Artificial Cognitive Systems

Module 6: Development and Learning

Lecture 3: Development from the perspective of psychology

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Cognitive Development

Two types of natural species

Precocial

- Born with well-developed behaviours, skills, and abilities direct result of their genetic make-up (phylogeny)
- After birth, these abilities are honed and tuned but they don't change greatly over their lifetime

Cognitive Development

Two types of natural species:

Altricial

- Born with poor or undeveloped behaviours and skills & highly-dependent for support
- Acquire complex cognitive skills over their life-time through ontogenetic development

Cognitive Development

Two types of natural species:

- Should view the precocial and altricial as two ends of a spectrum
- The goal is to strike the right balance between precocial and atricial
  - balance between innate and developmental potential
- Identify the appropriate phylogenetic configuration
  - i.e. cognitive architecture that will support subsequent development

Cognitive Development

Goal-directed and Prospective Nature of Action

- Movements of biological organisims are organized as actions not reactions
- Reactions: response to earlier events
- Actions:
  - Initiated by a motivated agent
  - Defined by goals
  - Guided by prospective information
  - Organized by goals not the trajectory or the movement

Cognitive Development

Core Cognitive Abilities in Infants

- Core knowledge systems
  - Basis of representations of objects, people, places
    - Object-like:

      complete
      connected
      solid bodies that maintain identity over time
      persist through occlusion

Cognitive Development

Core Cognitive Abilities in Infants

- Core knowledge systems
  - Two core systems for numbers:
    - Small exact numbers: discriminate 1 vs 2; 2 vs 3; not higher
    - Approximate numbers in sets
    - Discriminate without counting: subitization (independent of modality)

Cognitive Development

Core Cognitive Abilities in Infants

- Very attracted to sounds, movements, features of human face
- Look longer at a face that makes eye contact (mutual gaze)
- Turn-taking
- Imitation of facial gestures

Cognitive Development

Core Cognitive Abilities in Infants

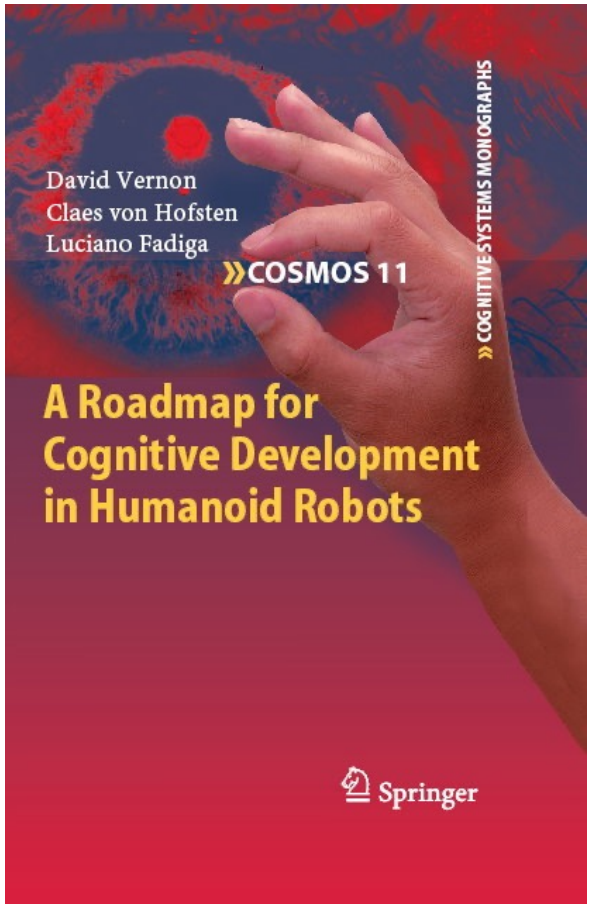
- Navigation and orientation
  - Adults: combine non-geometric (e.g. colour) with geometric information
  - Young children rely only on geometry
  - Momentary rather than enduring
  - Egocentric rather than geocentric
  - Capacity for path integration (cumulatively basing next step on previous ones) by recognizing landmarks rather than forming global representations of scenes

Cognitive Development

Ontogeny

- The path that development takes in scaffolding these abilities
- Anticipatory, prospectively-controlled goal-directed repertoire of possible actions
- Begins with actions that have minimal prospection
- Progresses to more complex and more prospective actions
  - Head-hand-eye coordination
  - Manual and bi-manual manipulation
  - Inter-agent interaction
  - Imitation
  - Communication (gestural and vocal)

Cognitive Development



36 design requirements for a developmental cognitive architecture

Requirements for an Emergent Developmental Cognitive Architecture	
Embodiment	
1	Rich array of physical sensory and motor interfaces
2	Humanoid morphology
3	Morphology integral to the model of cognition
Perception	
4	Attention fixated on the goal of an action
5	Perception of objecthood
6	Discrimination & addition of small numbers; groups of large numbers
7	Attraction to people (faces, their sounds, movements, and features)
8	Preferential attention to biological motion
9	Recognition of people, expression, and action
10	Prolonged attention when a person engages in mutual gaze
11	Perceive & communicate emotions by facial gesture and engage in turn-taking
12	Involvement of the motor system in discrimination between percepts
13	Mechanism to learn hierarchical representations
14	Mechanism for spatial attention
15	Mechanism for selective attention
Action	
16	Movements organized as actions
17	Early movements constrained to reduce the number of degrees of freedom
18	Navigation based on dynamic ego-centric path integration
19	Re-orientation based on local landmarks
20	Action selection modulated by affective motivation mechanisms
21	Hierarchically-structured representations of action-sequence skills

Anticipation	
22	Internal simulation to predict, explain, & imagine events, and scaffold knowledge)
Adaptation	
23	Self-modification to expand actions and improve prediction
24	Autonomous generative model construction
25	Learning affordances
26	Grounding internal simulations in actions
27	Learn from experience the motor skills associated with actions
28	Transient and generalized episodic memories of past experiences
29	Procedural memory of actions and outcomes associated with episodic memories
Motivation	
30	Social and exploratory motives
31	Affective drives associated with autonomy-preserving processes of homeostasis
Autonomy	
32	Autonomy-preserving processes of homeostasis
33	Encode space in motor & goal specific manner
34	Minimal set of innate behaviours for exploration and survival
35	Separate representations associated with each sub-system
36	Concurrent competitive operation of subsystems

Desiderata for Developmental Cognitive Architectures

Desideratum 1. Value systems, drives, motivation

Desideratum 2. Physical embodiment

Desideratum 3. Sensorimotor contingencies

Desideratum 4. Perception

Desideratum 5. Attention

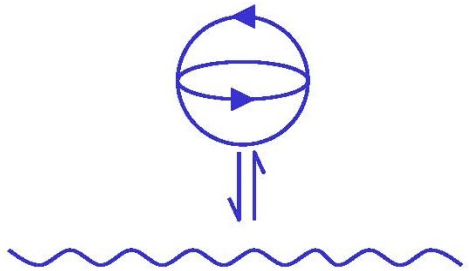
Desideratum 6. Prospective action

Desideratum 7. Declarative & procedural *m*emory

Desideratum 8. Multiple modes of learning

Desideratum 9. Internal simulation

Desideratum 10. Constitutive autonomy



Phylogeny
(Cognitive Architecture)

Ontogeny
(Learning & Development + Motivation)

Drives
Value System

(Merrick 2017)

"The value system is a core component of developmental systems because it facilitates the 'brain' to map behavioural responses to sensed external phenomena"

K. Merrick, "Value Systems for Developmental Cognitive Robotics: A Survey", Cognitive Systems Research, Vol. 41, pp. 38-55, 2017.

"Computational value systems aim not only to support learning, but also [to support] autonomous attention focus to direct learning"

K. Merrick, "Value Systems for Developmental Cognitive Robotics: A Survey", Cognitive Systems Research, Vol. 41, pp. 38-55, 2017.

Reading

Vernon, D. Artificial Cognitive Systems – A Primer, MIT Press, 2014, Chapter 6

Merrick, K. E. Value Systems for Developmental Cognitive Robotics, Cognitive Systems Research, Vol. 41, Issue C (2017).

Further Reading

Merrick, K. E. A Comparative Study of Value Systems for Self-motivated Exploration and Learning by Robots, IEEE Transactions on Autonomous Mental Development, Vol. 2, No. 2, 119–131 (2010).

Vernon, D., von Hofsten, C., and Fadiga, L. A Roadmap for Cognitive Development in Humanoid Robots, Cognitive Systems Monographs (COSMOS), Springer, ISBN 978-3-642-16903-8 (2010); Chapter 6.

Vernon, D., von Hofsten, C. and Fadiga, L. "Desiderata for Developmental Cognitive Architectures", Biologically Inspired Cognitive Architectures, Vol. 18, pp. 116-127 (2016).