Modules, Brains and Schemas

Michael A. Arbib

Computer Science, Neuroscience and USC Brain Project
University of Southern California
Los Angeles, California 90089-2520, USA
arbib@pollux.usc.edu

Abstract. A short personal note briefly traces the author's interactions with Hartmut Ehrig. Where Ehrig has devoted much work to an algebraic theory of modules, the author has developed schema theory primarily as a tool for brain theory, but the author's version of schema theory has also been associated with algebraic theory and robotics. Topics presented in the present informal overview of schema theory include the role of schemas in bridging from action-oriented perception to knowledge, the notion of schema instances and their role in cooperative computation, learning in schemas, and ways of linking schemas to the study of the brain.

1 A Personal Introduction

My friendship with Hartmut Ehrig can be traced back to the volume "Universal Theory of Automata" which he co-authored with W. Kühnel, H.-J. Kreowski, and K.D. Kiermeier and published with Teubner, Stuttgart, in 1974. In this work, he applied category theory to provide a general framework for parts of automata theory. At around the same time, Ernie Manes – then my colleague at the University of Massachusetts at Amherst – had developed an alternative approach, first published in "Machines in a Category: An Expository Introduction" (in *SIAM Review*, 1974,16:163-192). In 1974, Ernie Manes arranged workshops in Amherst and San Francisco and we welcomed Hartmut to the United States, while in the following years he returned our hospitality in Germany. As the years went by, Hartmut's interests diverged from ours as he worked more and more on graph grammars and we continued in system theory, but as we moved on to apply our methods to the semantics of programming languages, we developed complementary algebraic approaches to the study of abstract data types.

Hartmut and I have only written one joint paper, "Linking schemas and module specifications for distributed systems", which Hartmut presented at the *2nd IEEE Workshop on Future Trends of Distributed Computing Systems*, in Cairo in 1990. It must be confessed that the paper was more a program for research than a presentation of results, and that research remains to be done. Since many readers of this volume will be well acquainted with the theory of module specifications (e.g., H. Ehrig and B. Mahr, 1990,*Fundamentals of Algebraic Specification 2: Module Specifications and Constraints*, volume 21 of *EATCS Monographs on Theoretical Computer Science*. Berlin: Springer Verlag), I present here

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the *informal* background for schema theory in its motivation in the search for a high-level description of the ways in which brains function. Readers wishing a more formal treatment may find it in the paper "Port Automata and the Algebra of Concurrent Processes" written with Martha Steenstrup and Ernie Manes (*Journal of Computer and System Sciences*, 1983, 27:29–50) and its development with Damian Lyons of a schema-based framework for programming robots, "A Formal Model of Computation for Sensory-Based Robotics" (*IEEE Trans. on Robotics and Automation*, 1989, 5:280–293).

Finally, I want to acknowledge both Hartmut's continuing interest in brain theory, both as intellectual stimulation and for its potential yield of insights for new technology, and his support of my work in these areas. For example, his invitation to give a keynote address at *IDPT-2002: Integrated Design and Process Technology* in Pasadena in June 2002 was the stumulus for the perspective published as "Towards a neurally-inspired computer architecture" (*Natural computing*, 2003, 2:1–46).

I count myself fortunate to be among those many computer scientists who have benefited from both Hartmut's collaboration and his intellectual support, and I wish him many more years of intellectual excitement.

2 Basic Notions of Schema Theory

Many workers in cognitive science have little interest in brain or action, and much of their work focuses on linking Artificial Intelligence (AI) and cognition to symbol manipulation in general and to linguistics in particular. My own work, on the contrary, tries to see our cognitive abilities as rooted in our more basic capabilities to perceive and interact with the world. What, then, is this schema theory in which we are to give an account of the embodied mind, integrating an account of our mental representations with an account of the way in which we interact with the world?

There are many other approaches to schema theory, as outlined in the section "A Historical Sketch" below. My own version of *schema theory* [2,3] is an approach to cognitive neuroscience which explains behavior in terms of the concurrent interaction of many functional units called *schemas* (composable units of action, thought and perception). There are schemas for recognition of different objects, and the planning and control of different activities, and for more abstract operations besides. Schema theory now combines three distinct levels of theorizing:

1) **Basic Schema Theory:** Schema theory *simpliciter* provides a basic language which matches well with the "mental". It has its basic definition at a functional level which associates schemas with specific perceptual, motor, and cognitive abilities and other complex dispositions – and then stresses how our mental life results from the dynamic interaction, the competition and cooperation, of many schema instances. For example, one *perceptual* schema would let you recognize that a large structure is a house; in doing so,