Chapter 8

Causal Modeling with Fuzzy Cognitive Maps

In contemporary social and behavioral science, fuzzy logic is still rather unpopular, perhaps because of its major affiliation with electrical engineering, industrial systems control, and computer science. However, in view of the fact that fuzzy logic aims equally well at a formalization of the cognitive processes humans employ in their daily activities in private and working environments, we conclude that sociologists, political scientists, and psychologists are grossly mistaking the real impact of fuzzy logic upon cognition and action, because it provides a new framework for knowledge engineering.

The purpose of the present chapter is to prove and demonstrate that fuzzy logic offers us new ways to understand nonlinear dynamics in complex systems, and that it allows us to model cognitive processes in a variety of different ways on the basis of cognitive mapping and cognitive maps. Cognitive mapping means knowledge projection, and a cognitive map is basically a dynamical associative network which consists of nodes and directed arcs such that the nodes represent information associated with domain knowledge and the directed arcs represent cause-effect relationships between each pair of nodes.

It will be shown that cognitive maps are an indispensible framework for knowledge acquisition, knowledge representation, and dynamical knowledge processing, in particular for fields in which causal reasoning is of primary importance. The epistemic value of cognitive maps arises from their wide applicability, and from the advantage of being accessible to (a) qualitative, (b) experimental, (c) interactive,
(d) integrative, (e) quantitative, (f) computer based, and (g) dynamical analyses. Cognitive maps admit a proper consideration of causal reasoning, the derivation of causal logic schemes, and the establishment of a causal algebra in terms of qualitative verbal concepts or quantitative numerical values.

The most important property, however, is that cognitive maps are implementable as nonlinear dynamical system models with or preferably without limit cycles, thereby allowing qualitative and quantitative predictions, forward chaining of causal propagations, and local vs. global systems analysis. A further outstanding property is that individual cognitive maps can be combined into larger and definitely more representative cognitive maps, a prerequisite for efficient knowledge acquisition and comparative causal knowledge representation. There are plenty of other properties which we discuss in the following sections. Emphasis is stressed on applications of cognitive maps. Our examples are chosen from fields as diverse as urban ecology, mental health, medicine, neuropsychology, extreme sports, biometeorology, weather forecast, voter apathy, plant control, and achievement motivation.

Section 8.1 centers on a short account of the history of cognitive mapping and cognitive maps in order to underscore their relevance to social and behavioral science. Section 8.2 presents then a systematic treatment of fuzzy cognitive maps and causal reasoning. The contents are structured in such a way that formally less inclined readers may profit as much as possible without too many mathematical burden, thereby favoring the discussion of several more or less complex examples of fuzzy cognitive maps. Section 8.3 presents a detailed account of fuzzy causal algebra including fuzzy causality, proper fuzzy causality, and the causal flow in FCMs regarding indirect and total effects. Section 8.4 centers on the fuzzy structural modeling approach by showing how FCMs are constructed from scratch and how causal knowledge can grow through interpersonal aggregation of FCMs, a unique feature of FCMs which outperforms traditional knowledge spaces, Bayesian trees, or nondynamical tree structures in general. Section 8.5 covers then seven examples of FCMs in real and virtual worlds, whereby the reader gets a clear picture of the broad applicability of FCMs. Section 8.6 centers finally on continuous FCMs and the law of concomitant variation, including some open problems. The final topics are then evaluation, limitations, and implementation issues regarding FCMs, since they are important for practical fields of application.