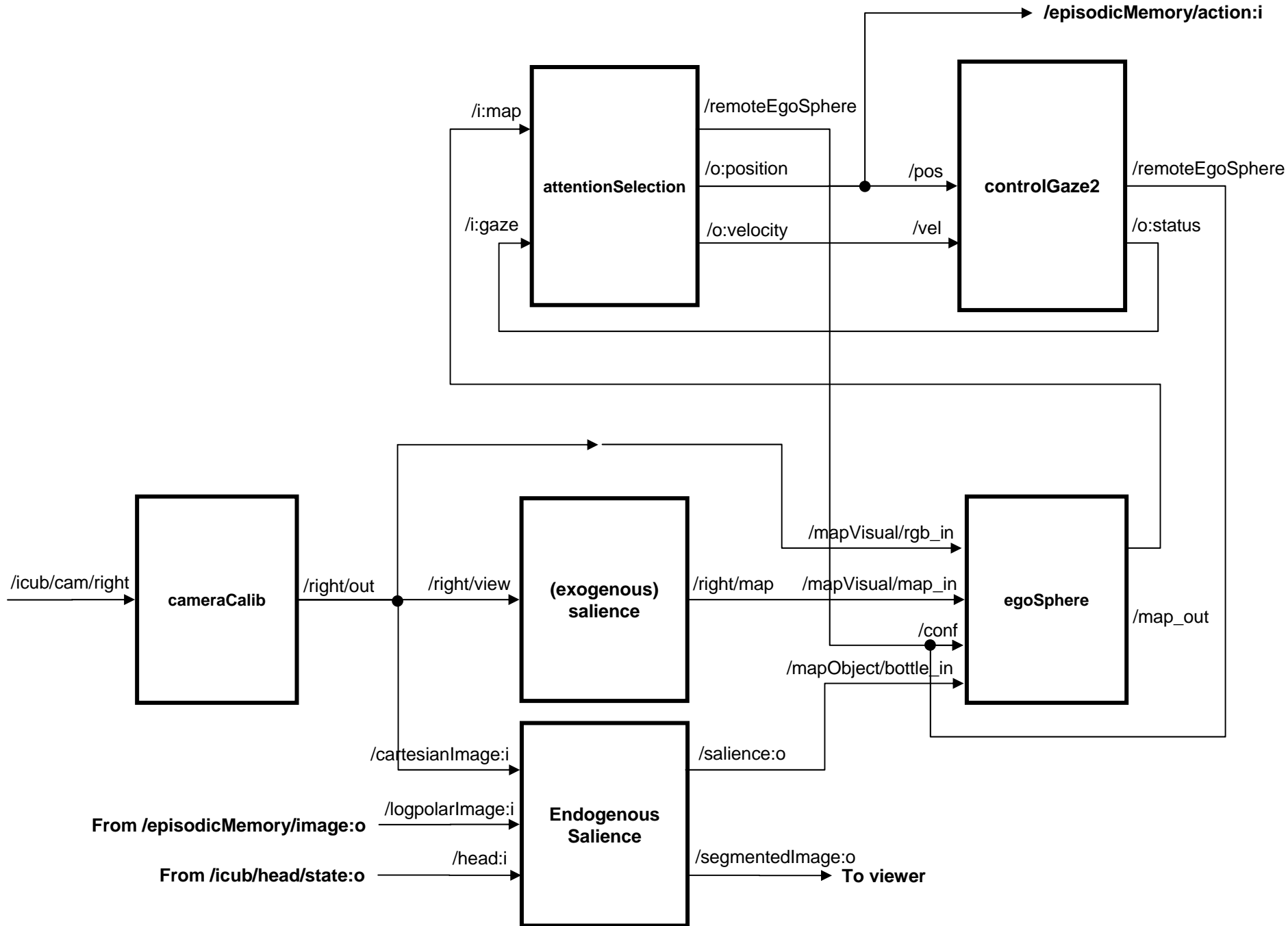
$$\sum_{C, E} \text{[Spike Diagram]} \times \text{[Spike Diagram]} \quad \text{Level of Curiosity \& Experimentation}$$

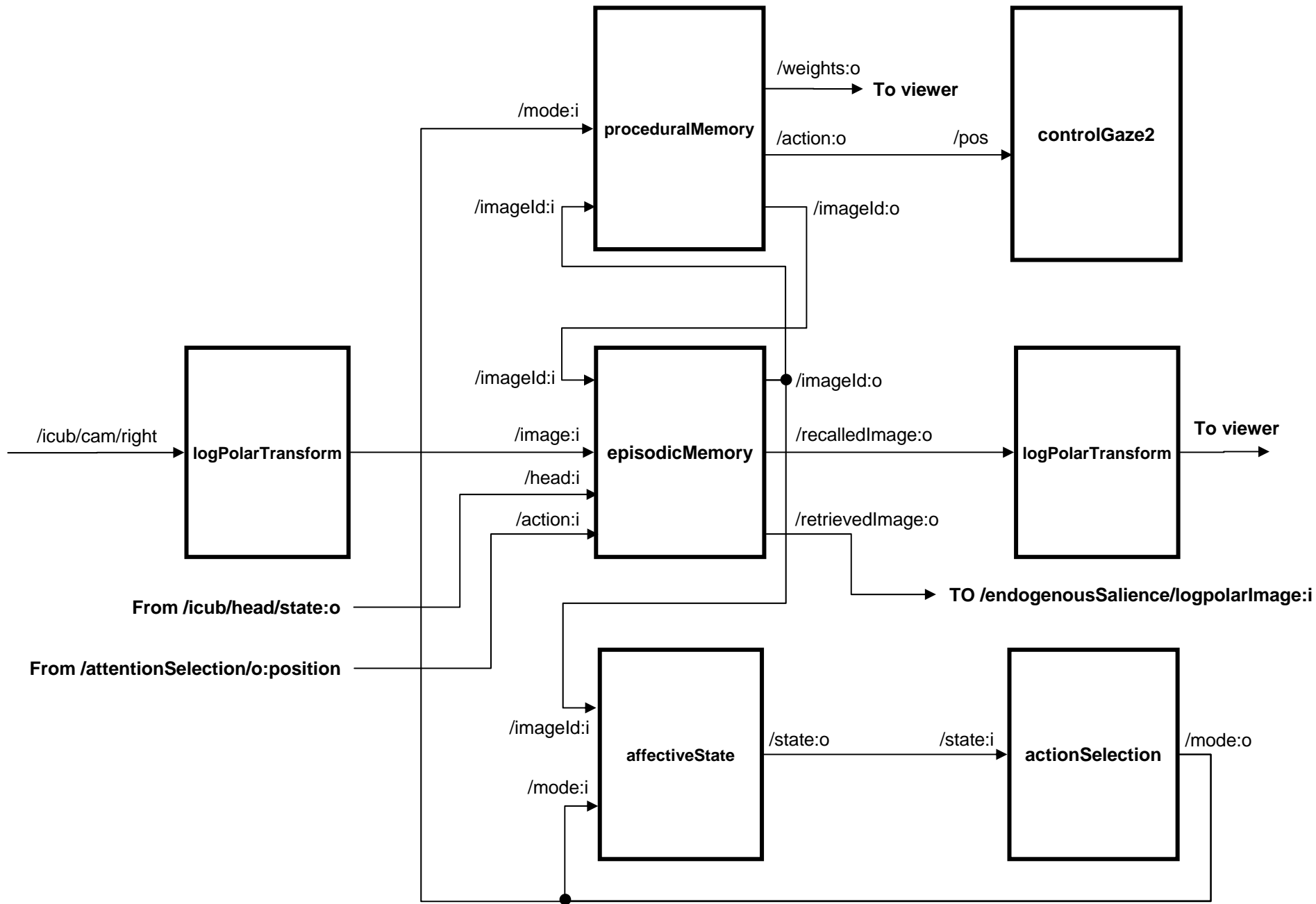
New Event | Expired Event \Rightarrow Curiosity Spike

Predicted Event \equiv Recalled Event \Rightarrow Experimentation Spike







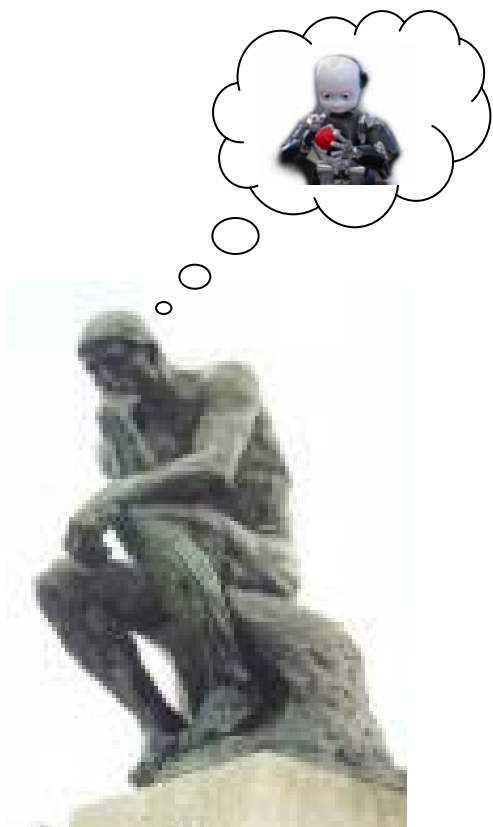


A thesis for discussion:

“Cognition emerges during development in a close interplay of experience, of the social and physical environment and of the neuronal mechanisms of growth.

An understanding of cognition cannot be achieved without an understanding of the development of cognition.

It is thus an necessity for artificial cognitive systems to take development on board”



Key Research Topics for the Future

Imagination

Self-Modification

Plasticity

Redundancy

Internal Dynamics

Social motives

The value system: creating order



RobotCub

Giulio Sandini, IIT & U. Genoa
Giorgio Metta, IIT & U. Genoa
Lorenzo Natale, IIT & U. Genoa
Francesco Nori, IIT & U. Genoa
Paul Fitzpatrick, IIT & U. Genoa
Francesco Orabona, IIT & U. Genoa
Matteo Brunettini, IIT & U. Genoa
Alessandro Scalzo, IIT
Marco Maggiali, IIT
Marco Randazzo IIT
Roberto Puddu, IIT
Gabriele Tabbita, IIT
Walter Fancellu, IIT
Bruno Bonino, IIT
Fabrizio Larosa, IIT
Claudio Lorini, IIT
Luciano Pittera, IIT
Davide Dellepiane, IIT
Mattia Salvi, IIT
Luca Rivano, IIT
Ravinder Dahiya, IIT
Alberto Parmiggiani, IIT
Matteo Fumagalli, IIT
Alexander Schmitz, IIT
Diego Torazza, IIT
Nikos Tsagarakis, IIT & U. Sheffield
Darwin Caldwell, IIT & U. Sheffield
Francesco Becchi, TeleRobot
Paolo Pino, TeleRobot
Giulio Maggiolo, TeleRobot
Gabriele Careddu TeleRobot
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David Vernon, U. Genoa

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Harold Martinez, U. Zurich
Gabriel Gomez, U. Zurich
Alexandre Schmitz, U. Zurich
Yvonne Gustain, U. Zurich
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Maria Chiara Carrozza, SSSA
Giovanni Stellin, SSSA
Giovanni Cappiello, SSSA
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Luís Vargas, IST
Ricardo Nunes, IST
Hugo Alves, IST
Nuno Conraria, IST
Julio Gomes, IST
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Miguel Praça, IST
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Luís Montesano, IST
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Laila Craighero, U. Ferrara
Andrey Olynyyck, U. Ferrara
Livio Finos, U. Ferrara
Giovanni Ottoboni, U. Ferrara
Claes von Hofsten, U. Uppsala
Kerstin Rosander, U. Uppsala
Olga Kochukova, U. Uppsala
Helena Gronqvist, U. Uppsala

