A psychology based approach for longitudinal development in cognitive robotics

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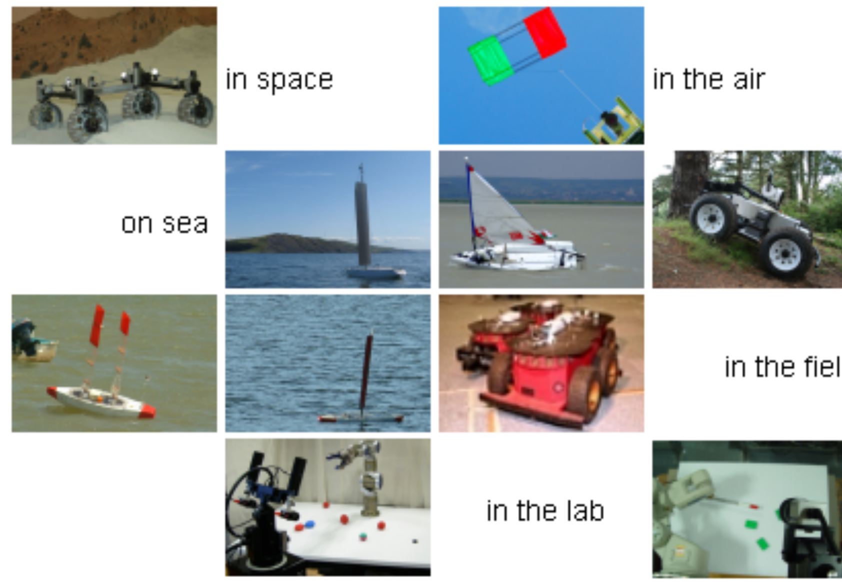
Intelligent Robotics in Aberystwyth



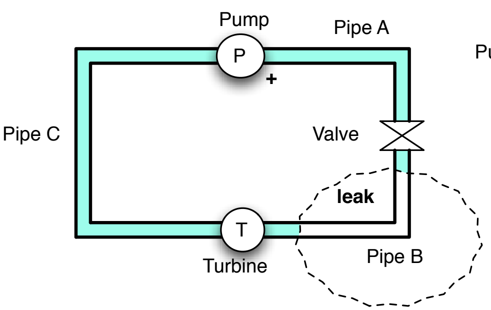

Aberystwyth, Wales

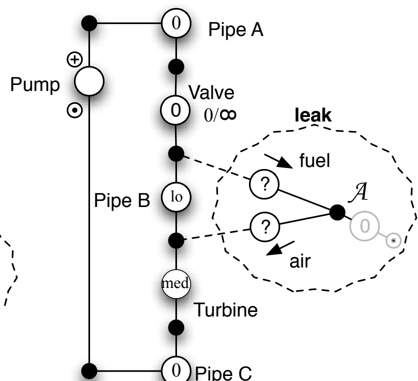
Contents

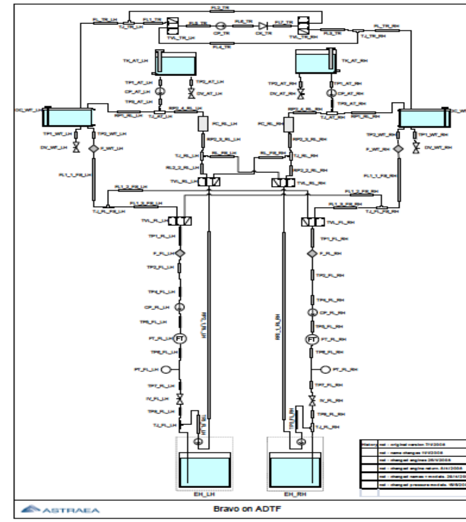
- Autonomy (the problem)
- Development (the solution)
- Our approach
  - Novelty and motivation
  - Sensorimotor structures
  - Longitudinal development
  - Play and cognitive growth
- Findings

Safety critical systems

- FMEA and FTA
- Task based
- Contingencies covered
- What could possibly go wrong?







Historical trends

Analysis, task based, goal based

⇒ AI

Synthesis, behaviour based, rehearsal

⇒ Cybernetics

also => grounded, embodied

Autonomy

- *The* key to advanced robotics
- Not task-based autonomy but full agency autonomy
- Approaches:
  - Classical AI
  - Neuroscience and bioscience
  - Psychology (developmental)

Autonomy - Essential features

- The "open-ended acquisition of novel behaviour"
- Autonomous handling of new and novel situations
- Cumulative learning from experience
- Qualitative growth of competence

Our approach - Infant development

- Centred on <u>early</u> infant behaviour
- Motor based
- Importance of staged development
- Importance of constraints
- Cephalocaudal and proximo-distal
- Abstract, top-down models
  - logic of algorithms, not methods

Inspiration from Alan Turing

"Instead of trying to produce a programme to simulate the adult mind, why not rather try to produce one which **simulates the child's**? If this were then subjected to an appropriate course of education, one would obtain the adult brain [...]"

A.M. Turing, Mind, 59, 433-460, 1950

Infant (to iCub) development

- Survey and study of literature on infant development
- Constructed a timeline of activity from conception to 12 months
- Prepared similar development chart for iCub
- Constructed constraint network and identified dependencies

Infant vision development

- Increase in image resolution (birth to 12 months)
- Widening field of view (6-10 weeks, 20-40 degrees)
- Increased sensitivity to stimulus (birth to 6 months)
- Increased Image transfer rate (birth to 3 months)
- Increased focal range (1 to 2 months), initially ~21cm
- Increased colour resolution (birth to 4 months)
- Stereopsis onset and improvement (3 to 12 months)
- Migration of rods and cones – At birth the distribution of rods and cones is roughly uniform, with migration to adult positions occurring over the first 11 years. Fastest migration occurs 2-3 months after birth.

Infant vision development

Age post-natal (months)	0	1	2	3	4	5	6	7 8 9 10 11 12
Eyes	Move eyes toward diffuse light.	Turn head and eyes toward light source. Stares at light colours. Attracted to novel stimulus 6-10 inches from face. Basic object tracking. Few, jerky saccades, fixating on object edges.	More, smooth saccades. Ability to fixate within objects.	Gazes at human face. Visual exploration by moving head and eyes. Hand regard. Vergence control.	Smooth tracking.	Fixates on self	Foot regard. Visual exploration by moving head and eyes. Attracted to novel visual stimulus. Eyes move in unison. Watches falling objects to resting place. Refinement of all eye movements.	
	Improved eyeball position control ----->							
Vision	Diffuse image, relatively sluggish image transfer rate. Lack of clarity in centre of visual field. Low sensitivity to stimulus.	Focus within limited range, around 21cm. Nonconjugate vision.	Increased depth of focus. Increase in image resolution.	Higher quality image resolution, fast image transfer. Coarse stereopsis emerges.			Increased sensitivity to stimuli. Increased resolution.	Good clarity in centre of visual field. Near adult stereopsis.

Increase ---------------- in ------------------ resolution --------------------->

Stereopsis ---- onset ---- and ---- improvement ------------------->

Increased ---- sensitivity ---- to ---- stimulus ---------------->

Increased colour resolution ----->

increased image transfer rate ------->

Increase in focal range ------>

Infant development

Time-lines and road-maps

- RoboCub – (Vernon et al. 2010)
- Italk – (Cangelosi et al. 2010)
- IM-CLeVeR – (Law et al. 2011)

Motor activity in infants

- sucking
- eye movements
- head rolling
- facial expressions
- body and limb kicking actions
- reaching
- touching

Play in infants

Essential behaviour,
Not goal directed,
Not object centred but activity based,
Discovers interesting new possibilities (goals?)

Repetitive,
Enjoyable,
Generates much audio, tactile and visual input

"The purposeful seeking of enjoyable action possibilities", Von Hofsten, 2004

Intrinsic Motivation

- Novelty = any new events
- Saliency – relative excitation
- Correspondence, <10ms
- Repeatability – more than once

- LCAS approach (2007)

Novelty

Novelty and motivation

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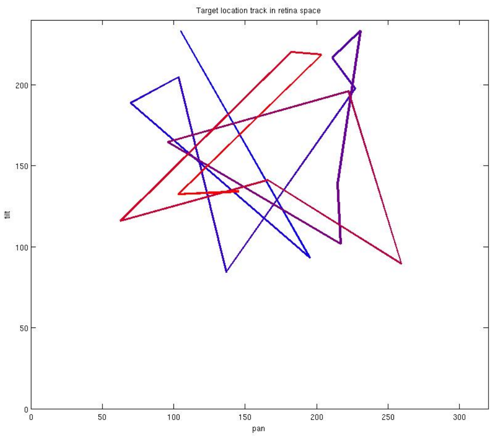
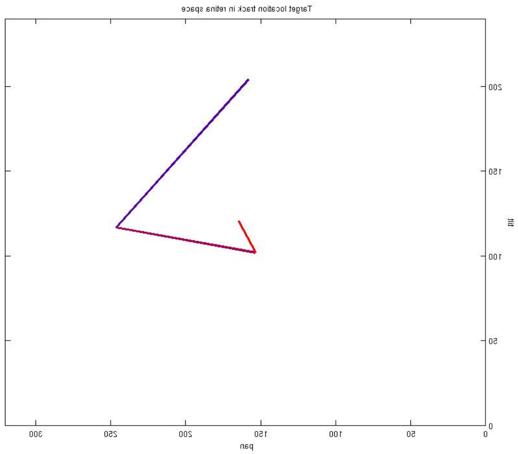
Intrinsic action – goal free

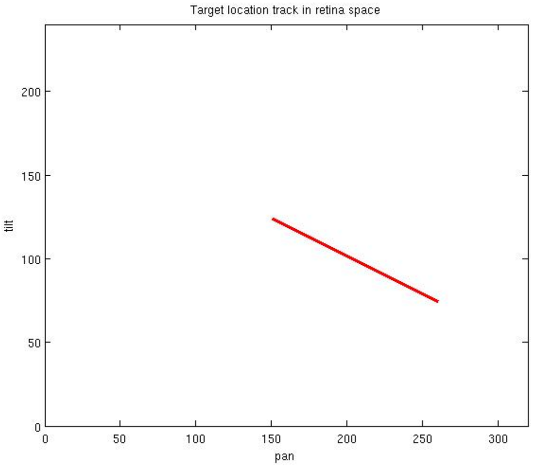
- Simplifies motivation
  - removes need for explicit goals
- Increases (probability of) contingency events
- Probes strength of existing contingency correlations

Babbling

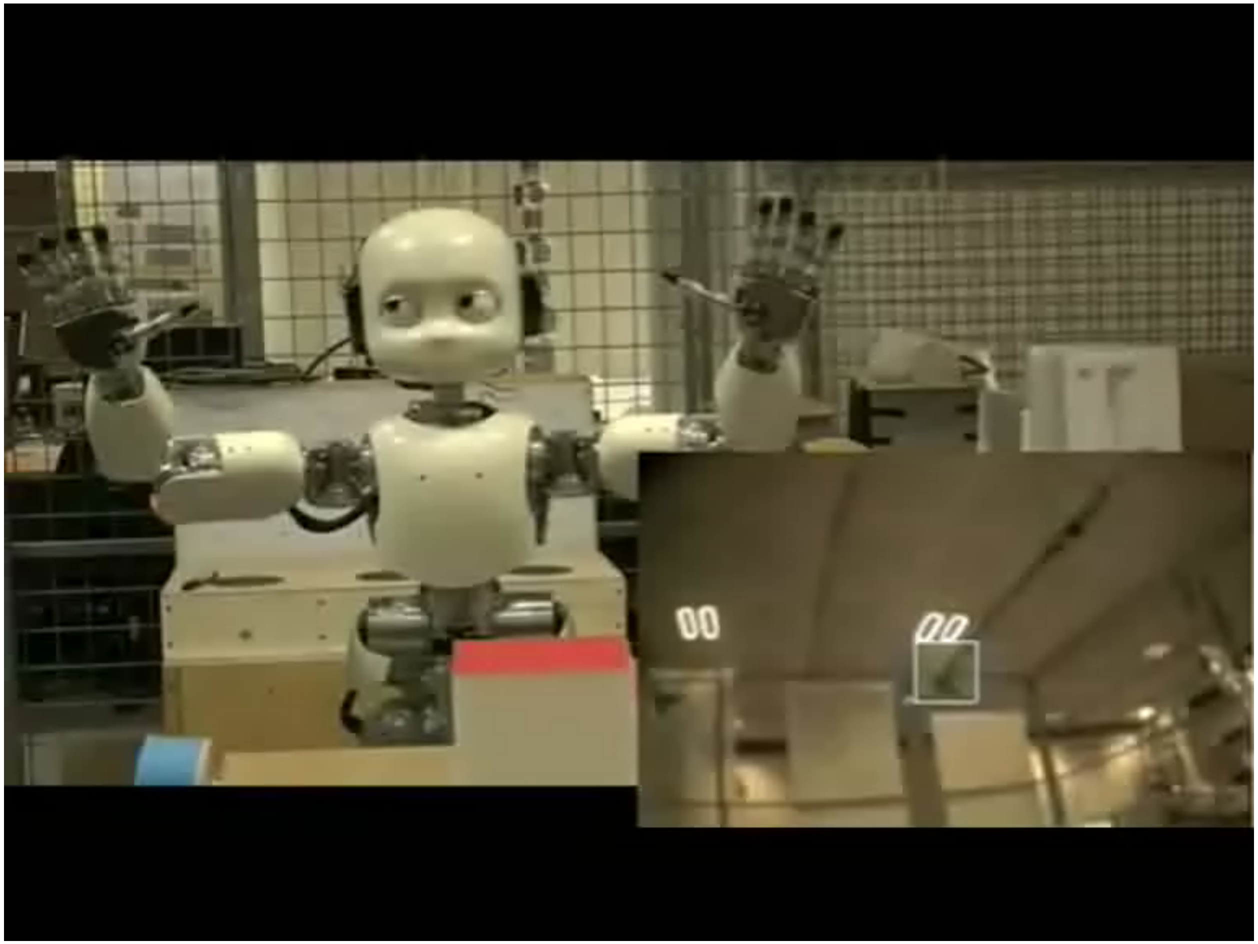
- A means of provoking environment, or as a response to exciting stimuli.
- Repetitive, exploratory action







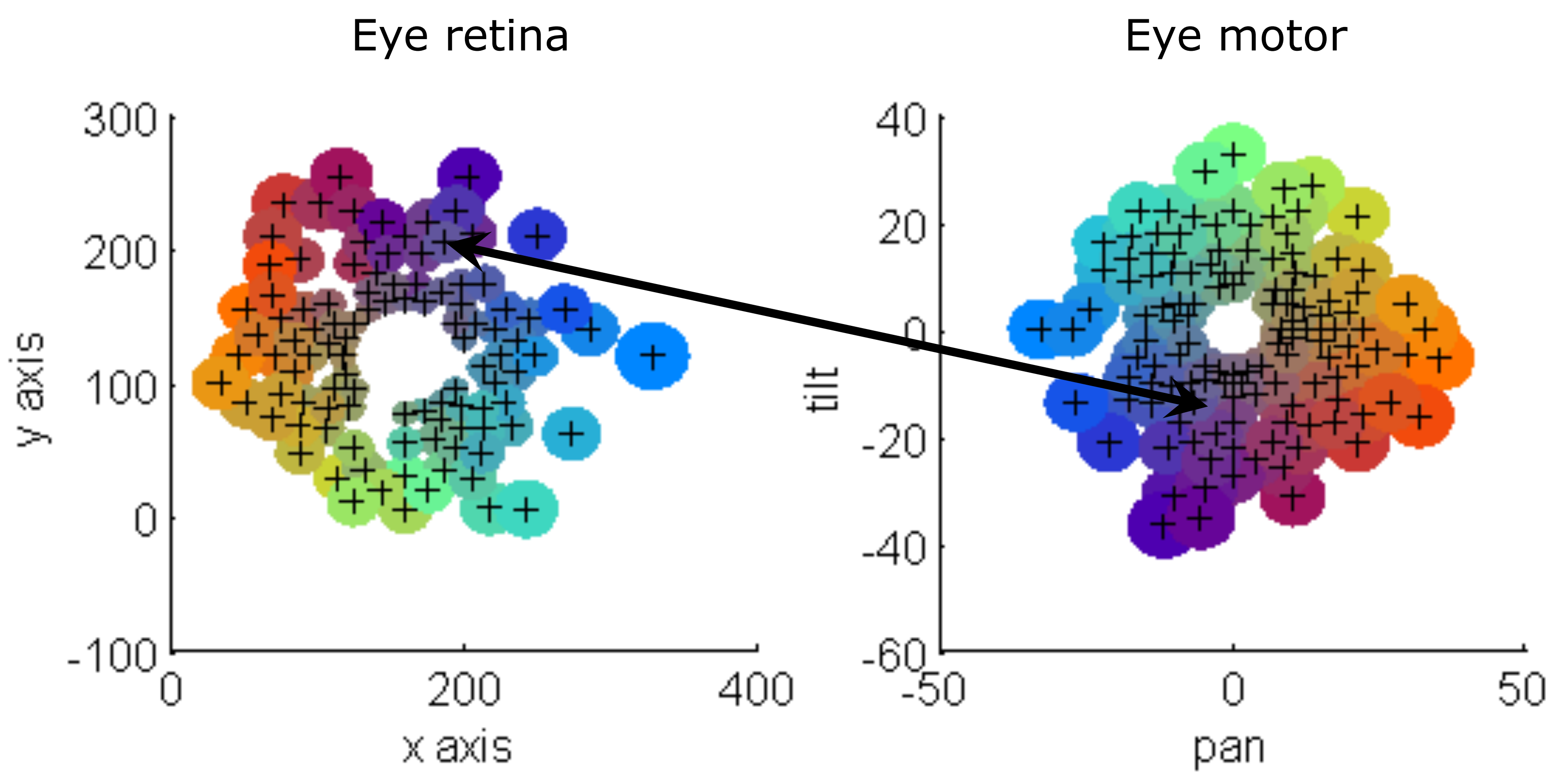
Early saccade learning



Neural representation

- Consists of connected ‘maps’ of ‘fields’
- Abstraction of neural maps in the brain
- Overlap between fields is interesting

Learning sensor-motor mappings



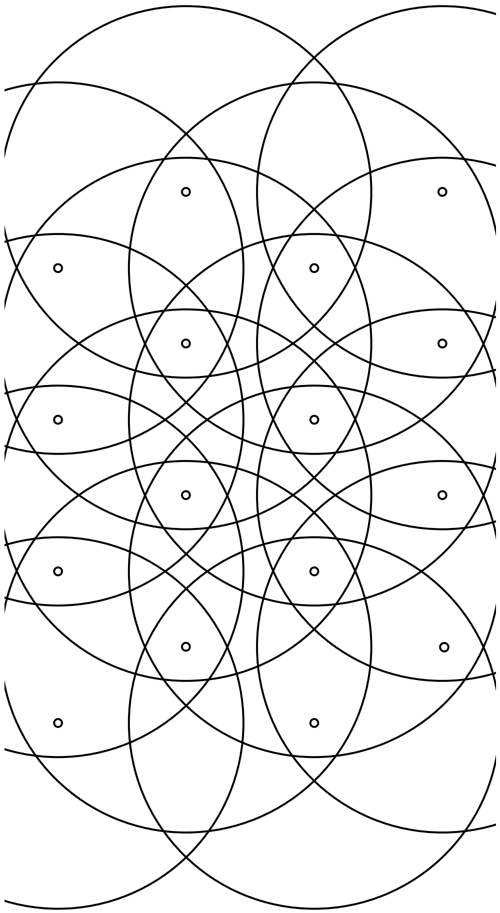
Sensorimotor structures

Overlapping fields

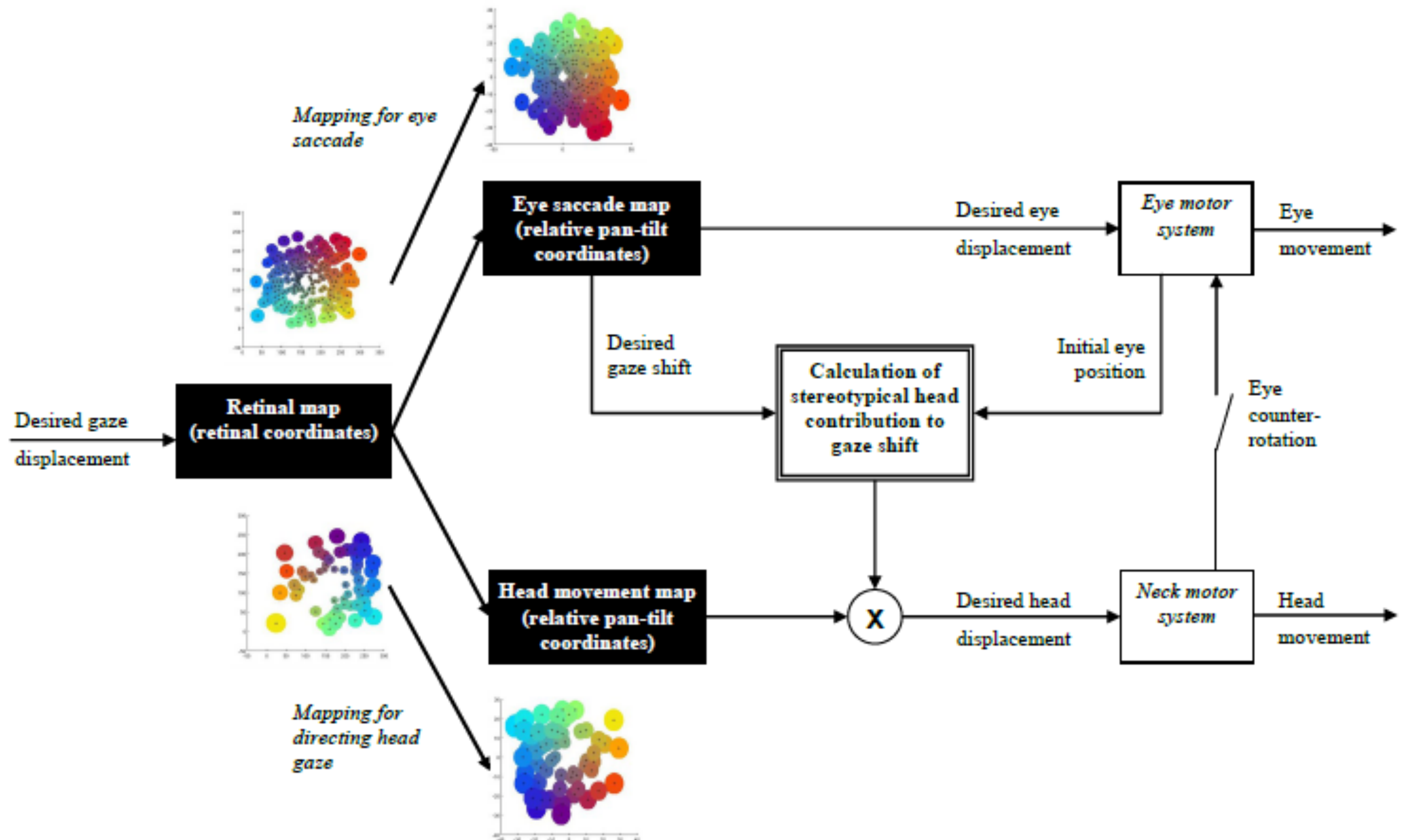
- Aim - minimise number of connections between maps (= fields)
- Optimum range for overlap, for robots:

  $$1.0 < r < 1.5$$

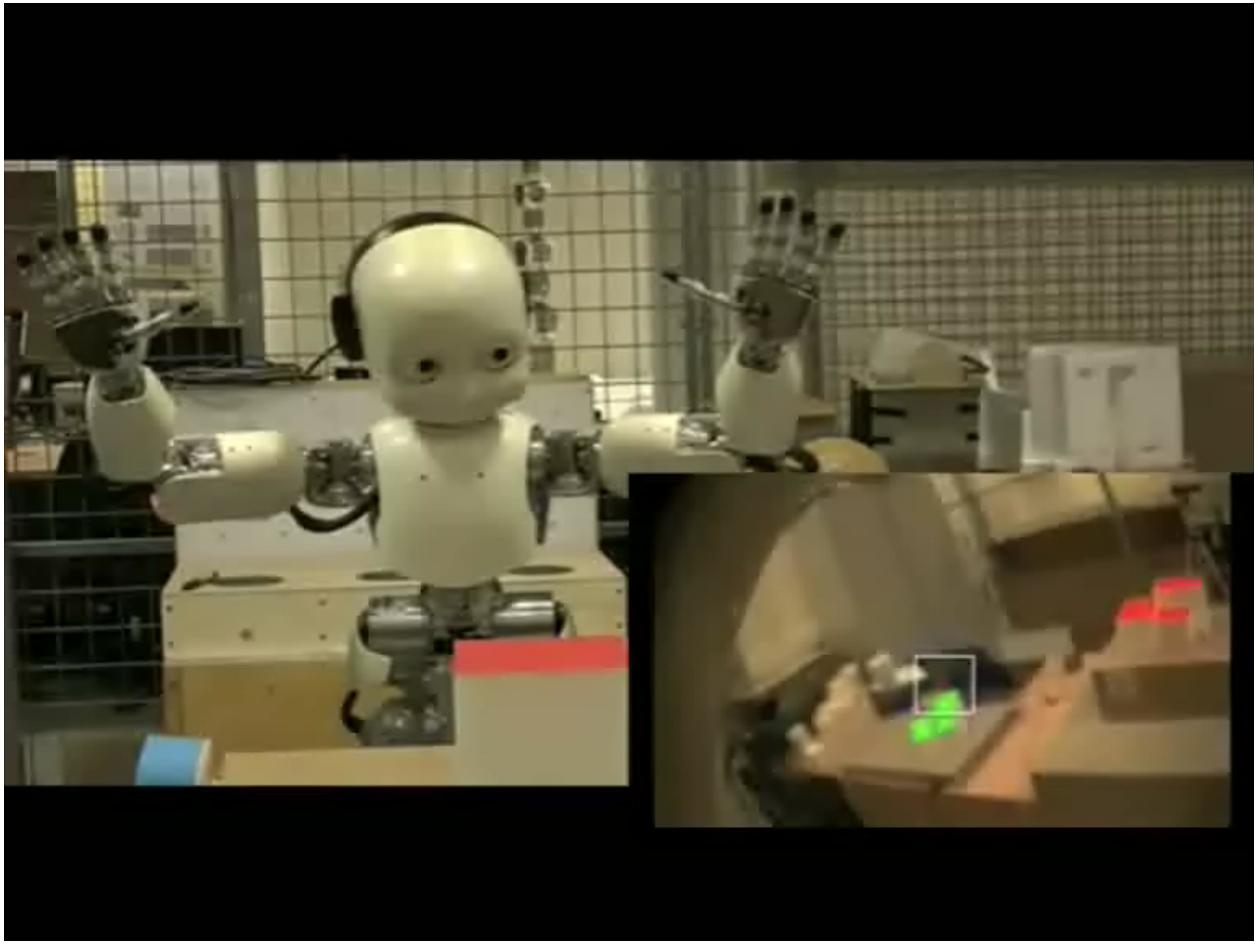
  (1.0 = centre spacing)
- Reported for brain fields: radii = 1.2



Sensorimotor architecture



Learning gaze control



The importance of constraints

- Scaffolding
- Bandwidth reduction
- Degrees of freedom reduction
- Many forms of constraint are possible:
  - Physical - morphology, mechanical, motor
  - Internal - cognitive, sensory, neural, maturational
  - Environmental - external, scaffolding, social.

Constraints

- Constraints – produce staged sequences.
- Shape learning - by restricting the range of sensorimotor functionality available (in infant and robot).
- Constraints can be maturational (Type A), or emergent (Type B).

Type A constraints - motor

Prenatal – motor, tactile, proprioception (no vision)

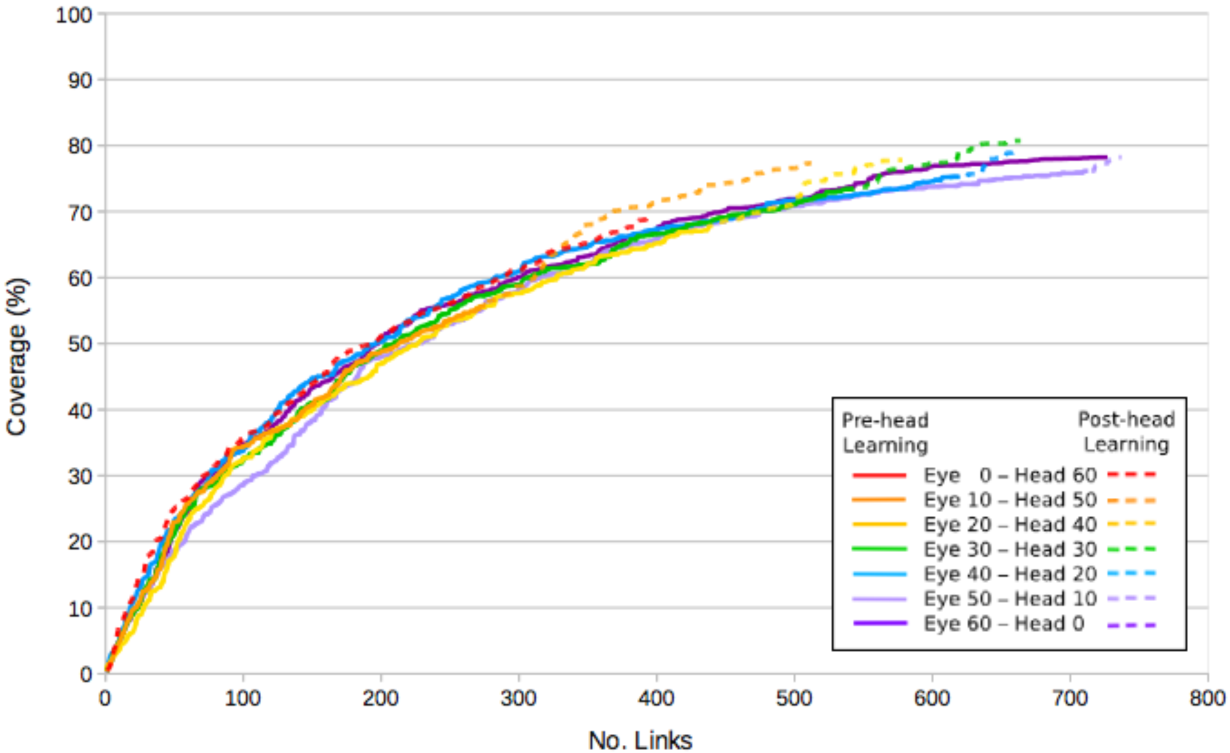
Newborn – motor - only eyes, head roll, vision crude

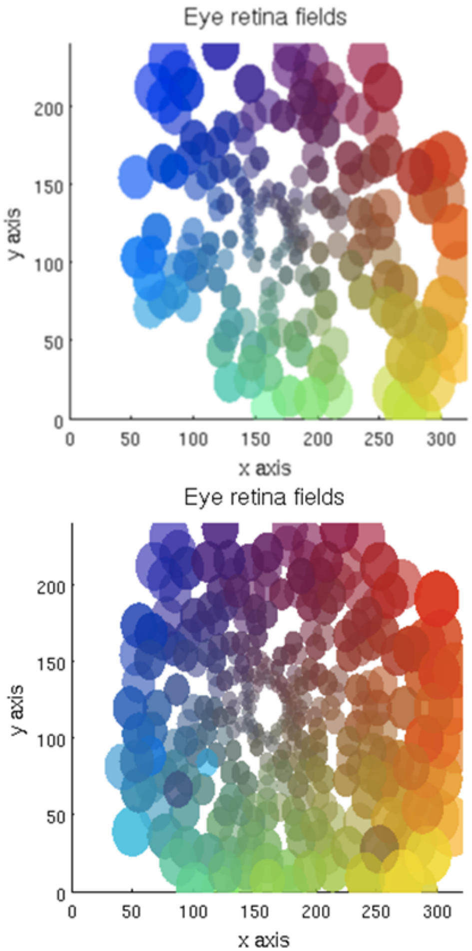
1 month – neck muscles, saccades, better acuity

3 months – reaching, arm but not hand

Hence: maturational constraints separate proprioception, from eye control, from arm control, from hand control, …

3 target saccade learning





Longitudinal development

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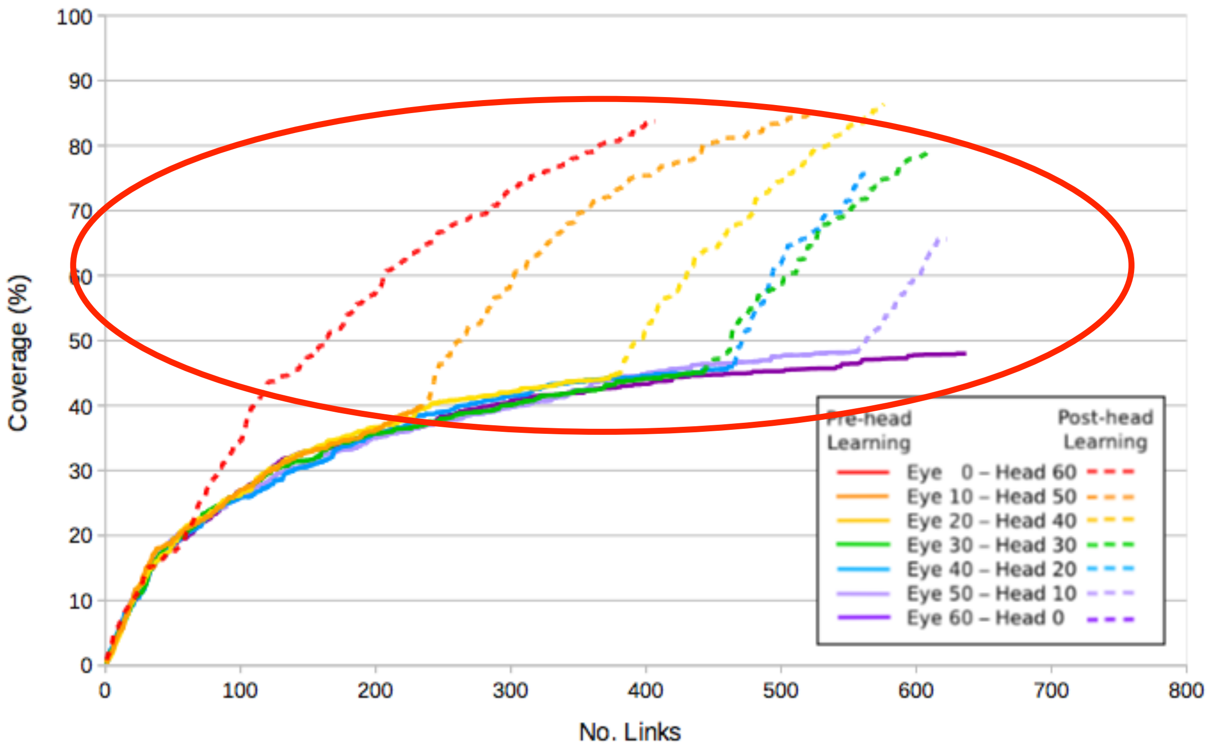
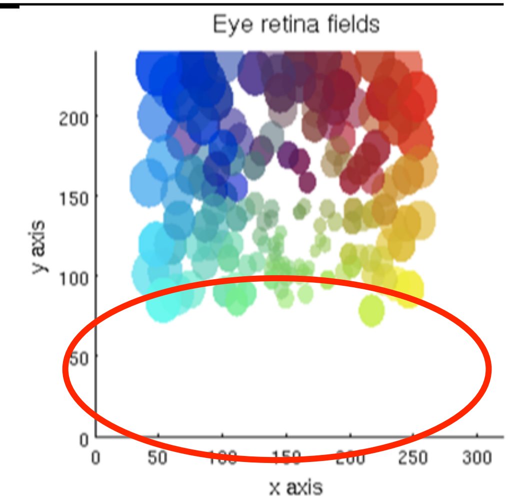
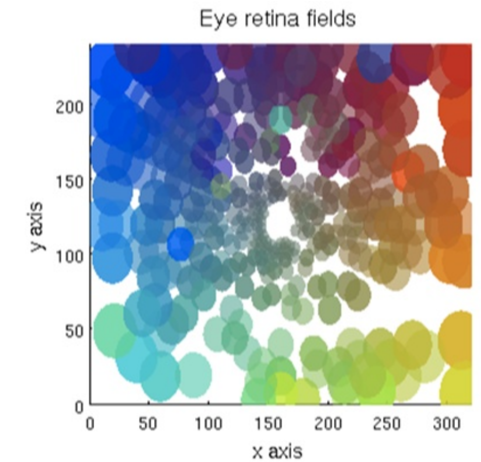
1 target saccade learning







Longitudinal development

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Longitudinal development

- Stages reflect the acquisition and consolidation of behaviours
- Development across infants tends to follow a broadly similar sequence and direction, with some variation
- Primitive behaviours bootstrap more complex ones
- Stages (and constraints) scaffold learning and reduce complexity

iCub motor development

Motor system		Simulated age (months)										
		"Birth"	1	2	3	4	5	6	7	8	9	10
Eyes	Pan, tilt	Increasing control										
	Vergence	Increasing vergence										
	Eyelids	Working										
Neck	Roll, pitch, yaw	Increasing control										
	Torque	Increasing torque										
Shoulder	Roll, pitch, yaw		Increasing control									
	Torque		Increasing torque									
Elbow	Pitch		Increasing control									
	Torque					Increasing torque						
Wrist	Roll, pitch, yaw							Increasing control				
Hand	Thumb opposition					Increasing range of opposition						
	Thumb					Thumb refinement						
	Fingers		Parallel finger use			Individual finger refinement						
	Grasps				Ulnar		Palmar	Radial	Pincer			
Torso	roll											
	pitch			Increasing movement precision								
	yaw				Increasing movement precision							
	torque			Increasing torque								

Longitudinal development

Staged learning

Play & relation to babbling

- Infant play – explore & find new behaviours
- Our play mechanism is based on schemas
  - Schemas record experience
  - Consist of pre-conditions, actions and post-conditions
  - Similar schemas produce generalisations, and exceptions can be learnt
  - Schemas chains - for complex acts and plans

Schema generalisation

Pre-conditions	Action	Post-conditions
	Reach to 35,-66	Hand at 35,-66

(a) Initially excited schema

Pre-conditions	Action	Post-conditions
Obj. 1 at 35,-66	Reach to 35,-66	Obj. 1 at 35,-66 Hand at 35,-66 Touching obj. 1

(b) Extended schema with new information

Pre-conditions	Action	Post-conditions
Obj. $a at $x,$y	Reach to $x,$y	Obj. $a at $x,$y Hand at $x,$y Touching obj. $a

(c) Generalised schema

Schema generalisation and chaining

Pre-conditions	Action	Post-conditions
Obj. $a at $x,$y	Reach to $x,$y	Obj. $a at $x,$y Hand at $x,$y Touching obj. $a

Pre-conditions	Action	Post-conditions
Obj. $a at $x,$y Touching obj. $a	Grasp	Obj. $a at $x,$y Hand at $x,$y Holding obj. $a

Schemas

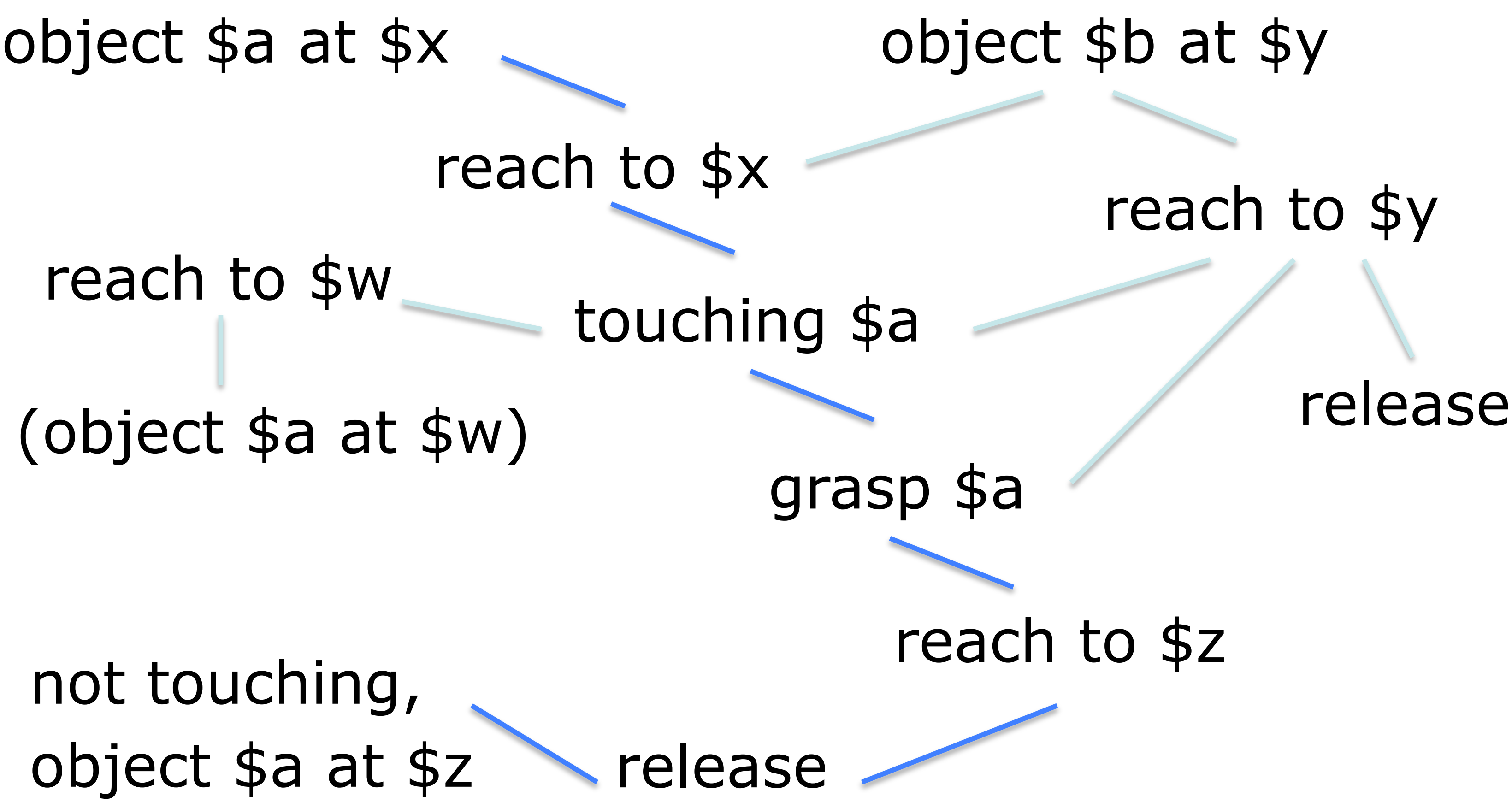
- Schemas act as LTM & support "planning"
- Similar to 'action chunking' in basal ganglia
- Generalisation aids affordance discovery – combining current information with prior exploratory behaviour.
- Focus learning on novel experiences
- Language tokens can be incorporated as an additional sensory stimulus

Learning to touch and point

Single object at any location

Scenario	Schemas produced
• Generalisation only (Simulated Robot)	19244
• Stages only (Simulated Robot)	347
• Stages, generalisation (Simulated Robot)	227
• Stages, generalisation (Physical Robot)	115

Play generator



Play

Sensory motor learning

	Motor DoF	Sensory maps dimensions	Stages time	Learning (mins)
Eyes	3	2+1	1	30
Head	2	2	1	60
Tactile		1		
Torso	2	2	1	20
Arms	4x2	3x2	4	~3*10+60
Total	15	14	7	~3.5hrs

From zero to full control (but can take less time!)...

IM bootstraps motor babbling into skilled visio-reaching behaviour

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Findings

- Mappings and overlap – very efficient for learning and representation (STM)
- Schemas for active LTM of experience
- Motor constraints - ease redundant degree of freedom problems.
- Sensory constraints - speed learning
- Developmental sequence confirmed – tactile, vision, head, torso, reaching, …

Findings - 2

- Emergent stages in behaviour possible <u>without</u> structural change
- Motor babbling – more than random, has internal structure
- Play – major intrinsic motivation, goal free behaviour productive, serendipitous goal discovery, intrinsic activation philosophy

Summary

- Development is *essential* for human learning
- Development *may be essential* for robot learning – for truly autonomous systems
- Infancy is a very important developmental period
- Developmental paradigm gives new models of learning
- A new field - still much work to be done!

Further information

Videos are available at: http://www.aber.ac.uk/en/cs/research/ir/robots/icub/dev-icub/

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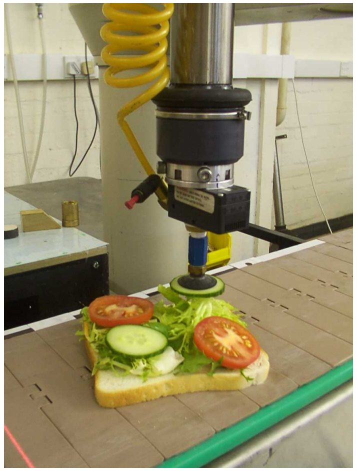
The Future ?

Two types of robot:

- Developmental
- Task based



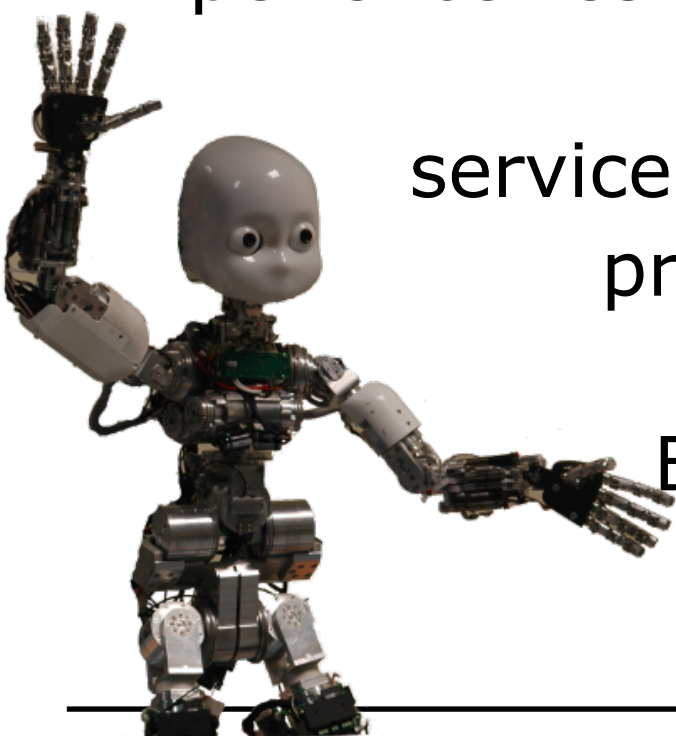
The Future ?

- No programming - only training (in the world)
- Customised in situ.
- Experience resides in systems, but all different,

(sets of individuals).

service centre = robot remedial school,

programs of corrective shaping.



But we can also examine brain!

so transferable skills?


Thank you for
your attention