Exploring Unforeseen Causal Relationships in Fuzzy Cognitive Maps

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Abstract: Cognitive maps were first introduced to the academic community in the 1970s by the political scientist Robert Axelrod, and they are used to examine an individual’s perception and interpretation of complex systems. Fuzzy cognitive maps (FCMs) extend Axelrod’s innovation by taking causal reasoning into consideration. In particular, relationships between concepts are represented on a scale of zero to one, depending on the certainty of the connection. However, the effect of seemingly unconnected concepts is not explored; this research fills that void. Specifically, this paper examines the potential impacts of unforeseen internal causal relationships or “unknown unknowns” on an FCM’s steady-state. We illustrate our approach on a small, theoretical example, as well as a more substantial, real-world FCM representing the degradation and deforestation of the Brazilian Amazon. We conclude our work by discussing the limitations of the approach and opportunities for future research.

Keywords: Fuzzy cognitive maps, sensitivity analysis, complex systems

1. Introduction

1.1 Cognitive Maps

Cognitive maps are signed directed graphs (or digraphs) that depict the causal relationships between concepts. Tracing its origins to Leonhard Euler’s seminal developments in graph theory in 1736 (Papageorgiou & Stylios, 2008), cognitive mapping found its first application outside of mathematics with Robert Axelrod’s use of digraphs to describe the influence between variables in social and political science (Kosko, 1986). Axelrod (1976) reasoned that the full complexity of many decisions cannot be adequately modeled; therefore, policy makers tend to oversimplify issues when making decisions. To address this shortcoming, Axelrod (1976) suggested cognitive maps, which could help decision makers work through the entire problem to ensure they, consciously or not, were not taking shortcuts in their reasoning. All policy alternatives, various causes and effects, and the goals and utility of the decision maker can be represented as concept variables in the cognitive map, and arrows between concepts represent how each influences the other (Axelrod, 1976). Axelrod (1976) focused on how the use of cognitive maps can contribute to more informed policy outcomes; however, the inherent structure of cognitive maps does not account for uncertainty, ignoring reality and limiting knowledge-base building. Simply put, causality is rarely binary. It is, by its nature, nebulous and difficult to define, and cognitive maps ignore this.

1.2 Fuzzy Cognitive Maps

1.2.1 Background

Introduced by Bart Kosko in the late 1980s, fuzzy cognitive maps (FCMs) enhance Axelrod’s innovation by integrating expert input through fuzzy causal logic and functions (Papageorgiou & Stylios, 2008). In fact, Kosko’s approach seems prescient, as fuzzy logic has recently been considered the foremost artificial intelligence method to imitate human reasoning (Furfaro, Kargel, Lunine, Fink, & Bishop, 2010). To illustrate the notion of fuzziness, consider a chef creating a dish for her restaurant. Measurements like how much of each ingredient to add and cooking time are precise, but the recipe includes more amorphous descriptors like “slightly browned” or “somewhat soft.” In the same way, an FCM supplements the binary