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A Review of Hybrid Machine Learning approaches for handling Uncertainty in Data analysis

S. Maitra[1*], S. Madan[2], R. Kandwal[3]

[1*]Dept. of computer science, Apaji Institute of Mathematics and Applied Computer Technology, Banasthali Vidyapith, Rajasthan, India
[2] Dept. of computer science, Lady Shri Ram College for women, University of Delhi, New Delhi, India
[3]Dept. of computer science, Mahan Institute of Technologies, New Delhi, India

[*]*Corresponding Author: msan324@gmail.com, Tel.: +91-9871133352*

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***Abstract*—** The advent of machine learning has brought about a revolution and has become key to classification and prediction problems encompassing a variety of application domains. There are a number of machine learning techniques with Naïve Bayes, Artificial Neural Networks (ANN) and decision tree being the more popular ones. This paper reviews the aforementioned machine learning algorithms in terms of their suitability for particular problem domains. It presents a comprehensive discussion on the strengths and weaknesses of each of these machine learning algorithms. Uncertainty prevails in data as learning data is usually imprecise, incomplete or noisy. The uncertainities in data mining affect the quality of results which are based on the data.The traditional data mining approaches are not suitable to handle some forms of uncertainty and vagueness. Several forms of vagueness and ambiguities are handled successfully by hybrid machine learning techniques.The paper further studies the efficacy of hybrid machine learning algorithms used in different application domains. It presents a discusssion on how uncertainty in data analyses can be addressed in an effective manner by the usage of hybrid machine learning techniques.

***Keywords*—** Naïve Bayes, artificial neural networks, decision tree, hybrid machine learning, uncertainty**.**

I. INTRODUCTION

Knowledge discovery is the non-trivial process of identifying valid, novel, potentially useful, and ultimately understandable patterns in data [1]. Data mining is the process of analyzing data from different perspectives by finding correlations or patterns among many fields in large databases and summarizing it to useful information. Predictive data mining techniques analyze current and historical facts to make predictions about future, or otherwise unknown events. Machine learning is a subfield of artificial intelligence, concerned with the design and development of algorithms and techniques that allow computers to "learn". The data analysis is susceptible to uncertainties of several kinds such as ambiguity, vagueness etc. and there are inadequate measures to handle them. Although it is not feasible to completely eliminate uncertainty in data analysis, one can identify and find methods to cope with it to avoid risk in case of high-quality decisions [2]. The uncertainty in information processing is an area to contend with despite the many research findings on applicability of contemporary theories such as rough set theory, fuzzy set theory and neural networks [2].

The mathematics underlying each of the machine learning algorithms influence their optimal hybridization. It is not easy to decide the order in which the models can be combined. Bagging, boosting and blending are three popular ways of combining machine learning models. In bagging training models are trained on random sets of training data with replacement. Further they are combined linearly or by majority vote. This is suitable for classifiers with high variance such as decision trees as they can be combined to reduce the variance. Boosting classifiers with weak learning capacity such as linear models recursively learn a new model based on residual error which enhances the models by lowering bias. Blending is used when we want to linearly combine different kind of models. In this method we learn the weight or relative importance of each classifier by considering it as a feature. In yet another way we can combine linear and nonlinear classifiers while using one of them to extract features. linear classifier shows poor performance for inherently nonlinear problems. Instead it is better to use a nonlinear classifier such as a neural network for extraction of features. Once the features are extracted linear model can be used on the extracted features [3]. [4] used a knowledge-driven sub model, and a data-driven sub

model integrated in different ways where KD can be given from the first principle or physically based functions, the DD can be neural networks. The review is performed in two phases :

- Phase I: Study on Strengths and limitations of machine learning techniques with emphasis on Naïve Bayes, artificial neural networks and decision tree techniques
- Phase II: Uncertainty handling in data analyses through hybrid machine learning techniques.

The Population under consideration is all applications domains. Intervention used is machine learning techniques for classification and prediction. Outcome is classification and prediction accuracy of techniques. Context is empirical studies such as preliminary Studies and experiments.

The research questions proposed in this study address popular machine learning techniques for classification and prediction,the important parameters affecting performance of the machine learning techniques, the strengths of Naïve Bayes, Artificial Neural Network and Decision tree machine learning techniques , the limitations of Naïve Bayes, Artificial Neural Network and Decision tree machine learning techniques and usage of hybrid machine learning techniques to handle uncertainty in data analysis.

II. RELATED WORK

[3] present survey results of usage of machine learning and data mining techniques for intrusion detection in cyber space. It is observed that the naïve bayes classifier is more suitable for cyber analytics as it is an online algorithm with linear complexity. The runtime for learning of artificial neural network increases with the number of features. It generates nonlinear models with one or more hidden layers and can model EX-OR logic because of its back-propagation feature. It is observed decision trees are simple, intuitive and have high accuracy for classification. For smaller trees intuitiveness is high and rule extraction is easy but as the size of the tree increases intuitiveness decreases and rule extraction becomes difficult. But larger trees have high classification accuracy. But smaller trees have better generalization capabilities. Faster incremental learning methods are a potential area of research useful for periodic updates of models for cyber analytics. The suitability of one method over the other is yet to be studied and the effectiveness compared in terms of several criteria such as accuracy, complexity, time for training and interpretation of final solution. In this regard the non availability of labeled data is a major bottleneck. It is observed by [4] that Naïve Bayes being a technique based on probabilities is applicable to a wide range of domains. The results of the approach can be used for many purposes as it does not require large amount of data for training and is computationally fast. Here the classifiers are used for malware prediction and web traffic data. Decision tree approaches are easily understandable, require only discrete values and use the divide and conquer strategy. It works well if attributes are highly co-related and gives poor performance when complex relationships exist. [5] conducted a survey on the use of machine learning techniques in diagnosis of different diseases. The Naïve Bayes classifier justifies the membership of an instance to a particular class with the help of probabilities. They observed that the accuracy of the classification is dependent on the metrics used which also gives a fair idea about the set of features which have been used. [6] reviewed machine learning classification techniques for dermatology diseases. It is observed that Naïve Bayes and artificial neural networks exhibited above 99% of accuracy while decision tree showed an accuracy of above 96%. The research gap is that hybrid techniques are not explored for disease classification. [7] studied both hybrid and ensemble classifiers using latest machine learning techniques from 130 journal papers and studied their aptness and limitations for credit scoring and bankruptcy prediction. It is seen that the efficiency of the models is based on data preprocessing for feature selection, determination of base line classifiers against which they are compared for robustness, selection of training as well as test data sets and cross validation. [8] conducted a survey on single and hybrid ensemble classifier architectures. A comparative statistical analysis of the single classifiers in terms of experimental set ups, data sets and feature selection step revealed that system performance is dependent on feature selection. The Naïve Bayes and neural network outperformed decision tree and other machine learning algorithms. It is further observed that these three algorithms have also been extensively used for building ensemble classifiers and that ensemble classifiers can replace single classifiers in performance measurement. Additionally the neural network, decision tree as well as Naïve Bayes showed comparitively higher detection rate when used as ensemble classifier. Decision tree, Naïve Bayes and neural network showed a high accuracy for detection of malicious web content. [9] used a neuro-fuzzy approach to classify students on the basis of their academic performance. The approach is found to be superior in classification accuracy in comparison with other popular classification approaches such as decision tree, neural network, support vector machines and Naïve Bayes. A new unsupervised hybrid classifier based on fuzzy integral which combines six well-tested base supervised classifiers is proposed by [10] where general rules are inferred through ID3 for natural texture identification in aerial images.This rule allows generation of a partition of the set of images used by the base classifiers to automatically estimate their parameters which serve as inputs to calculate the relative importance of each classifier in their combination by the Fuzzy Integral. When classification of data is difficult

the combination of classifiers reduces the errors due to cluster overlapping or some other problems. The resulting classifier has been compared with related techniques getting an improvement of 8.04% average. [11] perform a comparative analysis of machine learning techniques in terms of their efficiency for the prediction of diabetes. Three algorithms namely Support Vector Machines, Deep Neural Networks and Hybrid Deep Learning are studied. The hybrid deep networks are superior in performance comparatively while hybrid deep learning has better processing capability to make an accurate prediction of many diseases. The research gap is more extensive data needs to be used with regression substitution in case of missing values.

Several machine learning methods are compared for their estimation of uncertainty[12][13]. The combination of new theories such as Zadeh‘s fuzzy set and Pawlak‘s rough set has laid a foundation for processing various types of uncertain and incomplete information[14]. Rough set theory deals mainly with vagueness of information caused by granular description of objects, while fuzzy set theory mainly handles fuzziness in concepts and linguistic categories[14]. The rough set does not need additional information about data such as grade of membership in fuzzy set theory and is therefore useful in situations where set of empirical data is too small to employ standard statistical methods[15]. [16] have shown effective applicability of rough set theory to robotics for uncertainty management in several ways. Fuzzy theory handles subjective categories in human decision processes which do not follow axioms and lexical uncertainty which is uncertainty of the definition of the event itself [24]. There is a close relationship between the rough set theory and the fuzzy set theory and they cannot inter substitute [14], but their inter-complementary property suggest their hybridization for uncertainty handling [18]. While fuzzy logic draws inferences under cognitive uncertainty, neural networks are efficient in adaptation, parallelism, fault-tolerance, and generalization. To enable a system to deal with cognitive uncertainties like humans, one may incorporate fuzzy logic into the neural networks. Neural network learning techniques can automate the fuzzy process and substantially reduce development time and cost while improving performance. Nevertheless, the neural network being a black box suffers from lack of support to simplify the learning procedure. There has been active research on uncertainty in neural networks [20]. Hybridization of fuzzy and neural as well as rough set and neural network have been areas of active research for classification and uncertain decision respectively [21]. The combination of these theories can interpret hidden knowledge in the black box of neural networks. The usage of rough set minimizes the rules to enable faster learning of neural network [22]. Rough fuzzy neural networks are known to show better performance as compared to fuzzy neural networks. Methods were also proposed for construction of such networks [23]. [16] explore effective applicability of rough set theory to robotics for uncertainty management in several ways. [14] focused on theoretical problems yet to be solved by rough set theory. The authors presented a discussion on a relationship between rough set theory and fuzzy set theory. Further emphasis was laid on extension of rough set theory and rough set theory based reasoning mechanism. New effective algorithms are proposed for finding all possible attribute reductions in an information system for attribute value reduction and rule generation respectively. [13] present a frame work to assess total model uncertainty. It is a generalization of a frame work based on machine learning techniques for assessing predictive models. Uncertainty is indicated by deviations between observed and predicted values measured as predicted intervals. All potential sources of uncertainty such as model structure, parameter, input and output data are studied for uncertainty. [17] discusses the development of fuzzy logic as a consequence of lack of framework to represent common sense knowledge which is inherently non categorical to handle the lexical imprecision and uncertainty where first order logic and classical probability fail. Fuzzy systems are suitable for uncertain or approximate reasoning, where it is difficult to derive mathematical models and where decision making with estimated values is required under uncertain or incomplete information. Further neural networks are proposed for their adaptability and simplified mathematical modeling, learning, fault tolerance, parallelism and generalization. To enable a system to deal with cognitive uncertainties in a manner more like humans, the author suggests to incorporate the concept of fuzzy logic into the neural networks. Several aspects of the hybridization of neuro fuzzy systems have been discussed. [20] proposed a network model which represent incomplete model with the help of interval. The learning algorithm decreases the total uncertainty of information in the network by decreasing the width of interval weights. It also facilitates matching of the intervals by ordering relations. [12] provide an overview on control and estimation of learning machines by discussing algorithms theory and empirical methods for robust estimation. It also discusses the problem of uncertainty estimation in devices with limited resources. The paper by [18] explores and throws light on different aspects of uncertainty which surface in navigation system. The authors further propose rough set and fuzzy set based approach to deal with the uncertainties in navigation system. [19] proposed a hybrid model of intuitionistic fuzzy model and rough sets based on similarity relation. An intuitionistic fuzzy logic operator and similarity relation are introduced and certain properties of operator are classified examined and proved. The approach is also claimed to be more accurate in classification and decision. [21] proposed an architecture based on rough set theory and neural network which is more robust and stable with better decision and possessing field independence and with user complexity to address attribute value rough equality problem. [15] proposed a Rough set membership function based approach to grey measures of

knowledge to define formally the grey degree of grey numbers and grade of grey numbers with explicitly stated semantics and reasonably interpreted for classification of object and establishment of set of rules with different grades of grey degree. The proposal fills the shortages of grey degrees of grey numbers in grey system. Grey rules are abstracted by setting levels of grey degree thus making up for insufficiency of rough set theory. [22] proposed a rough neuro fuzzy classifier for pattern classification of high dimensional data which uses rough set to minimize the rules as well as attributes and enable faster learning of neural networks. [23] propose a method to construct a fuzzy neural network structure based on rough set theory. The method derives its strength from combining the strong ability of rough set theory to analyze numerical value, ability of fuzzy set theory for approximation and good intelligibility, simple computation and fast convergence of neural network. [2] discuss hybridization of Zadeh's concepts of fuzzy set theory, possibility theory and Pawlak's concept of rough set theory to overcome disadvantages of existing method of rough sets. The author proposes a rough set theory based on possibility measure which includes pawlak's rough set model coupled with better analysis property to tackle information processing problem with possibility characteristics effectively. For the sake of measuring fuzzy uncertainty and rough uncertainty of real datasets, the fuzzy rough membership function (FRMF) defined in fuzzy rough set is introduced by [25]. A new fuzzy rough neural network (FRNN) is constructed based on neural network implementation of fuzzy rough membership function. fuzzy rough neural network has the merits of quick learning and good classification performance. And then a new neural network feature selection algorithm based on FRNN is designed. The input nodes of FRNN are pruned according to the descent of classification accuracy; thereby the search of optimal feature subset is realized with reference to residual input nodes. The test results on UCI datasets show that the algorithm is quick and effective, and has better selection precision and generalization capability than RBF feature selection. [27] studied about integrated solutions to cyber security using high performance computing and Data sciences and observed that machine learning builds classifiers to identify network traffic as good or bad based on the analysis. The spam filters are based on these techniques to identify normal emails from ad's, phishing and other types of spam. Application of machine learning tools to enterprise security gives rise to a new set of solutions. These tools can analyze networks, learn about them, detect anomalies and protect enterprises from threats machine learning as an indispensable tool for developing cyber security solutions. They concluded that prospective security solutions rely heavily on integrated approaches using predictive power of machine learning processing and storage power of High Performance Computing and to process big data of cyber space. [28] use a multistrategy model based on decision tree and artificial neural network to understand online customer's buying behavior. They used C4.5 and SPRINT algorithm's Gini function to select best attribute to branch. Further 70% of data is used for analysis using Artificial neural network and 30% is used for prediction and scoring using decision tree. The approach showed a precision of 96.65% and an F1-score of 0.968.

III. RESULTS AND DISCUSSION

A review of studies conducted on each of the three popular machine learning techniques namely Naïve Bayes, Artificial Neural Networks and Decision tree revealed their strengths and limitations as follows :

NAÏVE BAYES

Strengths

- It is an online algorithm with linear complexity
- Being a technique based on probabilities is applicable to a wide range of domains
- The results of the approach can be used for many purposes as it does not require large amount of data for training
- It is computationally fast
- The Naïve Bayes classifier justifies the membership of an instance to a particular class with the help of probabilities.

Limitations

The accuracy of the classification is dependent on the metrics used which also gives a fair idea about the set of features which have been used

ARTIFICIAL NEURAL NETWORK

Strengths

- They generate nonlinear models with one or more hidden layers
- They can model EX-OR logic because of its back-propagation feature.
- They are adaptable
- They require simplified mathematical modeling
- They possess good fault tolerance
- They exhibit parallelism
- They can be easily generalized.

Limitations

- learning runtime of artificial neural network increases with the number of features.

- The neural network being a black box suffers from lack of support to simplify the learning procedure.

DECISION TREES

Strengths

- They are simple
- They are intuitive
- They have high accuracy for classification
- Their intuitiveness is high with smaller trees
- Data can be easily structured.
- They reveal the associations between various rules.
- Rules pride an appropriate and comprehensive description of all the classes in the training data set
- The computation cost is low .
- Rule extraction is easy with smaller trees .
- Classification accuracy increases with size of the tree.
- Smaller trees have better generalization capabilities.
- Decision tree approaches are easily understandable
- They require only discrete values
- They easily model large problems with simple relationships as they use the divide and conquer strategy
- They give good performance if attributes are highly co-related

Limitations

- Their intuitiveness decreases with smaller trees
- Rule extraction becomes difficult with increase in size of tree
- They give poor performance when complex relationships exist and complex rules are generated.
- Requires large data set with more number of attributes for good classification accuracy increases with size of the tree

IV. CONCLUSION AND FUTURE SCOPE

It is observed that specific machine learning techniques are suited for particular problem domains. A study of several papers on machine learning techniques revealed that the efficiency or system performance of the machine learning techniques is dependent on various factors such as feature selection process, choice of base line classifiers for robustness comparison, type and size of training and data sets used and cross validation. The performance of these techniques is measured in terms of accuracy, complexity and time for training and interpretation of the solution. Futher a study of research papers on hybrid machine learning approaches emphasize that all the techniques demonstrate superior performance when used in combination as hybrid techniques. The research by several authors on uncertainty show that fuzzy theory systems are useful for drawing inferences by approximate reasoning with estimated values to handle bias in human decision processes, uncertainty in concepts and lexical imprecision. It is also used in situations where it is complex to derive mathematical models and where decision making is required under incomplete information. Nevertheless, additional information such as degree of membership of data is required. Rough set theory deals mainly with vagueness of information due to description of objects. Unlike fuzzy theory it does not need additional information about data. Rough set theory and the fuzzy set theory are closely related. They are inter-complementary and cannot be a substitute for each other and therefore their hybridization is indispensable for uncertainty handling. Fuzzy rules will be formed with interdependent parameters fed to neural network or a decision tree for quantification. Further the rules can be reduced using rough set theory.

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Authors' Profile

Ms. Sandhya Maitra is Associate Professor in IT at Institute of Information technology. She is B.A.(Hons.) Maths, M.A. Maths qualified from Delhi University, M.Phil Maths from VMU, M.C.A. from GJUSIT, UGC NET (CS& A) qualified and is currently pursuing her Phd (Computer science) from Banasthali Vidyapith. She has worked in various capacities for over 19 years for Higher Education Institutions. She has been Convener of several IT conferences, conducted FDPs. She has published and presented research papers in journals and conferences of national & international repute. She is on the review board of reputed conferences and publication houses .

Dr. Sushila Madan is an Associate Professor in Computer Science, Lady Shri Ram College, University of Delhi. She is M.Sc. in Applied Maths from I.I.T. Delhi and MTech from BITS Pilani. To her credit there are many research papers, books, articles and is reviewer on board of reputed International journals. She has chaired various sessions in it domain and is a corporate trainer and consultant to industry for information security. She is Lead Auditor and Tutor for Information Security Management System standards (ISO 27001). She is actively guiding research students and is an active Member of CSI, FMS (Delhi University), Gerson Lehrman Group Councils SM, Fellow member IETE , Advisory Board of IGI Global, US.

Dr. Rekha Kandwal holds 22 years of professional and research experience in the field of administration, software development, project planning and execution, training, education, technical and creative writing. Dr. Rekha Kandwal did her B.Sc (Hons) Maths & M.Sc(Maths) from Delhi University, Mtech from I.E.T.E and Phd (Computer Science) from JNU. She was working in India Meteorological Department as Meteorologist in September 1993 in Instrumentation division. During her stay with IMD, she was associated with some technical boards and universities for academic activities and research. Dr. Kandwal has papers in reputed international Conferences and Journals.

