

Contents

1	A Conceptual Framework for Developmental Cognitive Systems	1
1.1	Introduction	1
1.2	Cognition	2
1.3	Enaction	3
1.3.1	Enaction and Development	5
1.3.2	Enaction and Knowledge	7
1.3.3	Phylogeny and Ontogeny: The Complementarity of Structural Determination and Development	8
1.4	Embodiment: The Requirements and Consequences of Action	8
1.5	Challenges	10
1.6	Summary	11
2	Pre-natal Development and Core Abilities	13
2.1	Action as the Organizing Principle in Cognitive Behaviour	13
2.2	Prenatal Development	15
2.2.1	Morphological Pre-structuring	16
2.2.2	Pre-structuring of the Motor System	16
2.2.3	Pre-structuring of the Perceptual System	18
2.2.4	Forming Functional Systems	20
2.3	Core Abilities	20
2.3.1	Core Knowledge	20
2.3.2	Core Motives	23
2.4	Summary	24
2.4.1	Actions	24
2.4.2	Prenatal Development	25
2.4.3	Core Abilities	26

3	The Development of Cognitive Capabilities in Infants	29
3.1	The Development of Perception	29
3.2	Visual Development	30
3.2.1	Space Perception	32
3.2.2	Object Perception	34
3.3	Acquiring Predictive Control	35
3.3.1	Development of Posture and Locomotion	35
3.3.2	Development of Looking	40
3.3.3	Development of Reaching and Manipulation	44
3.3.4	Development of Social Abilities	54
3.4	Summary	57
3.4.1	The Basis for Development	57
3.4.2	Visual Processing	58
3.4.3	Posture	59
3.4.4	Gaze	60
3.4.5	Reaching and Grasping	61
3.4.6	Manipulation	63
3.4.7	Social Abilities	63
4	What Neurophysiology Teaches Us About Perception and Action	65
4.1	The Premotor Cortex of Primates Encodes Actions and Not Movements	65
4.2	The System for Grasping	68
4.3	The Distributed Perception of Space	70
4.4	Perception Depends on Action	72
4.5	Action and Selective Attention	73
4.6	Structured Interactions	76
4.7	Summary	76
4.7.1	Grasping	77
4.7.2	Spatial Perception	77
4.7.3	Perception-Action Dependency	78
4.7.4	Structured Interactions	79
4.7.5	Selective Attention	79
5	Computational Models of Cognition	81
5.1	The Three Paradigms of Cognition	81
5.1.1	The Cognitivist Paradigm	85
5.1.2	The Emergent Paradigm	86
5.1.3	The Hybrid Paradigm	86
5.1.4	Relative Strengths	87
5.2	Cognitive Architectures	89
5.2.1	The Cognitivist Perspective on Cognitive Architectures	89

5.2.2	The Emergent Perspective on Cognitive Architectures	90
5.2.3	Desirable Characteristics of a Cognitive Architecture	91
5.2.4	A Survey of Cognitive Architectures	95
5.3	Summary	98
6	A Research Roadmap	101
6.1	Phylogeny	103
6.1.1	Guidelines from Enaction	103
6.1.2	Guidelines from Developmental Psychology	103
6.1.3	Guidelines from Neurophysiology	105
6.1.4	Guidelines from Computational Modelling	105
6.1.5	A Summary of the Phylogenetic Guidelines for the Development of Cognition in Artificial Systems	108
6.2	Ontogeny	110
6.2.1	Guidelines from Developmental Psychology	110
6.2.2	Scenarios for Development	111
6.2.3	Scripted Exercises	114
7	The iCub Cognitive Architecture	121
7.1	The iCub Humanoid Robot	121
7.1.1	The iCub Mechatronics	122
7.1.2	The iCub Middleware	124
7.2	The iCub Cognitive Architecture	125
7.2.1	Embodiment: The iCub Interface	127
7.2.2	Perception	130
7.2.3	Action	134
7.2.4	Anticipation & Adaptation	138
7.2.5	Motivation: Affective State	141
7.2.6	Autonomy: Action Selection	142
7.2.7	Software Implementation	142
7.3	The iCub Cognitive Architecture vs. the Roadmap Guidelines	144
7.3.1	Embodiment	144
7.3.2	Perception	145
7.3.3	Action	148
7.3.4	Anticipation	149
7.3.5	Adaptation	150
7.3.6	Motivation	151
7.3.7	Autonomy	151
7.4	Summary	153

8	Conclusion	155
8.1	Multiple Mechanisms for Anticipation	155
8.2	Prediction, Reconstruction, and Action: Learning Affordances	156
8.3	Object Representation	156
8.4	Multi-modal and Hierarchical Episodic Memory	157
8.5	Generalization and Model Generation	157
8.6	Homeostasis and Development	158
A	Catalogue of Cognitive Architectures	159
A.1	Cognitivist Cognitive Architectures	160
A.1.1	The Soar Cognitive Architecture	160
A.1.2	EPIC — Executive Process Interactive Control	161
A.1.3	ACT-R — Adaptive Control of Thought - Rational	162
A.1.4	The ICARUS Cognitive Architecture	165
A.1.5	ADAPT — A Cognitive Architecture for Robotics	167
A.1.6	The GLAIR Cognitive Architecture	168
A.1.7	CoSy Architecture Schema	170
A.2	Emergent Cognitive Architectures	174
A.2.1	Autonomous Agent Robotics	174
A.2.2	A Global Workspace Cognitive Architecture	175
A.2.3	Self-directed Anticipative Learning	178
A.2.4	A Self-Affecting Self-Aware (SASE) Cognitive Architecture	179
A.2.5	Darwin: Neuromimetic Robotic Brain-Based Devices	181
A.2.6	The Cognitive-Affective Architecture	183
A.3	Hybrid Cognitive Architectures	186
A.3.1	A Humanoid Robot Cognitive Architecture	186
A.3.2	The Cerebus Architecture	187
A.3.3	Cog: Theory of Mind	189
A.3.4	Kismet	190
A.3.5	The LIDA Cognitive Architecture	192
A.3.6	The CLARION Cognitive Architecture	194
A.3.7	The PACO-PLUS Cognitive Architecture	196
	References	199
	Index	219