**Fuzzy Neural Networks**

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**Introduction and Motivation**

Fuzzy neural networks have become a popular and promising approach among researchers to solve modern business problems. With the current traditional methods incapable of predicting future events, either due to the complexity of the problem or the vast and vagueness of the data, a system that can adapt and learn without needing precise data such as a fuzzy neural network can be very useful. The aim of this paper is to look into field of fuzzy neural network systems of how they are formed and the problems they are being used for as well as an outlook of the current real world applications within multiple domains.

**Theoretical and Technical and Foundations**

**Introduction**

Fuzzy neural networks are the combination of fuzzy logic and neural networks. There can be three types of fuzzy networks depending and which techniques are applied from which field. The first is co-operative fuzzy neural network; this is an adapting fuzzy system that uses neural algorithms. Basically both the fuzzy systems and the artificial neural network are working independently from one another. The artificial neural network tries to learn the parameter from the fuzzy systems and can be done both online and offline while the fuzzy system is applied. Figure 1 illustrates a few different variations of a co-operative fuzzy neural network and how the data is exchanged between the neural network and the fuzzy system. An example of how this can be applied has be shown by Tsao, Bezdek and Pal which uses “a fuzzy Kohonen clustering network which integrates the fuzzy c-means (FCM) model into the learning rate and updating strategies of the Kohonen network” (Tsao, Bezdek and Pal, 1994). Another example is a paper by Vuorimaa which introduces “a fuzzy version of the model called: Fuzzy Self-Organizing Map” (Vuorimaa, 1994).

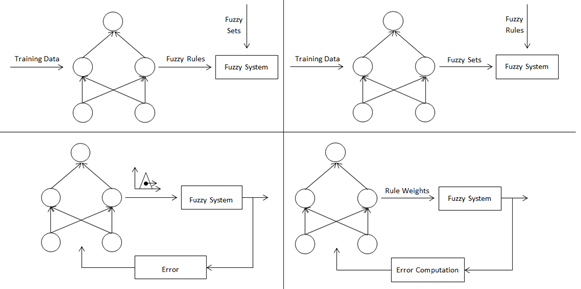


Figure 1 Co-operative Fuzzy Neural Network

The second is concurrent fuzzy neural network, illustrated in Figure 2, where the two techniques are applied one after another as a pre or post processing. Abraham states that “in a concurrent model, ANN assists the FIS continuously to determine the required parameters” (Abraham, 2001). Vieira, Dias and Mota state that “a concurrent system is not a neuro-fuzzy system in the strict sense, because the network works together with the fuzzy system” (Vieira, Dias and Mota, 2004), unlike the other models in which the neural network and fuzzy system work independently.

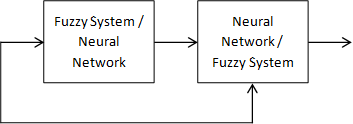


Figure 2 Concurrent Fuzzy Neural Network

And thirdly is hybrid fuzzy neural network as illustrated in Figure 3. Nauck described it as “a fuzzy system that uses a learning algorithm based on gradients or inspired by the neural networks theory (heuristical learning strategies) to determine its parameters (fuzzy sets and fuzzy rules) through the patterns processing (input and output)” (Nauck, Kruse and Klawonn, 1997). The benefit from a hybrid system is that due to it being a combination of fuzzy system and neural network it does not need to communicate with each other because they are a fused entity.

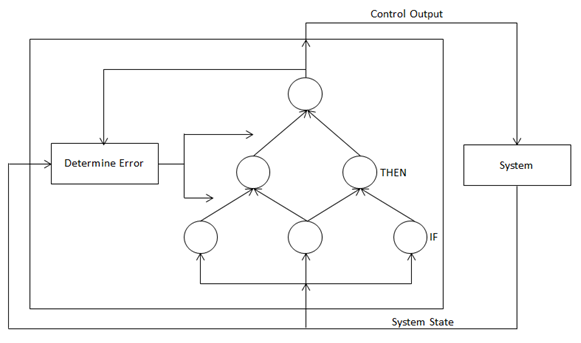


Figure 3 Hybrid Fuzzy Neural Network

**Basics & foundation to subject**

**Fuzzy Logic**

Fuzzy logic is a rule based systems that was first introduced by Lotfi Zadeh (Zadeh 1965) and is about getting computers to mimic human decision making and consists of fuzzy sets and fuzzy rules. Fuzzy sets allow us to model concepts and objects in the real world and to deal with situations that are not precise. For example it can describe the weather as hot without using precise numbers.

Real world decisions contain high levels of uncertainty which need to be taken into account. Fuzzy sets are a collection of related items which belong to that set to different degrees. A basketball team is a set and the player are the items in the set, if you want to find out who is tall, you can set that anyone over a certain height is and if they are shorter they are classified as not tall. If you apply fuzzy logic you can say that all players are tall to a certain degree which gives much more detail about the items in the set.

Fuzzy rules take partially true facts such as a person is tall or their agility and finds out to what degree they are true, then takes another fact making it true to that degree for example how tall a person should be for a certain sport, if a person is tall and agile then consider basketball is short and broad they should consider wrestling. A number of rules can then be combined and a decision can be made. This whole process is called inference. Rules use human concepts not strict measurements and can be thought of as common sense rules. In rules we use worlds rather that numbers to describe items. Knowledge is represented by fuzzy sets combed using fuzzy rules and when all of this information is considered a decision can be made.

**Neural Networks**

Artificial neural network are mathematical models of a biological brain’s neural network and should be able to produce similar responses and behaviours as their biological counter parts. Figure 4 illustrates a typical three layer feedforward network architecture. Both biological and artificial networks have neurons which work by processing information and are joined with synapses to form networks. These neurons are what dictate the leaning and in artificial neural networks this refers to the method of modify the weights of the synapses. The overall learning ability of the network is determined by the learning style chosen for training and the architecture of the network. There are two learning styles which can be used which are supervised learning and unsupervised learning.

Supervised learning is where the network is given training data sets and desired response. Once it has completed the learning process they can be used on new data sets to find the desired response. They are often used within the fields of robotics, pattern recognition and prediction systems and with a variety of network types they can be applied to many more problems such as the medical field for drug discovery, financial application (Doumpos, Zopounidis, and Pardalos, 2012) or for algorithmic trading (Vella and Ng, 2014).

Unsupervised learning is essentially learning by doing, in which no desired response is provided but training data sets are still given. This causes methods like clustering to be used where the network tries to categorise data by their similarities. This makes unsupervised learning methods useful for data mining of large data such as in the medical field or object recognition within computer vision applications.

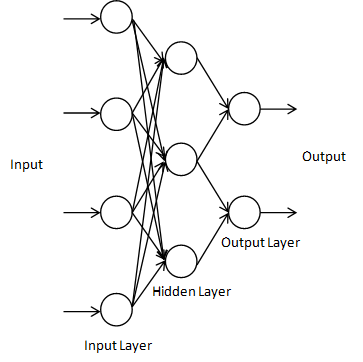


Figure 4 Typical three-layered Neural Network

**Fuzzy Neural Networks**

The combination of fuzzy logic and neural networks constitutes a powerful means for designing intelligent systems. A fuzzy system is good at things like knowledge representation, uncertainty tolerance and imprecision tolerance however it lacks the ability to learn and discovery knowledge. Whereas neural networks are good at dealing with raw data and have the ability to learn and adapt as well as knowledge discovery and data mining but unlike a fuzzy system they are bad at knowledge representation and explanation ability.

And this is where the idea of fuzzy neural networks comes from. Integrated fuzzy neural systems can combine the knowledge discovery and learning abilities of neural networks with the human-like knowledge representation and explanation abilities of fuzzy systems. This causes the neural networks to become much more translucent, whilst the fuzzy systems are able to learn. A fuzzy neural network is a neural network which is functionally equivalent to a fuzzy inference model.

When it comes to training a fuzzy neural network Akerkar states that “a neurofuzzy system can be trained to develop “if-then” fuzzy rules and determine membership functions for input and output variables of the system” (Akerkar et al, 2010). Negnevitsky explains that “expert knowledge can be easily incorporated into the structure of the neuro-fuzzy system. At the same time, the connectionist structure avoids fuzzy inference, which entails a substantial computational burden” (Negnevitsky, 2005). He also discusses about how a fuzzy neural network looks “similar to a multi-layer neural network” (Negnevitsky, 2005) and thus it can apply “standard learning algorithms developed for neural networks, including the back-propagation algorithm (Kasabov, 1996; Lin and Lee, 1996; Nauck et al., 1997; Von Altrock, 1997)” (Negnevitsky, 2002).

**Literature review**

Over the past few decades of research on fuzzy neural networks there have been many variations and improvement of the models used. Some of these models resulted in new architectures such as GARIC (Berenji and Khedkar, 1992), ANFIS (Jang, 1993), FuNe (Halgamuge and Glesner, 1994), NEFCON (Nauck, 1994) and Fuzzy RuleNet (Tschichold-Gürman, 1996).

With such an abundance of architectures that could be used researchers looked at how to apply these to applications and areas of research. Vlachos and Tolias “investigates an alternative modeling of the system (firm), combining neural networks and fuzzy controllers” (Vlachos and Tolias, 2003).Some researchers have used fuzzy systems such as Kumar and Ravi explored the use of “a fuzzy 'if-then' rule based classifier” (Kumar and Ravi, 2006) which “performed very well and in the case of 2 partitions outperformed the multi-layer perceptron by yielding higher average classification rate and lower average Type-I error” (Kumar & Ravi, 2006). A different approach using adaptive network – based fuzzy inference system (ANFIS) by Purvinis looked into “bankruptcy dependency of Lithuanian enterprises on their financial ratios and its dynamics over time” (Purvinis et al, 2008). From this paper it showed that their approach could be useful to the enterprise manager as “test of that model showed that percentage of right failure and success predictions reached 80 %” (Purvinis et al, 2008). After many studies demonstrated the effectiveness of ANFIS another groups of researchers such as Zanganeh started applying it to prediction problems such as bankruptcy (Zanganeh, Rabiee and Zarei, 2011).

**Emerging technologies, Innovations and Applications**

**Advances in Research**

Over the past decade there have been many improvements on the models used, especially ANFIS which has been the most popular model to choose amongst researchers due to its accuracy in classification and prediction that can be applied to a wide range of problems. One improvement to this model is presented by Pillai, Pushpak and Nisha with their ANFIS model called “extreme learning adaptive neuro-fuzzy inference system (ELANFIS) which can be applied to control of nonlinear systems.” (Pillai, Pushpak and Nisha, 2014) an approach similar to ANFIS but the parameters are not tuned to learn faster sacrificing generalisation capability and produces results showing an improved performance with less computation time.

An in depth look at financial decision making by Doumpos et al. covers algorithmic trading, discussing how “financial markets has made algorithmic trading systems extremely popular” (Doumpos, Zopounidis, and Pardalos, 2012) and about how, based on the rise in “the need for quantifying qualitative information...into new trading algorithms” (Doumpos, Zopounidis, and Pardalos, 2012). With such a vast amount of data in such as short amount of time the current human analysts simply could not keep up where their computer counterparts could, using newer techniques.

**Applications of Research**

There are many problems from a variety of areas that can be solved with fuzzy neural networks. ANFIS is a model that has been applied to many prediction and control systems. With vehicles becoming more intelligent and aiding the driver’s decision making one area that has had recent applications of this model is in intelligent transportation systems. An approach was presented by Marasigan et al. with their paper which “focuses on parallel parking the car-like mobile robot” (Marasigan et al., 2014). They use eight ultrasonic sensors to gather the necessary data for the inference system to decide the proper movement and direction to efficiently and accurately park. Another related application involved an improved ANFIS for “car-following behaviour model” and was stated to have “a very close compatibility with the real-world data and reflect the situation of the traffic flow in a more realistic way” (Khodayari et al., 2014).

Financial and banking issues have always been an area being researched. Following the financial crisis in 2008 Fang saw the need to be able to predict when another may happen and developed an application of the financial crisis forecast using an adaptive neurofuzzy inference system with factor analysis and which has a correctness rate of 93.94% (Fang, 2012). Predicting bankruptcy is an area that has a gathered a lot of attention and that fuzzy neural network can be applied to. Arora and Saini approached this problem with an adaptive neuro-fuzzy inference system which utilized time series and they demonstrated that the “model can predict bankruptcy status at any time in future with an error in range of 0.8506 to 0.3204” (Arora and Saini, 2013). A year later they attempted the problem again this time using independent component analysis and fuzzy support vector machines and showed that this approach can “predict bankruptcy of financially distressed companies with an accuracy of 93.12% on unseen inputs” (Arora and Saini, 2014). Within the banking area research has also been undertaken on the automated teller machines by Arora and Saini using an approximation method which had a “prediction rate of 96.05% makes the model suitable for daily replenishment of cash” (Arora and Saini, 2014).

Another field that has been attempted by researchers is the stock market or more specifically the automation of the stock market trading called algorithmic trading. With its potentially high risk trading having a system that could predict the market, learn trends and patterns and be able to focus on a long term trading rather than daily would be useful. Vella and Ng’s paper “provides new insights into improving the time-varying risk-adjusted performance of trading systems” (Vella and Ng, 2014). What they study is the different ways of approaching this problem with various trading systems and compares their success and viability as a model.

A newer area to research is education where fuzzy systems are being developed to classify students and predict their academic performance. Recent research in classification has been done by Saber Iraji who used LVQ networks and an ANFIS method to show that “ANFIS outperforms LVQ method with root mean square error 0.1348 over 0.2374” (Saber Iraji et al., 2012). Inyang and Joshua specifically looked into classifying at-risks students’ identification and monitoring, and used FCM, k-means algorithms and ANFIS to show that “RMSE of the model is 0.2819 which makes it suitable for the prediction and clustering of students” (Inyang and Joshua, 2013). The other area prediction has been done in a few different ways. Arora and Saini used a fuzzy probabilistic neural network to show that a “model is efficient in prediction with overall error 2.6667 giving 98.56% accuracy in expected results” (Arora and Saini, 2013) whereas Do & Chen used a neuro-fuzzy approach in the classification of students’ academic performance and showed that the “model achieved an accuracy of over 90% better than support vector machine, naive bayes, neural network, and decision tree approaches” (Do and Chen, 2013).

**Critical Reflection and Conclusions**

This paper has investigated fuzzy neural networks, examining the essential components of the networks for solving problems in both academic and practical fields. The most important goals that have directed research into various areas over the past decades have been presented as well as new areas that these approximation systems can be applied to such as education.

Neural networks and fuzzy systems have their own limitation such as a neural network being unable to represent knowledge or how a fuzzy system lacks the ability to learn or discover knowledge. Each of these weaknesses are the others strengths and by combining them they could mitigate each other’s limitations. However there are still a few disadvantages such as in the types of fuzzy neural networks. The co-operative model structure is not totally interpretable or how the concurrent model result in result that is not completely interpretable which can be considered disadvantages to the researcher. Hybrid systems have become the most popular and provided many different architectures for example ANFIS, however hybrid systems have learning capacities which for structures like ANFIS which only concern themselves with the adaptation of internal parameters, complex problems will be too computationally demanding to determine all the parameters due to the parameter exponential growth. To help with these limitations it is possible, by combing this field with other fields such as evolutionary algorithms, to overcome these weaknesses. Abraham and Nath (Abraham and Nath, 2000) suggested an evolutionary approach based on genetic algorithms to help with the optimisation issue. For example evolutionary strategies are able to use more general functions than differentiable functions. Or in comparison to neural networks and evolutionary algorithm would be able to navigate a search space without being as affected by the problem of finding local minima.

Within the field of fuzzy neural networks there have been many application areas such as medicine, physics, education, manufacturing and system modelling and one of the current most popular economics. There have been many attempts to solve problems particularly in the business sector, for example banking and the stock market, using different approaches and methods to try and achieve the best predictions. Given that almost all businesses will suffer problems that could be predicted with these systems it is likely that research will continue to find the most efficient or accurate. Intelligent transportation systems are an area that is starting to have models, specifically ANFIS, applied to due to their ability to simulate and predict scenarios which is important when driving. The systems being created are allowing the car to become more autonomous. Further development in education, particularly in student modelling, through further investigation and research could be improved for instance an intelligent system could be designed for helping students during learning interaction that is based on student classification in regards to their learning style.

In conclusion the area of fuzzy neural networks, although old, is still finding new applications to be used on and new ways to solve problems more efficiently and accurately. It is able to be applied to many different situations and through combing different fields the systems are able remove limitations they have independently and offer the opportunity to produce more powerful hybrid systems.

**References**

Abraham, A. (2001). *It is time to Fuzzify Neural Networks!*. Tutorial, ICIMADE. pp. 1-3. Retrieved 20.04.2015 From http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.16.6963&rep=rep1&type=pdf

Abraham, A. and Nath, B. (2000). *Hybrid Intelligent Systems: A Review of a decade of Research*. School of Computing and Information Technology, Faculty Information Technology, Monash University, Australia, Technical Report Series, 5/2000. pp. 1-55.

Akerkar, R. and Sajja, P., S. (2010). *A Neuro-Fuzzy Decision Support System for Selection of Small Scale Business*. In Information Processing and Management of Uncertainty in Knowledge-Based Systems. Applications Springer Berlin Heidelberg. pp. 306-315.

Arora, N. and Saini, J., R. (2013). *A fuzzy probabilistic neural network for student’s academic performance prediction*. International Journal of Innovative Research in Science. Engineering and Technology, 2 (9). pp. 4425-4432.

Arora, N. and Saini, J., R. (2013). *Time series model for bankruptcy prediction via adaptive neuro-fuzzy inference system*. International Journal of Hybrid Information Technology, 6 (2). pp. 51-64.

Arora, N. and Saini, J., R. (2014). *Approximating methodology: Managing cash in automated teller machines using fuzzy ARTMAP network*. International Journal of Enhanced Research in Science Technology & Engineering, 3 (2). pp. 318-326.

Arora, N. and Saini, J., R. (2014). *Bankruptcy Prediction of Financially Distressed Companies using Independent Component Analysis and Fuzzy Support Vector Machines.* International Journal of Research in Computer and Communication Technology, 3 (2). pp. 924-931.

Berenji, H. and Khedkar, P. (1992). *Learning and tuning fuzzy logic controllers through reinforcements*. IEEE Trans. Neural Netw., 3 (5). pp. 724-740.

Do, Q. and Chen, J. (2013). *A Neuro-Fuzzy Approach in the Classification of Students’ Academic Performance*. Computational Intelligence and Neuroscience, 2013. pp. 1-7.

Doumpos, M., Zopounidis, C., and Pardalos, P. M. (2012*). Financial decision making using computational intelligence.* 70. Springer Science & Business Media.

Fang, H. (2012), *Adaptive neurofuzzy inference system in the application of the financial crisis forecast.* International Journal of Innovation, Management and Technology, 3 (3). pp. 250-254

Inyang, U. and Joshua, E. (2013). *Fuzzy Clustering of Students’ Data Repository for At-Risks Students Identification and Monitoring*. Computer and Information Science, 6 (4).

Jang, J. (1993). *ANFIS: adaptive-network-based fuzzy inference system*. IEEE Trans. Syst., Man, Cybern., 23 (3). pp. 665-685.

Karamzadeh, M.S. (2013). A*pplication and comparison of Altman and Ohlson models to predict bankruptcy of companies.* Research Journal of Applied Sciences, Engineering and Technology, 5 (6). pp. 2007-2011

Kasabov, N. (1996). *Foundations of neural networks, fuzzy systems, and knowledge engineering*. Cambridge, Mass.: MIT Press.

Khodayari, A., Ghaffari, A., Braunstingl, R., Alimardani, F. and Kazemi, R. (2014). *Improved adaptive neuro fuzzy inference system car-following behaviour model based on the driver–vehicle delay*. IET Intelligent Transport Systems, 8 (4). pp. 323-332.

Kumar, P., R. and Ravi, V. (2006) *Bankruptcy prediction in banks by fuzzy rule based classifier*. In: Proceedings of the 2006 first international conference on digital information management. pp. 222–227.

Lin, C. and Lee, C. (1996). *Neural fuzzy systems*. Upper Saddle River, N.J.: Prentice Hall.

Marasigan, J., Saberon, I., San Jose, D., Sevilla, P. and Bandala, A. (2014). *Autonomous parallel parking of four wheeled vehicles utilizing adoptive Fuzzy-Neuro control system*. 2014 IEEE REGION 10 SYMPOSIUM.

Nauck, D. (1994). *A Fuzzy Perceptron as a Generic Model for Neuro-Fuzzy Approaches*, In: Proc. Fuzzy-Systeme 94 (Munich)

Nauck, D. and Kruse, R. (1996). *Neuro-Fuzzy Classification with NEFCLASS*. in P. Kleinschmidt, A. Bachem, U. Derigs, D. Fischer, U. Leopold-Wildburger and R. Möhring (eds.), Operations Research Proceedings 1995, (Berlin), pp. 294-299

Nauck, D. and Kruse, R. (1997). *Function Approximation by NEFPROX*. in Proc. Second European Workshop on Fuzzy Decision Analysis and Neural Networks for Management, Planning, and Optimization (EFDAN'97), (Dortmund), pp. 160-169

Nauck, D., Kruse, R. and Klawonn, F. (1997). *Foundations of neuro-fuzzy systems*. Chichester: John Wiley.

Negnevitsky, M. (2005). Artificial intelligence. Harlow, England: Addison-Wesley.

Pillai, G., Pushpak, J. and Nisha, M. (2014). *Extreme learning ANFIS for control applications*. 2014 IEEE Symposium on Computational Intelligence in Control and Automation (CICA).

Purvinis, O., Virbickaite, R., & Sukys, P. (2008). *Interpretable nonlinear model for enterprise bankruptcy prediction*. Nonlinear Analysis: Modelling and Control, 13 (1). pp. 61-70.

S. K. Halgamuge and M. Glesner, (1994). *Neural networks in designing fuzzy systems for real world applications.* Fuzzy Sets and Systems 65. pp. 1-12.

Saber Iraji, M., Aboutalebi, M., Seyedaghaee, N. and Tosinia, A. (2012). *Students Classification with Adaptive Neuro Fuzzy*. IJMECS, 4 (7). pp. 42-49.

Tsao, E., Bezdek, J. and Pal, N. (1994). *Fuzzy Kohonen clustering networks.* Pattern Recognition, 27 (5). pp. 757-764.

Tschichold-Gürman, N. (1996). *RuleNet-A New Knowledge--Based Artificial Neural Network Model with Application Examples in Robotics*. Ph.D thesis. ETH Zerich.

Vella, V. and Ng, W., L. (2014). *Enhancing risk-adjusted performance of stock market intraday trading with Neuro-Fuzzy systems*. Neurocomputing 141. pp. 170-187.

Vieira, J., Dias, F. M., & Mota, A. (2004*). Neuro-fuzzy systems: A survey*. In 5th WSEAS NNA International Conference on Neural Networks and Applications, Udine, Italia.

Vlachos, D. and Tolias, Y. (2003). *Neuro-fuzzy modeling in bankruptcy prediction*. Yugosl. j. oper. res., 13 (2). pp. 165-174.

Von Altrock, C. (1997). *Fuzzy logic and neuroFuzzy applications in business and finance*. Upper Saddle River, N.J.: Prentice Hall PTR.

Vuorimaa, P. (1994). *Fuzzy self-organizing map*. Fuzzy Sets and Systems, 66 (2). pp. 223-231.

Zadeh, L. (1965). *Fuzzy sets. Information and Control*, 8 (3). pp. 338-353.

Zanganeh, T., Rabiee, M. and Zarei, M. (2011). *Applying Adaptive NeuroFuzzy Model for Bankruptcy Prediction*. International Journal of Computer Applications, 20 (3). pp. 15-21.