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Study of Integration of Neural Networks with Other Existing or Developing Technologies: A Review

Rahul A. Vishwakarma[1] and Minesh Ade[2]
Student, Department of MCA[1]
Faculty, Department of MCA[2]
LBHSST's Institute of Computer Application, Mumbai, India

Abstract: *The popularity of Artificial Neural Networks (ANN) as significant intelligence methods has been growing. Their applications in numerous fields have been greatly influenced by their capacity to emulate the cognitive processes and decision-making of the human brain. The fundamentals of an ANN's nature and operation are described in this study. This paper's main goal is to provide a quick overview of how neural networks might be combined with other forms of artificial intelligence, such as fuzzy logic, expert systems, and genetic algorithms. It describes the working models of these hybrid systems as well as the areas in which they can be used. Finally, it discusses current developments in the study of neural networks.*

Keywords: Artificial Neural Network, Neuro-Fuzzy System, Neuro-expert system, Neuro-genetic system, Hybrid systems

I. INTRODUCTION

Neural Network (NN), a significant subdivision of Artificial intelligence (AI), has recently gained popularity as a useful model for classification, clustering, pattern recognition, and prediction in a variety of fields [1]. NNs are a computational model that mimics theinformation processing abilities of the neural networks present in the human brain. Just as the brain can process multiple stimuli, while also performing other highly complex functions at the same time, NNs can perform or rather are trained to perform certain computations many times faster than most computers in existence today.This high-speed processing ability in massive parallel implementation has heightened the need for research in this domain.

NN's characteristics give them a façade similar to the human brain. These include distributed memory, parallel processing, capability of generalization, fault tolerance, learning ability and network structures. The most important, however, is the unique nonlinear adaptive information processing ability.It helps them overcome the shortcomings of traditional AI methods such as intuition, mode, speech recognition and unstructured information processing; making them more effective in their applications in pattern recognition, intelligence control, portfolio optimization, forecasting and other fields [2].

Although neural networks have been successfully applied in several domains, many elements still require research. Among these, hybrid systems and the integration of neural networks with other conventional AI technologies have gained popularity as research topics. NN has been progressing toward replicating human cognition in recent years. A new path has been opened up for the theoretical study of artificial neural network by combining with fuzzy system, genetic algorithm, expert system, evolutionary mechanism, and other systems to produce practical applications and broaden the scope of AI [1, 2]. The purpose of this review is to examine these recent technological fusions and assess the potential use of NN and its advancement of AI.

II. WHAT IS ARTIFICIAL NEURAL NETWORK

A neural network, more properly referred to as an 'artificial' neural network (ANN), is defined by Dr. Robert Hecht-Nielsenas "...a computing system made up of a number of simple, highly interconnected processing elements, which process information by their dynamic state response to external inputs." [3]

ANNs are a type of machine learning (ML) model that supersedes traditional AI methods which were based on regression and statistical models. Modern AI (machine learning, neural networks, deep learning, robotics), information security, big data, cloud computing, the internet, and forensic science are all prominent and fascinating areas in Information and Communication Technologies (ICT) right now.

2.1 Architecture of ANNS

The basic unit of computation in a neural network is the neuron, often called a node or a unit. It receives input from some other nodes, or from an external source, processes the received input and computes an output. Fig. 1 shows a typical architecture of an ANN.

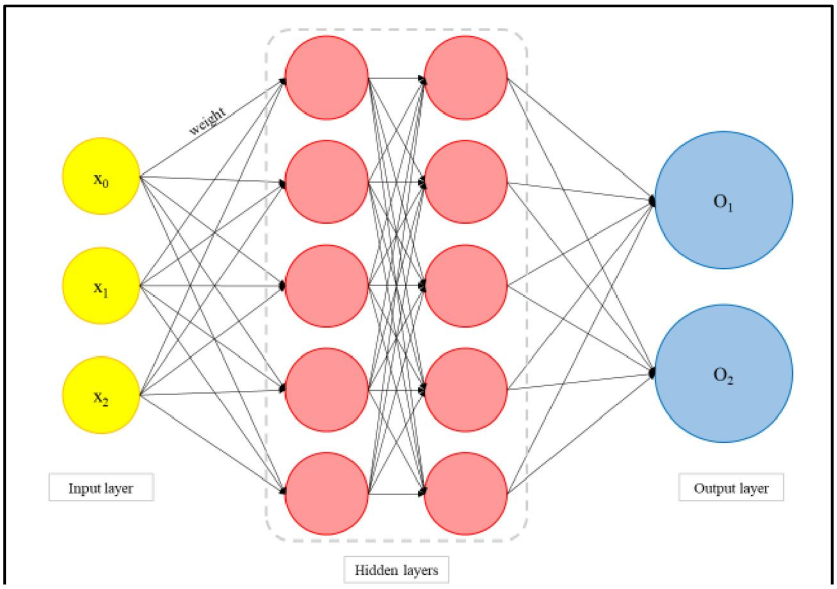

Figure 1: Architecture of a neural network.

Let us look at the function of each fragment individually.

- Input Nodes: The units which receive an input comprise the input layer, denoted by the yellow circles in the above figure. Since no computation is done in this layer, sometimes the input units are regarded as a virtual layer having 0 layers.These neurons just pass the information to the next layer, which generally is the hidden layer [1, 5].
- Hidden nodes (hidden layer):The hidden layer neurons, denoted by the red circles in figure 1,executethe intermediate processing. Theycalculate and then transfer the weights (signals or information) from the input layer to the next layer (another hidden layer or to the output layer). NNs with two or more hidden layers are called deep networks because the network has become complex with more than 1 hidden layer. Please note that it is possible to have a neural network without a hidden layer (a single layer perceptron) [1, 5].
- Connections and weights: The network consist of connections, denoted by black arrows in Fig. 1. Each connection transfers the output of a neuron i to the input of the next neuron j. Each link is given a weight W_{ij}. In simple terms, the weights of the network connections measure the potential amount of the knowledge of the network [5].
- Activation function: the activation function or transfer function of a node gives the output of that node when provided an input or set of inputs. This nonlinear activation function allows NNs to compute complex problems using only a small number of nodes. Every activation functiontakes a number and executes a certain fixed mathematical operation on it. Common activations functions found in practice are Sigmoid, Tanh, ReLU and Leaky ReLU [5].
- Output Nodes (output layer): These neurons use their activation function to the desired output format (e.g.softmax for classification).

2.2 Working of an ANN

Artificial Neural Networks can be seen as weighted directed graphs in which artificial neurons are nodes, and directed edges with weights are links between neuron outputs and neuron inputs. The external world provides information to the artificial neural network in the form of patterns and vector images. The notation x(n) for n number of inputs is used to identify these inputs. It multiplies each input by the corresponding weights. The data that the neural network uses to solve a problem are called weights. Typically, weight in a neural network refers to how strongly neurons are connected to one another. Inside the computing unit, all of the weighted inputs are added together. To prevent the output from being zero or to increase the system reaction when the weighted total is zero, bias is added. The weight and input are always set to "1" in bias. Any number from 0 to infinity can be used to represent the sum. The threshold value is set up to restrict the answer so that it reaches the required value. The sum is passed forward through anactivation function in this case. To obtain the desired output, the activation function is set to the transfer function. Both linear and nonlinear activation functions exist.

III. INTEGRATION OF NEURAL NETWORKS WITH DIFFERENT TECHNOLOGIES

A Hybrid system is an intelligent system that is framed by combining at least two intelligent technologies like Fuzzy Logic, Neural networks, Genetic algorithms, reinforcement learning, etc. The combination of different techniques in one computational model makes these systems possess an extended range of capabilities. These systems are capable of reasoning and learning in an uncertain and imprecise environment. These systems can provide human-like expertise like domain knowledge, adaptation in noisy environments, etc.

3.1 Neuro-Fuzzy Systems

In a Neuro-Fuzzy System,Neural Networks Learning Algorithms are fused with the fuzzy reasoning of fuzzy logic.The term fuzzy refers to things that are vague or unclear. Fuzzy logic refers to the logic developed to express the degree of truthfulness by assigning values between 0 and 1, unlike traditional Boolean logic representing 0 (absolute false) and 1 (absolute truth). These intermediate values represent partially true and partially false input data.

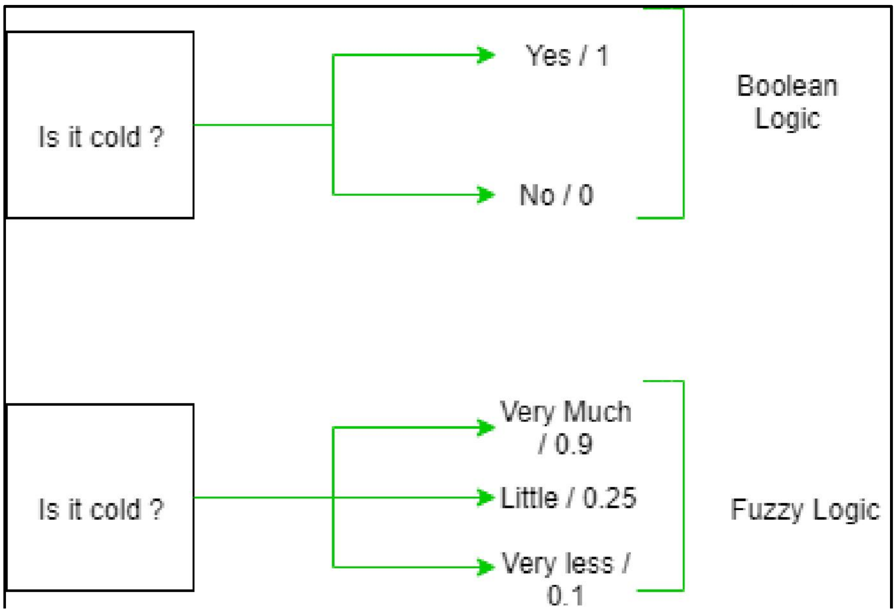

Figure 2: Difference between Boolean and Fuzzy logic. adapted from [8]

Fuzzy sets were introduced by Zadeh in 1965 as a means of representing and manipulating data that was not precise, but rather fuzzy [7]. In a hybrid (neuro-fuzzy) model, Neural Networks Learning Algorithms are fused with the fuzzy reasoning of fuzzy logic. The neural network determines the values of parameters, while if-then rules are controlled by fuzzy logic.

The learning process operates only on the local information and causes only local changes in the underlying fuzzy system. A neuro-fuzzy system can be seen as a 3-layer feedforward neural network. The first layer represents input

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variables, the middle (hidden) layer represents fuzzy rules and the third layer represents output variables. Fuzzy sets are encoded as connection weights within the layers of the network, which provides functionality in processing and training the model.

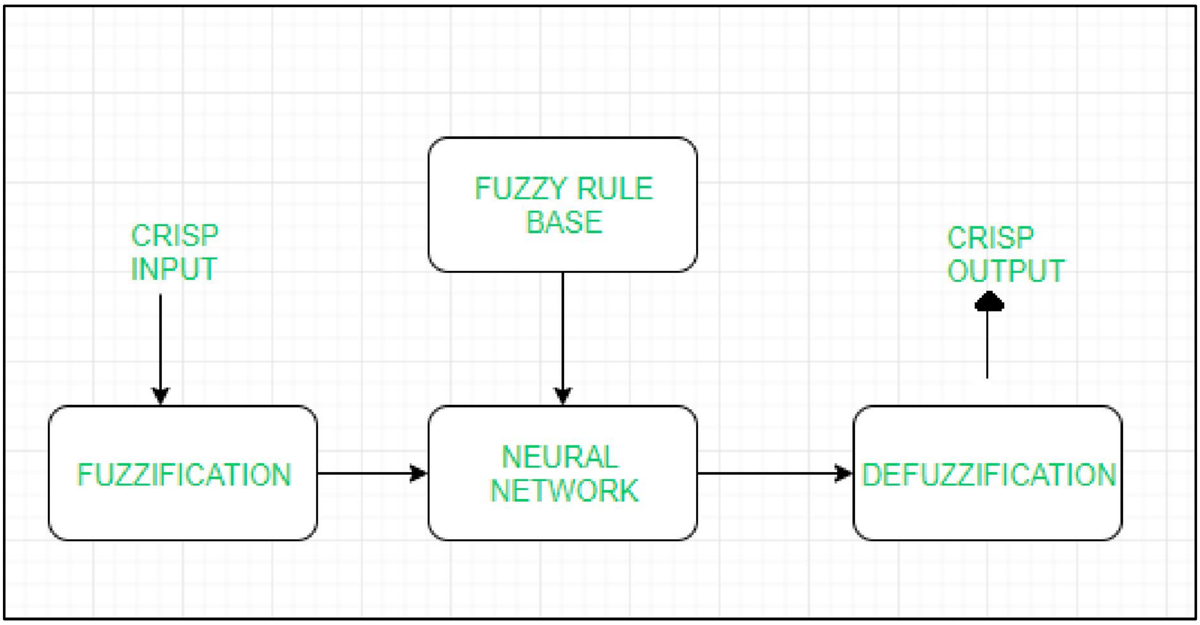

Figure 3: Workflow of a Neuro-Fuzzy system. Adapted from [10].

In the input layer, each neuron transmits external crisp signals directly to the next layer.Each fuzzification neuron receives a crisp input and determines the degree to which the input belongs to the input fuzzy set. The fuzzy rule layer receives neurons that represent fuzzy sets.An output neuron combines all inputs using fuzzy operation UNION.Each defuzzification neuron represents the single output of the neuro-fuzzy system. The detailed comparison of existing neuro-fuzzy models is given in [9].

The hybrid system has many advantages over their traditional counterparts. It can handle numeric, linguistic, logic, etc kind of information.It can also manage imprecise, partial, vague, or imperfect information.It can resolve conflicts by collaboration and aggregation.It has self-learning, self-organizing and self-tuning capabilities. And most importantly, it can mimic the human decision-making process.

The neuro-fuzzy system has been successfully applied in areas such as Student Modelling, Medical systems, Traffic control systems, Forecasting and predictions, Automotive engineering, Applicant screening of jobs, Control of crane and Monitoring of glaucoma. The method of Adaptive Neuro-Fuzzy Inference System (ANFIS) to model the dew point temperature (DPT) is described in [10].

3.2 Neuro-Expert System

A fundamental AI technique of former times, Expert Systems perform reasoning using previously-established rules and domain-specific facts for a well-defined and narrow domain. They consist of two main components; a knowledge base and an inference engine. The knowledge base stores propositions or rules — which are encoded pieces of information — while the inference engine uses rules of inference to derive new propositions.

Expert systems were especially good for closed-system applications for which inputs are literal and precise, leading to logical outputs. For stable applications with well-defined rules, expert systems were easily developed to provide good performance. Hence, expert systems were typically found in domains such as medical science, law, and other areas requiring specialized yet explicit knowledge of facts and procedures.

The rule-based Expert Systems, however, had a few limitations. Firstly, the construction of the highly exhaustive knowledge base was a time consuming and a highly tedious task. Secondly, if the knowledge base did not contain the necessary information about a particular situation, the expert system will be unable to process the input and return any inference. And lastly, expert systems automate inferences based on only descriptive knowledge. Descriptive (also called explicit or declarative) knowledge, is based on facts and rules. It can be characterizedby words or symbols, and

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changed using logic or some other calculus. While procedural (also called implicit or performative) knowledge, is more about knowing how to do things. It is generally relatedto concepts like intuition, muscle memory, and practice. Building a knowledge base for procedural knowledge is a challenge.
While new propositions and rules could be added easily to the knowledge base because the architecture separated the inference from the inference engine, it was still a roadblock every time the system came across such a proposition. This is where neural networks and deep learning comes into the picture. An ANN trained on the inferences obtained as per the inference engine of Expert systems, can use these inputs and inferences to generate new rules even for procedural knowledge.
Each methodhas its own merits and demerits: neural networks are extremely fast patternassociators, can handle sensor noise, learn from experience,and generalize in novel situations if sufficientlytrained, however they are black-box operatorsunable to explain their own reasoning methodology,incorrectly generalize novel faults if improperly trained, andforget past training if retrained on new data; expert systemshave explicit representations of knowledge which eases themodification and validation of the systems, are able togenerate explanations for their reasoning methodology, andcan use deep knowledge to reason about novel events, butthey are unable to learn from experience, are hard tomaintain if the knowledge base becomes extremely large,and require extensive computational time if a deep model ofthe process must be consulted.
As opposed to expert systems where the knowledge contained by the system is stored explicitly in the knowledge base as symbols such as words and phrases, the knowledge learned by a neural network is stored implicitly in a distributed manner throughout the network, as the numerical values computed for the different synaptic weights and neuron biases.
An integration of Expert Systems and Neural Networks to diagnose faults commonly encounteredin chemical process plants is discussed in [12].

3.3 Neuro-Genetic System

A Neuro Genetic hybrid system is a system that combines Neural networks with Genetic Algorithm (GA). The idea is to combine two nature derived technologies to create a hybrid which could mimic human cognitive processes. Neural network's ability to learn various tasks from examples, classify objects and establish relations between them, is combined with important search and optimization techniques of GA.

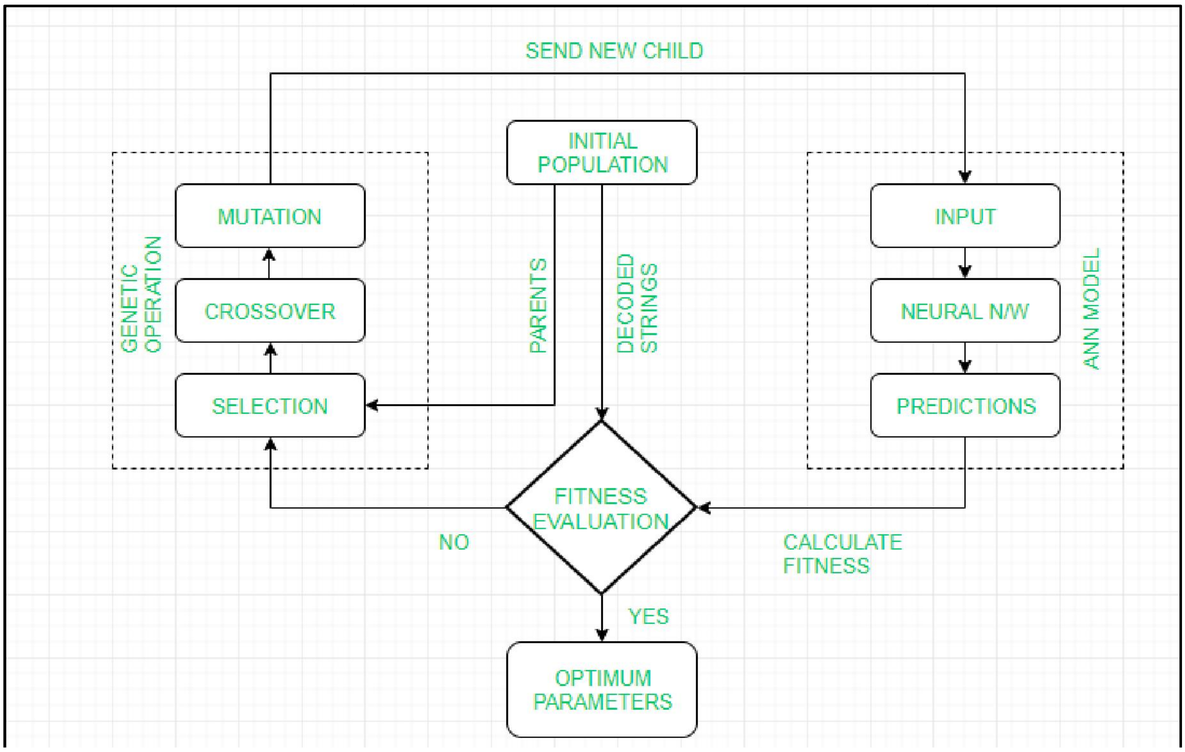

Figure 4: Working of a Neuro-genetic hybrid system. Adapted from [11].

Genetic Algorithms (GAs) are adaptive exploratory search algorithms that belong to the larger part of evolutionary algorithms. Genetic algorithms are builtupon the concepts of natural selection and genetics. These are smartmanipulation of random search provided with past data to direct the search into an area of better performance in solution space. They are regularly used to create high-quality solutions for optimization problems and search problems.

In the hybrid system, use of GA improves the performance of Neural Networks and they can be used to decide the connection weights of the inputs.

How it works? As shown in Fig.4, GA constantly modifies a population of individual solutions. GA appliesthe following guidelines at each step to create the next generation from the current population:

1. Selection operatorto select the individuals, called parents, that contribute to the population at the next generation.
2. Crossoveroperator to combine two parents to form children for the next generation.
3. Mutation operator to apply random changes to individual parents in order to form children.

GA then directs the new child generation to ANN model as a new input.Finally, the fitnessia calculated by the ANN model.

These algorithms can be used for topology selection and training networks as well. GA is used for topology optimization which refers to selection of the number of hidden layers, number of hidden nodes, and interconnection pattern for ANN.In GAs, the erudition of ANN is expressed as a weight optimization problem, usually using the inverse mean squared error as a fitness measure.Control strictures such as learning rate, momentum rate, tolerance level, etc.remain optimized by GA.

The hybrid system has been applied in areas such as Face recognition, DNA matching, Animal & human research and Behavioral system.

3.4 Liquid Machine Learning

A specific class of neural network has been created by MIT researchers Hasani et al. that learns while being used, rather than only during training. The fundamental equations of these adaptable algorithms, often known as "liquid" networks, are constantly modified to accommodate fresh data inputs. The development may facilitate decision-making based on time-varying data streams, such as those used in autonomous driving and medical diagnostics.

Hasani created a neural network that can adjust to the complexity of actual systems. Hasani carefully studied the electrical impulses used by nematode C. elegans neurons to activate and interact with one another before coding his neural network. With just 302 neurons in its whole nervous system, C. elegans is able to produce complicated outcomes. He enabled the parameters in the equations he used to build his neural network to vary over time based on the solutions of a layered set of differential equations. This adaptability is vital. The majority of neural networks are poor at adapting to changes in the incoming input stream since their behaviour is fixed after the training phase.Hasani claims that because his "liquid" network is fluid, it is more resistant to unexpected or noisy data, such as when a self-driving car camera is obscured by heavy rain. It's stronger, he argues.

IV. CONCLUSION

Studies in the field of neural networks have made clear that the system's primary characteristic—its capacity for self-learning and non-limitation—is what has made it so widely applicable. Combining these traits with technologies such as fuzzy logic's ability to reason, expert systems' database, and genetic algorithms' search and optimization tools has led to the development of hybrid systems, which are able to solve real-world issues considerably more quickly and effectively. The numerous methods for combining neural networks with other intelligence techniques are outlined in this study. Lastly, we discussed the merits of the hybrid systems over their standard counterparts and their areas of application.

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