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Rule-based Fuzzy Cognitive Maps - Enhanced Reasoning Mechanism with Impact Strength Parameter for Knowledge Modelling

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Abstract

Rule-Based Fuzzy Cognitive Maps (RBFCM) extend Fuzzy Cognitive Maps by incorporating fuzzy rule-based reasoning, enabling the modelling of complex qualitative systems with causal feedback. However, the standard reasoning mechanisms of RBFCM, designed for variation-based domains, exhibit poor performance when applied to level-based domains, such as knowledge modelling of learners, due to their reliance on assumptions about fuzzy set construction. This paper proposes enhancements to the RBFCM reasoning mechanism by introducing an Impact Strength (iS) parameter that explicitly represents the strength of influence between concepts and improves the construction of the Influence Output Set (IOS). Furthermore, this paper also introduces a new shifting mechanism and a simplified impact accumulation process, ensuring semantic consistency, preserving fuzziness, and preventing impact saturation. Experiments on a real learner dataset demonstrate that the enhanced RBFCM significantly outperforms the standard RBFCM, achieving an accuracy of 85.29%, a 28% improvement, with a higher F1-score and lower RMSE and standard deviation of error. These results confirm that the proposed enhancements enable RBFCM to model level-based knowledge domains effectively while maintaining interpretability and robustness.

Keywords

Rule-based fuzzy cognitive maps (RBFCM), fuzzy cognitive maps (FCM), reasoning mechanism, fuzzy causal relationship, fuzzy influence relation, fuzzy logic, knowledge modelling

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1 Introduction

Rule-Based Fuzzy Cognitive Maps (RBFCM), proposed by Carvalho and Tomé (1999), enhance Fuzzy Cognitive Maps (FCM) in Kosko (1986) to model complex qualitative systems. By utilizing fuzzy IF-THEN rule bases, RBFCM captures causal relationships between concepts (Carvalho & Tomé, 2009). This approach enables representation of non-monotonic causality and incorporates feedback mechanisms, offering a refined framework for dynamic cognitive and causal modelling.

RBFCM has been utilized effectively in various domains, including socio-economic systems (Carvalho & Tomé, 2009), forest fire propagation modelling (Carvalho & Tomé, 2006), fisherman behavior analysis (Wise et al., 2012), and student-centered education systems (Pena-Ayala & Sossa-Azuela, 2013). Recent advancements further demonstrate its relevance, with applications in complex dynamic systems (Carvalho & Gregorio, 2019), human reliability analysis in healthcare (Naskali et al., 2020), aerial vehicle combat systems (Zhong et al., 2021), computer-aided diagnostics (Apostolopoulos et al., 2021), and traffic flow modeling (Amini et al., 2022).

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