axioms

MDPI

Article

Hybridised Network of Fuzzy Logic and a Genetic Algorithm in Solving 3-Satisfiability Hopfield Neural Networks

Farah Liyana Azizan [1,2], Saratha Sathasivam [1,*], Majid Khan Majahar Ali [1], Nurshazneem Roslan [1,3] and Caicai Feng [1]

1 School of Mathematical Sciences, Universiti Sains Malaysia (USM), Penang 11800, Malaysia
2 Centre for Pre-University Studies, Universiti Malaysia Sarawak, Kota Samarahan 94300, Malaysia
3 Institute of Engineering Mathematics, Universiti Malaysia Perlis, Arau 02600, Malaysia
* Correspondence: saratha@usm.my

Abstract: This work proposed a new hybridised network of 3-Satisfiability structures that widens the search space and improves the effectiveness of the Hopfield network by utilising fuzzy logic and a metaheuristic algorithm. The proposed method effectively overcomes the downside of the current 3-Satisfiability structure, which uses Boolean logic by creating diversity in the search space. First, we included fuzzy logic into the system to make the bipolar structure change to continuous while keeping its logic structure. Then, a Genetic Algorithm is employed to optimise the solution. Finally, we return the answer to its initial bipolar form by casting it into the framework of the hybrid function between the two procedures. The suggested network's performance was trained and validated using Matlab 2020b. The hybrid techniques significantly obtain better results in terms of error analysis, efficiency evaluation, energy analysis, similarity index, and computational time. The outcomes validate the significance of the results, and this comes from the fact that the proposed model has a positive impact. The information and concepts will be used to develop an efficient method of information gathering for the subsequent investigation. This new development of the Hopfield network with the 3-Satisfiability logic presents a viable strategy for logic mining applications in future.

Keywords: 3-SAT; fuzzy logic; genetic algorithm; Hopfield neural network; metaheuristic algorithm

MSC: 03B52; 68T27; 68N17; 68W50

Citation: Azizan, F.L.; Sathasivam, S.; Ali, M.K.M.; Roslan, N.; Feng, C. Hybridised Network of Fuzzy Logic and a Genetic Algorithm in Solving 3-Satisfiability Hopfield Neural Networks. *Axioms* **2023**, *12*, 250. https://doi.org/10.3390/axioms12030250

Academic Editor: Oscar Castillo

Received: 21 November 2022
Revised: 21 December 2022
Accepted: 22 December 2022
Published: 1 March 2023

1. Introduction

Artificial intelligence (AI) technology has advanced significantly with the development of a hybrid system that combines neural networks, logic programming models, and SAT structures. The artificial neural network (ANN) is a robust analysis operating model that has previously seen extensive investigation and application by specialists and researchers due to its capacity to manage and display complex challenges. The Hopfield neural network (HNN), established by Hopfield & Tank [1], is one of the many neural networks. The HNN is a recurrent network that performs similarly to the human brain and can solve various challenging mathematical problems. A symbolised representing structure that governs the data stored in the HNN was produced by using Wan Abdullah's (WA) approach that describes logic rules [2]. Abdullah suggested one of the earliest approaches to incorporate SAT into the HNN. The work was explained by embedding the SAT structure into the HNN by reducing the cost function to a minimum value. Abdullah offered a unique logic programming as a symbolic rule to represent the HNN to solve the issue by determining the symbol's reduced cost function using the final Lyapunov energy function. Therefore, the method successfully surpassed the traditional learning method like Hebbian learning and can intelligently compute the relationship between the reasoning.

The work is expanded by Sathasivam when the SAT structure, specifically Horn Satisfiability (HornSAT), is utilised [3]. The proposed logic demonstrates how well the

HornSAT can converge to the least amount of energy. Years later, Kasihmuddin et al. [4] pioneered the work of 2-Satisfiability (2SAT). The 2SAT structure is being implemented in the HNN as the systematic logical rule. According to the previous work, the proposed 2SAT in the HNN manages to reach a high global minima ratio in a respectable amount of time. Two literals are used in every clause of the suggested logical structure, and a disjunction joins all clauses. By contrasting the cost function and the Lyapunov energy function, this logical rule was incorporated into the HNN. Mansor et al. [5] then expanded the logical rule's order by suggesting a systematic logical rule with a higher order. This work improves the previous work by adding three literals per clause, namely 3-Satisfiability (3SAT) in the HNN. The third-order Lyapunov energy function is evaluated with the cost function to determine the third-order synaptic weight. Despite the suggested study's associative memory of the HNN with 3SAT expanding exponentially, it defined the global minimum ratio's superior value. The proposed 3SAT increases the network's storage capacity in the HNN because the neuron's ability to produce many local minima solutions is still limited. The use of systematic SAT in ANNs was made possible in large part by this research. The rigidity of the logical composition, which added to overfitting results in the HNN, is the drawback of any kSAT. As soon as the number of neurons is elevated, the literals in a clause result in low synaptic weight values, which reduces the likelihood of finding global minimum solutions. Various options in the search space solutions are required to ensure a thorough exploration of the neurons. Thus, to overcome the downside of the structure, we offer a hybridised network of 3SAT logic that uses fuzzy logic and a metaheuristic algorithm to significantly widen the search space and improve the presentation of logic programming in the HNN.

The word fuzzy refers to things that appear not to be adequate or ambiguous [6]. Numerous-valued logic allows an idea to have some degree of reality [7]. It can simulate human experience and decision-making. Fuzzy logic has been used in numerous scientific fields, including neural networks, machine learning, artificial intelligence, and data mining [8–11]. This method can handle insufficient, inaccurate, inconsistent, or uncertain data. Since then, a broad range of research has shown the benefits of this approach, including the fact that the fuzzy sets are straightforward to use, the method does not require a sophisticated mathematical model, and the cost of computing is little [12]. Fuzzy logic builds the proper rules via a fuzzification and defuzzification process. Incorporating the fuzzy logic process with the HNN lowers the processing cost and enables the suggested scheme to accommodate more accurate neurons. As part of the defuzzifying procedure, any suboptimal neuron will be modified using the alpha-cut technique until the ideal neuron state is found. Then, we integrate the network with a metaheuristic algorithm, a Genetic Algorithm (GA). The Darwinian Theory of Survival of the Fittest is replicated by the GA, a form of natural selection. The GA was proposed by Holland [13] as a widely used optimisation technique founded on the population of metaheuristic algorithms. A population of potential solutions is improved over time as part of the implementation of the GA, which is an iterative process. The paradigm of computer intelligence known as metaheuristic algorithms is particularly effective at handling challenging optimisation problems.

Thus, the objectives of this research are listed as follows: (1) To construct a continuous search space by applying a fuzzy logic system in the training phase of 3-Satisfiability logic. (2) To create a design structure integrating a Genetic Algorithm to improve all the logical combinations of reasoning that will minimise the cost function. (3) To produce a new performance metric to evaluate the method's efficiency in obtaining the highest clauses of satisfying assignments in the learning phase. (4) To establish a thorough assessment of the suggested hybrid network using the generated datasets that can perform significantly with the Hopfield neural network model. Our findings indicated that the suggested HNN-3SATFuzzyGA exhibits the finest performance in conditions of error analysis, efficiency evaluation, energy analysis, similarity index performance, and computational time. The layout of this article is as follows: Section 2 provides an outline structure of 3-Satisfiability. Section 3 describes the application of 3SAT into the Hopfield Neural Network. The general