Chapter 13
Adaptive Estimation of Fuzzy Cognitive Networks and Applications

T.L. Kottas, Y.S. Boutalis and M.A. Christodoulou

Abstract Fuzzy Cognitive Networks (FCN) have been introduced by the authors as an operational extension of Fuzzy Cognitive Maps (FCM), which were initially introduced by Kosko to model complex behavioral systems in various scientific areas. One important issue of their operation is the conditions under which they reach a certain equilibrium point after an initial perturbation. This is equivalent to studying the existence and uniqueness of solutions for their concept values. In this chapter, we present a study on the existence of solutions of FCMs equipped with continuous differentiable sigmoid functions having contractive or at least non-expansive properties. This is done by using an appropriately defined contraction mapping theorem and the non-expansive mapping theorem. It is proved that when the weight interconnections fulfill certain conditions the concept values will converge to a unique solution regardless the exact values of the initial concept values perturbations, or in some cases a solution exists that may not necessarily be unique. Otherwise the existence or the uniqueness of equilibrium cannot be assured. Based on these results an adaptive weight estimation algorithm is proposed which employs appropriate weight projection criteria to assure that the uniqueness of FCM solution is not compromised. Fuzzy Cognitive Networks are in the sequel invoked providing an application framework for the obtained results.

Thodoris Kottas
Democritus University of Thrace, 67100 Xanthi, Greece; e-mail: tkottas@ee.duth.gr

Yiannis Boutalis
Democritus University of Thrace, 67100 Xanthi, Greece and Department of Electrical, Electronic and Communication Engineering, Chair of Automatic Control, University of Erlangen-Nuremberg, 91058 Erlangen, Germany; e-mail: ybout@ee.duth.gr

Manolis Christodoulou
Technical University of Crete, 73100 Chania, Crete, Greece; e-mail: manolis@ece.tuc.gr

13.1 Introduction

Fuzzy Cognitive Maps (FCM) have been introduced by Kosko [1] based on Axelrod’s work on cognitive maps [2]. They are inference networks using cyclic directed graphs that represent the causal relationships between concepts. They use a symbolic representation for the description and modelling of the system. In order to illustrate different aspects in the behavior of the system, a fuzzy cognitive map consists of nodes where each one represents a system characteristic feature. The node interactions represent system dynamics. An FCM integrates the accumulated experience and knowledge on the system operation, as a result of the method by which it is constructed, i.e., by using human experts who know the operation of the system and its behavior. Different methodologies to develop FCM and extract knowledge from experts have been proposed in [3–6].

Kosko enhanced the power of cognitive maps considering fuzzy values for their nodes and fuzzy degrees of interrelationships between nodes [1,7]. He also proposed the differential Hebian rule [7] to estimate the FCM weights expressing the fuzzy interrelationships between nodes based on acquired data. After this pioneering work, fuzzy cognitive maps attracted the attention of scientists in many fields and have been used to model behavioral systems in many different scientific areas. Application examples can be found in political science [8, 9], in economic field [10, 11], in representing social scientific knowledge and describing decision making methods [12–14]. Other applications include geographical information systems [15–17], cellular automata [18], pattern recognition applications [19, 20] and numerical and linguistic prediction of time series functions [21]. Fuzzy cognitive maps have also been used to model the behavior and reactions of virtual worlds [22–26], as a generic system for decision analysis [14, 27] and as coordinator of distributed cooperative agents.

Regarding FCM weight estimation and updating, recent publications [28–32] extend the initially proposed differential Hebian rule [7] to achieve better weight estimation. Another group of methods for training FCM structure involves genetic algorithms and other exhaustive search techniques [33–37], where the training is based on a collection of particular values of input output historical examples and on the definition of appropriate fitness function to incorporate design restrictions.

Various extensions of FCMs have been proposed in the literature [38–49]. Dynamic Cognitive Networks (DCN) appear in [41], the Fuzzy Causal Networks in [42–46], while the neutrosophic cognitive maps appear in [47, 48]. Recently Fuzzy Cognitive Networks (FCN) [49] has been proposed as a complete computational and storage framework to facilitate the use of FCM in cooperation with the physical system they describe.

Fuzzy Cognitive Networks (FCNs) and their storage mechanism assume that they reach equilibrium points, each one associated with a specific operation condition of the underlying physical system. However, the conditions under which FCMs and consequently FCNs reach an equilibrium point and whether this point is unique have not been adequately studied so far. Simple FCMs have bivalent node values and trivalent edges (weights) and are equipped with binary threshold functions or