Development & Learning

Phylogeny
(Cognitive Architecture)

Ontogeny
(Learning & Development + Motivations)

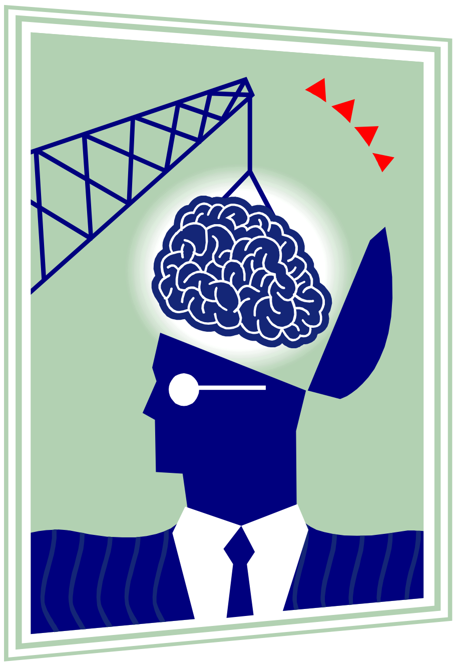
Phylogeny vs. Ontogeny

- What is the minimal architecture required to configure a cognitive system & enable it to boot-strap cognitive development?

- Cognitivist stance:
  - Balance between 'pre-knowledge' and acquirable knowledge
  - What do you need to know in order to learn?

- Emergent stance
  - Balance between phylogeny and ontogeny
  - Phylogeny: evolution of the system configuration from generation to generation
  - Ontogeny: adaptation, development, and learning of the system during its lifetime
  - Can't wait for evolution so need a minimal phylogenic state

Phylogeny and Ontogeny



Minimal set of sensory and motoric control structures

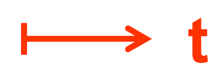
To boot-strap ontogenic development

No time to evolve a complete system

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

Phylogeny and Ontogeny

Phylogeny
(Cognitive Architecture)

Ontogenesis
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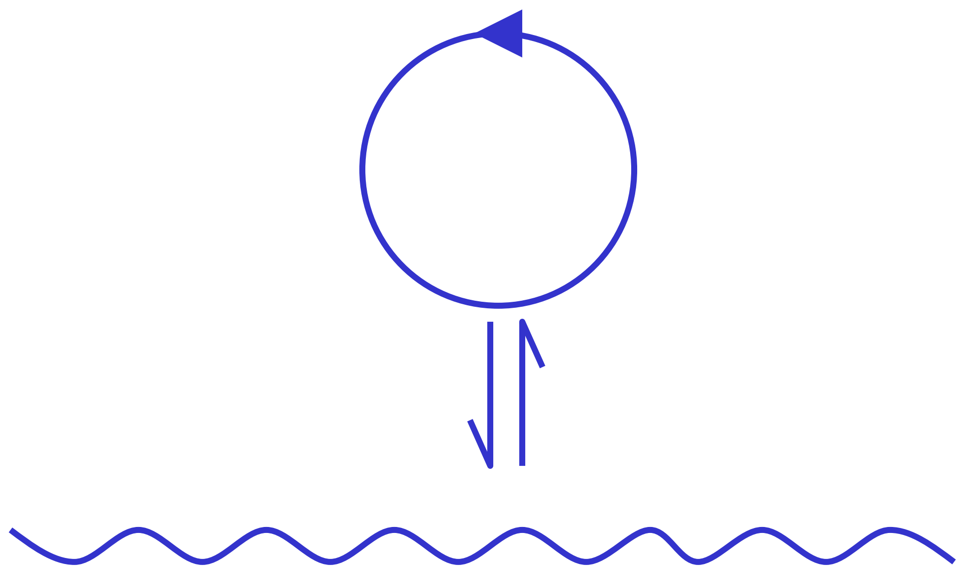
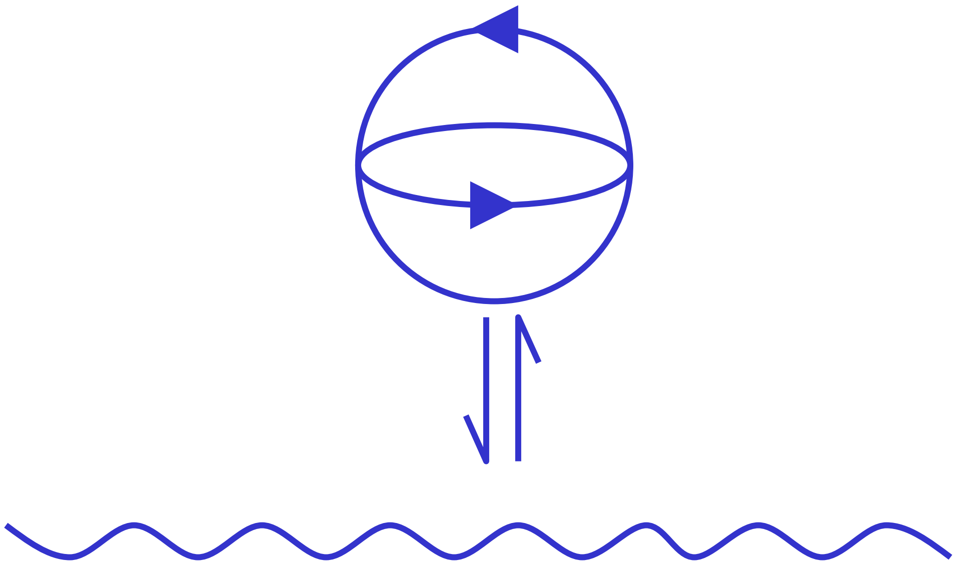


Co-Determination / Structural Coupling

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

Development vs. Learning

Learning

a process for estimating or improving the parameter values that govern the behaviour of a known model,

Development

a process for generating or discovering the model itself

Development vs. Learning

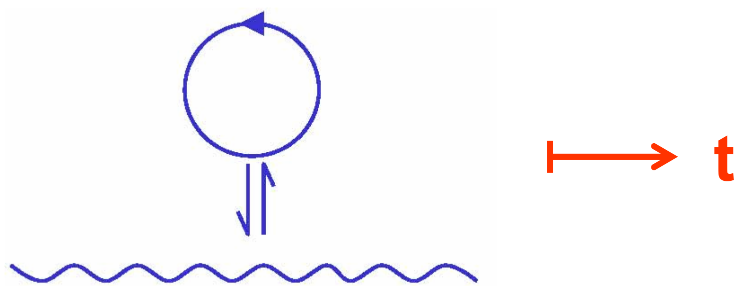
Learning arises as a consequence of the interaction between the cognitive agent and the world around it.

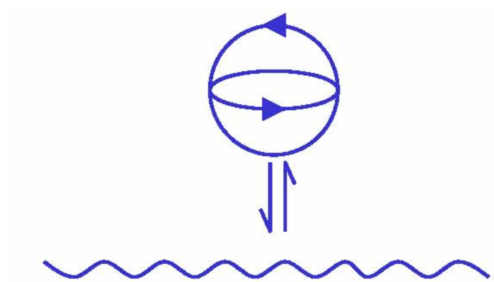
Development arises from learning as a consequence of the interaction of the cognitive agent with itself

Both learning and development are forms of adaptation

Learning

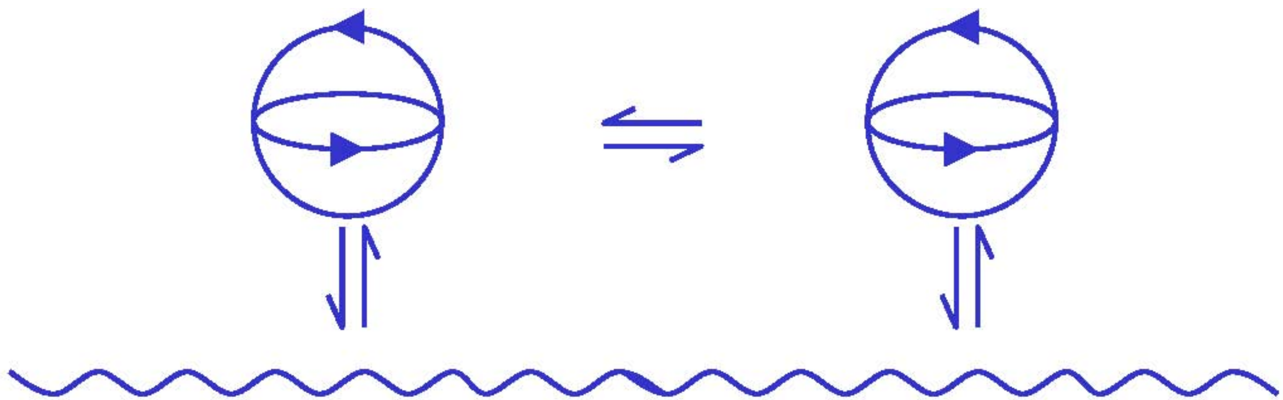
- 3 types
  - Supervised: teaching signals are directional error signals
  - Reinforcement: teaching signals are scalar rewards or reinforcement signals
  - Unsupervised: no teaching signals
- [Doya 99]
  - Supervised: Cerebellum ← **Internal models of the environment; Short-cut models of input-output associations learned elsewhere**
  - Reinforcement: Basal Ganglia ← **Evaluate given state; Select action**
  - Unsupervised: Cerebral Cortex ← **Represent external state & internal context; Provide common representational framework for Cerebellum and BG**
- [McClelland et al. 1995]
  - Hippocampus – Cortex Complementary Learning
  - Hippocampus: rapid auto- and hetero-associative learning
  - Hippocampus reinstates neo-cortex memories





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.]

The Cognitive Systems Monographs (COSMOS) publish new developments and advances in the fields of cognitive systems research, rapidly and informally but with a high quality. The intent is to bridge cognitive brain science and biology with engineering disciplines. It covers all the technical contents, applications, and multidisciplinary aspects of cognitive systems, such as Bionics, System Analysis, System Modelling, System Design, Human Motion, Understanding, Human Activity Understanding, Man-Machine Interaction, Smart and Cognitive Environments, Human and Computer Vision, Neuroinformatics, Humanoids, Biologically motivated systems and artefacts Autonomous Systems, Linguistics, Sports Engineering, Computational Intelligence, Biosignal Processing, or Cognitive Materials as well as the methodologies behind them. Within the scope of the series are monographs, lecture notes, selected contributions from specialized conferences and workshops, as well as selected PhD theses.

» COSMOS

David Vernon • Claes von Hofsten • Luciano Fadiga

A Roadmap for Cognitive Development in Humanoid Robots

This book addresses the central role played by development in cognition. The focus is on applying our knowledge of development in natural cognitive systems, specifically human infants, to the problem of creating artificial cognitive systems in the guise of humanoid robots. The approach is founded on the three-fold premise that (a) cognition is the process by which an autonomous self-governing agent acts effectively in the world in which it is embedded, (b) the dual purpose of cognition is to increase the agent's repertoire of effective actions and its power to anticipate the need for future actions and their outcomes, and (c) development plays an essential role in the realization of these cognitive capabilities. Our goal in this book is to identify the key design principles for cognitive development. We do this by bringing together insights from four areas: enactive cognitive science, developmental psychology, neurophysiology, and computational modelling. This results in roadmap comprising a set of forty-three guidelines for the design of a cognitive architecture and its deployment in a humanoid robot. The book includes a case study based on the iCub, an open-systems humanoid robot which has been designed specifically as a common platform for research on embodied cognitive systems.

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Vernon et al.

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» COGNITIVE SYSTEMS MONOGRAPHS

A Roadmap for Cognitive Development in Humanoid Robots

Springer

Guidelines for the Phylogeny of a Developmental Cognitive System	
Number	**Guideline**
	Enaction
1	Rich array of physical sensory and motor interfaces
2	Autonomy-preserving processes of homeostasis
3	Humanoid morphology
4	Self-modifi cation to expand actions and improve prediction
5	Autonomous generative model construction
6	Internal social and exploratory motives
7	Learning affordances
8	Internal simulation to predict, explain, & imagine events, and scaffold knowledge
9	Grounding internal simulations in actions
	Developmental Psychology
10	Movements organized as actions
11	Social and explorative motives
12	Attention fi xated on the goal of an action
13	Morphology integral to the model of cognition
14	Early movements constrained to reduce the number of degrees of freedom
15	Perception of objecthood
16	Discrimination & addition of small numbers; groups of large numbers
17	Navigation based on dynamic ego-centric path integration
18	Re-orientation based on local landmarks
19	Attraction to people (faces, their sounds, movements, and features)
20	Preferential attention to biological motion
21	Recognition of people, expression, and action
22	Prolonged attention when a person engages in mutual gaze
23	Perceive & communicate emotions by facial gesture and engage in turn-taking
	Neurophysiology
24	Encode space in motor & goal specifi c manner
25	Motor system encoding of actions with associated effector-specifi c percepts
26	Involvement of the motor system in discrimination between percepts
27	Mechanism to learn hierarchical representations
28	Pre-motor theory of attention —spatial attention
29	Pre-motor theory of attention —selective attention
	Computational Modelling
30	Minimal set of innate behaviours for exploration and survival
31	Value system that govern actions and development
32	Attentional mechanism
33	Learn from experience the motor skills associated with actions
34	Affective drives associated with autonomy-preserving processes of homeostasis
35	Anticipation and planning based on internal simulation
36	Action selection modulated by affective motivation mechanisms
37	Separate representations associated with each component / sub-system
38	Transient and generalized episodic memories of past experiences
39	Procedural memory of actions and outcomes associated with episodic memories
40	Mechanism to learn based on comparison of expected and observed outcomes
41	Mechanism to learn co-joint object-action affordances by exploration
42	Hierarchically-structured representations of action-sequence skills
43	Concurrent competitive operation of components and subsystems

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Actions are

- initiated by a motivated subject
- defined by goals
- guided by prospective information

Hans-Hellmut Nagel:

- Actions entail an *agent* & an implicit *goal*
- Actions situated
- Concatenated actions → an *intention*
- Extended sequences of concatenated situated actions → a *behaviour*
- The set of all admissible behaviours of an agent → a *scenario*
- Scenarios:
  - canonical representations
  - relationships among them, &
  - (linguistic) manifestation for *explanation* and *construction*

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Anticipation	
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Adaptation	
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7 (25, 41)	Learning affordances
9 (40)	Grounding internal simulations in actions
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Motivation	
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Autonomy	
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Development

Learning: to tune phylogenetic skills

Development: change system dynamics new action spaces

Self-modification

- Improve the predictive performance

- Increase the space of viable actions