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DEEP LEARNING BASED ON ROUGH SETS AND ROUGH NEURAL NETWORKS FOR EFFICIENT DECISION SUPPORT SYSTEM

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Abstract: Rough sets are efficient in approximately represent the whole space associated with data. Rough neural networks are the phenomena based on rough sets on top of neural networks. In the existing systems, the rough set learning is compatible with one decision table. However, in many real-world applications, there is need for multiple decision tables. To address this problem, this paper proposes a novel approach with rough sets based on deep learning architecture. In other words, a deep rough set theory is used to define a deep learning model with multiple decision tables a to realize a decision support system. The proposed deep learning architecture considers each decision table's local properties to arrive at an approximate decision globally. We also proposed an algorithm known as Deep Neural Network on Rough Sets (DNNRS) to realize the proposed deep learning architecture. The ability of the proposed model to handle multiple decisions tables with soft computing and machine learning paves way for solving real world problems. The proposed rough sets based deep learning model has capability that mimics human brain thinking which is suitable in many decision support systems. Empirical study has revealed the significance of the proposed model.
Keywords – Rough Sets, Deep Learning, Rough Neural Networks, Machine Learning, Soft Computing

INTRODUCTION

Rough sets and associated theory is widely used in many real time applications. The rationale behind this is that rough sets can model an entire dataset. This capability has made rough sets useful for solving different problems. Moreover, rough sets are widely used in machine learning applications [6]. Machine learning involves in supervised and unsupervised learning models. The former is known as supervised learning where it has training and testing phases while the latter does not have explicit training. When training is involved, it is important to learn from the data. In this context, rough sets play crucial role in representation of training data. There are ensemble applications also where multiple machine learning models are involved in voting approach to predict class labels with higher level of accuracy [19].

ML techniques as part of Artificial Intelligence (AI) play an important role in making learning based solutions to many real world problems. Neural networks are also used widely for solving problems as such models resemble human brain process. Advanced forms of neural networks come under deep learning became more popular off ate. The rationale behind this is that deep

learning models exploit soft computing and mathematics in order to have depth in learning process. With convolutional layers and pooling layers, deep learning models are found better equipped in processing input data. There are many deep learning models that are designed to have supervised learning approach while some models do have unsupervised learning phenomenon. In either case, the deep models are well known for solving problems in the real world with highest level of accuracy.

Literature has revealed many contributions on rough sets usage in real world applications. Many deep learning models are found to be suitable for processing images as explored in [9], [10], [12], [15] and [20]. Maggiori et al. [9] proposed a deep learning framework based on Convolutional Neural Network (CNN) for classification of remote sensing images in large scale. Lopez-Martin et al. [10] focused on soft computing based deep learning model for network traffic classification. They used CNN and Recurrent Neural Network (RNN) to achieve this. Tavanaei et al. [12] investigated on spiking neural networks with deep learning based approach. Mai et al. [15] investigated on the usage of rough sets to represent textual data which is used for deep learning to predict bankruptcy cases. Guo et al. [20] used CNN for analysing machine health with underlying data representations. From the literature, it is understood that there is need for exploiting deep learning model by considering rough sets for data representation leading to decision support systems. Our contributions in this paper are as follows.

A deep learning framework based on rough sets is proposed to solve classification problems.

An algorithm known as Deep Neural Network on Rough Sets (DNNRS) to realize the proposed deep learning architecture.

Python is the language used to build a prototype application to evaluate the performance of existing prediction models the proposed deep learning based method.

The remainder of the paper is structured as follows. Section 2 reviews literature on existing methods pertaining to rough sets and their related applications with machine learning. Section 3 throws light on the proposed system. Section 4 presents results of empirical study and Section 5 concludes the work and gives possible scope for future work.

2. RELATED WORK

This section reviews literature on existing methods pertaining to rough sets and their related applications with machine learning. Wanga et al. [1] explored feature selection based on rough sets considering fuzzy neighbourhood. By selecting contributing features, it is possible to have better solutions with machine learning. Their method could be useful for generating fuzzy inference for better decision making. Hassanienc et al. [2] proposed a bio-inspired algorithm based on rough sets to detect crop diseases in agricultural domain. Their method is based on the heuristics associated with the algorithm for automatic detection of crop diseases. Thus it is significant to solve one of the problems in agriculture domain. Dai et al. [3] used fuzzy rough sets theory in order to perform dimensionality reduction for improving prediction performance. Since there are more number of features in any given data, it is important to reduce number of features. Unless it is done so, there is a problem popularly known as curse of dimensionlaity which deteriorates decision making accuracy in real world applications. Zhang et al. [4] focused on the notion of neighbourhood rough sets for discovering business intelligence

through representative based classification. This kind of classification is learning based approach that helps in understanding given inputs and learn from the same for making good decisions. Deer et al. [5] investigated on the covering based rough sets which is a variant of rough sets proposed by Pawlak. Since rough sets help in representing data in real world, it is useful to have mechanisms on top of the rough sets in order to arrive at suitable decisions. Bello and Falcon [6] used rough sets in realizing machine learning based solution to real world problems such as prediction of class labels. Since ML models are good at learning, it is important to exploit feature engineering based on rough sets towards improving quality in the process of training. Da et al. [7] explored soft computing based approach with deep neural networks for classification of medical images such as brain CT scans. Since brain CT scans come under image data, deep learning models are found to be highly suitable for medical imagery classification. It solves many real world problems with automated approach. It is also useful to perform disease diagnosis in healthcare domain. Zhao et al. [8] proposed a credit scoring function by improving neural networks with rough sets. It is observed that deep neural networks could function better with data representation in the form of rough sets. The idea behind this is that rough sets provide chances to deal with fine representation issues and also dimensionality reduction. Maggiori et al. [9] proposed a deep learning framework based on Convolutional Neural Network (CNN) for classification of remote sensing images in large scale. It is found from their empirical study that CNN is capable of exploiting features from the given inputs. In other words, CNN has mechanisms to have better feature engineering prospects. Lopez-Martin et al. [10] focused on soft computing based deep learning model for network traffic classification. They used CNN and Recurrent Neural Network (RNN) to achieve this. By combining CNN and RNN, it is possible to exploit both feature engineering and also efficient classification.

Serrano-Cinca et al. [11] explored the usage of representing data pertaining to peer to peer lending. It is a novel phenomenon where it is possible to have a lending application that works in a distributed environment. Such systems that are based on distributed environments are essential to solve many real world applications. Tavanaei et al. [12] investigated on spiking neural networks with deep learning based approach. It is observed that the spiking neural networks are essential advanced neural networks that exploit human brain functioning. It is widely used in different real world applications. Amina et al. [13] used rough set theory for customer churn prediction process in telecommunication domain. Customer churn is the process in which existing customers leave an organization. Unless, the churn rate is analysed and corrective steps are made, the company loses reliable talent in the long run leading to many growth issues. Edelen et al. [14] exploited the rough sets theory for modelling and controlling particle accelerators as part of neural networks. From their work, it is observed that there is possible improvement in the internal functioning of deep neural networks by using rough sets based mechanisms. Mai et al. [15] investigated on the usage of rough sets to represent textual data which is used for deep learning to predict bankruptcy cases. Since textual data is dominating in the real world applications, it is very important to have ideal representation of such data. Once the data is optimally represented, it is possible to exploit ML applications towards solving problems and realizing decision support systems. Aggoun and Amira [16] used multimodal neural networks in order to have a mechanism to identify speaker. It also used

wavelet analysis with neural networks based phenomenon. Since each neural network is designed for specific purpose, combining multiple neural networks with hybrid approach can reap benefits of those underlying models. Bazrafkan et al. [17] proposed a neural network to model Iris data and performed segmentation using deep neural network. Segmentation is one of the important aspects in image processing. Moreover, deep learning models are found highly suitable for processing imagery data. Torres-Huitzil et al. [18] modelled given data using neural networks for identification of error and fault tolerance. Their research has assumed significance as there is importance towards fault tolerant approaches in different real world applications. Poriaa et al. [19] used ensemble approach with CNN and multiple kernel learning towards effective sentiment analysis. Ensemble approach could improve prediction performance due to the involvement of multiple models and with different subsets of training samples. Guo et al. [20] used CNN for analysing machine health with underlying data representations. Since CNN can understand features of given data well, it is very important to analyse the machine data and find machine health as accurately as possible. More deep learning or machine learning methods coupled with rough sets are found in [21]-[30]. From the literature, it is understood that there is need for exploiting deep learning model by considering rough sets for data representation leading to decision support systems.

Notation	**Description**
U	non-empty finite set of objects called a universe
C	non-empty finite set of attributes
V_C	values set C
D	attribute
x	equivalence class
I	Relation
$\underline{X}$ and $\bar{X}$	lower and the upper approximation of the class
X	Objects
E	minimal set of attributes
p	conditional part of the rule
q	decision part of the rule
J	set of deep relations
f	an information function
W	a real-valued non-zero weights

$\widetilde{C_1}$	average attributes-values
w_i	total weight
x and y	pair of objects
$J_B(X)$	set of all objects from U1 or U2
$\propto_i$	weighting coefficients of i^{th} neuron
λ_i	bias
$output_Y$	output of the conventional neuron

Table 1: Notations used in this paper

As shown in Table 1, different notations used in the proposed system section of this paper are provided.

3. PROPOSED SYSTEM

Any dataset in the real world can be represented in the form of rough sets. It is possible to use the rough sets for solving different problems such as classification. In this connection, a relation can be expressed as in Eq. 1.

$$I = \{(x,y) \in U \times U : a(x) = a(y), \forall a \in A\} \quad (1)$$

With respect to the above relation, for x, the equivalence class is expressed as in Eq. 2.

$$[x] = \{a(y) = a(x), \forall a \in A\} \quad (2)$$

The lower an upper approximations of the relation can be expressed as in Eq. 3

$$\underline{X} = \{x \in U : [x] \subseteq X\}, and \\ \underline{X} = \{x \in U : [x] \cap X \neq \emptyset\} \quad (3)$$

In presence of reduct which is minimal set of attributes, the classification accuracy dynamics is expressed as in Eq. 4.

$$I(E) = I(C) \ldots . and \\ \forall_{e \in E} I(E - \{e\} \neq I(C) \quad (4)$$

In this context, decision rules play crucial role in classification problems. Decision rule is nothing but the relationship between decision and conditional attributes. Rough set theory is widely used to solve classification problems as it can represent data which is useful for decision making. With respect to training data, data representation in the form of rough set plays important role. The proposed deep learning model is denoted as in Eq. 5.

$$\sum_{ij} c_i w_{ij} = 1, \forall j \in U/C \& c_i \in c_j \quad (5)$$

Weights computation for decision table derived from a dataset can be expressed as in Eq. 6.

$$w_i = 2c_i + \sum_j w_{ij}\, c_j \quad (6)$$

Considering a deep relation J, the expression is in the form of Eq. 7.

$$xJy \Leftrightarrow f(x, c \in C) \quad (7)$$

A relation with deep rough equivalence is expressed as in Eq. 8.

$$[x]_j = \{y \in U_1 \vee U_2 \ldots \vee U_n : c(y = c(x), \forall c \in C\} \quad (8)$$

Now the lower and upper approximations are denoted as in Eq. 9.

$$\underline{X} = \{X \in U_1 \vee U_2 \ldots \vee U_n : J_B(X) \subseteq X\} \\ \bar{X} = \{X \in U_1 \vee U_2 \ldots \vee U_n : J_B(X) \cap X \neq \emptyset\}, \quad (9)$$

The concept of using rough sets with the proposed deep learning model has its significance. Since rough sets can approximate given dataset well, the proposed deep learning model exploits it with soft computing

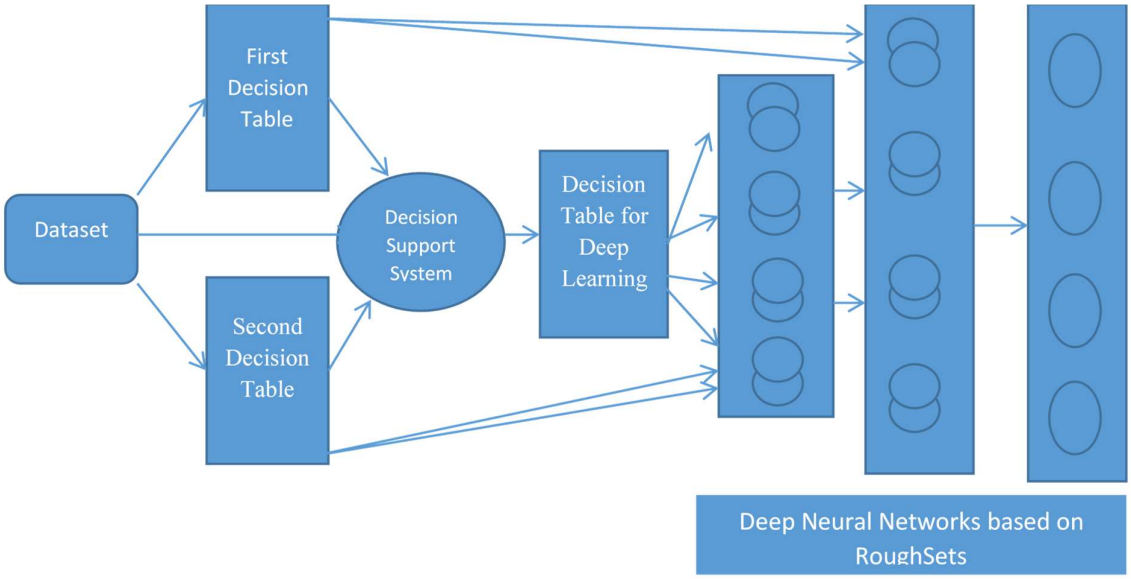

Figure 1: Proposed deep learning model based on rough sets

As presented in Figure 1, the proposed model has different phases such as creation of decision tables, creation of decision support system, deep neural networks based on rough sets. These three phases or layers are stacked; it results in an architecture which is meant for classification. The rough set theory is used in each phase of the model. The input layer deals with multiple decision tables. Each decision table is multi-dimensional in nature. Decision tables are constructed from dataset through rough sets. The rough neurons used in each layer are two dimensional in nature. At a given neuron feature value is computed as in Eq. 10.

$$h_i(x) = f(\infty_i^T x + \lambda_i \quad (10)$$

The outcome of a rough neuron is computed as in Eq. 11.

$$Y_{max} = mix\left(f(\bar{X}), f(X)\right) and\ Y_{min} = min\left(f(\bar{X}), f(\underline{X})\right) \quad (11)$$

When it comes to conventional neurons, the outcome is as in Eq. 12.

$$output_Y = \frac{Y_{max} - Y_{min}}{average(Y_{max}, Y_{min})} \quad (12)$$

An algorithm named Deep Neural Network on Rough Sets (DNNRS) is proposed and implemented to realize the framework for decision support system based on rough sets and deep learning.

Algorithm: Deep Neural Network on Rough Sets (DNNRS)

Input: Dataset D

Output: Classification results R

1. Start

   Input Layer

2. Derive decision tables from D

3. Derive rules from decision table

Hidden Layers

4. Add hidden layers with rough neurons
5. Rough neurons read data from local and global decision tables

Output Layer

6. Use conventional neurons to have output layer
7. Apply back propagation as learning algorithm
8. Perform testing
9. Obtain results into R
10. Display R
11. End

Algorithm 1: Deep Neural Network on Rough Sets (DNNRS)

As presented in the Algorithm 1, it takes given dataset as input and produces classification results as output. In each step it exploits rough sets in the process of deep learning where the learning depth is into multiple layers and multiple decision tables are involved in the process. For learning from data, the algorithm makes use of back propagation kind of procedure. The supervised learning with rough sets representation of data leads to a knowledge model which is used to predict class labels.

4. EXPERIMENTAL RESULTS

This section presents experimental results in terms of data distribution dynamics, data classification results comparison and data classification results for different datasets such as Facebook, Wikipedia and Twitter.

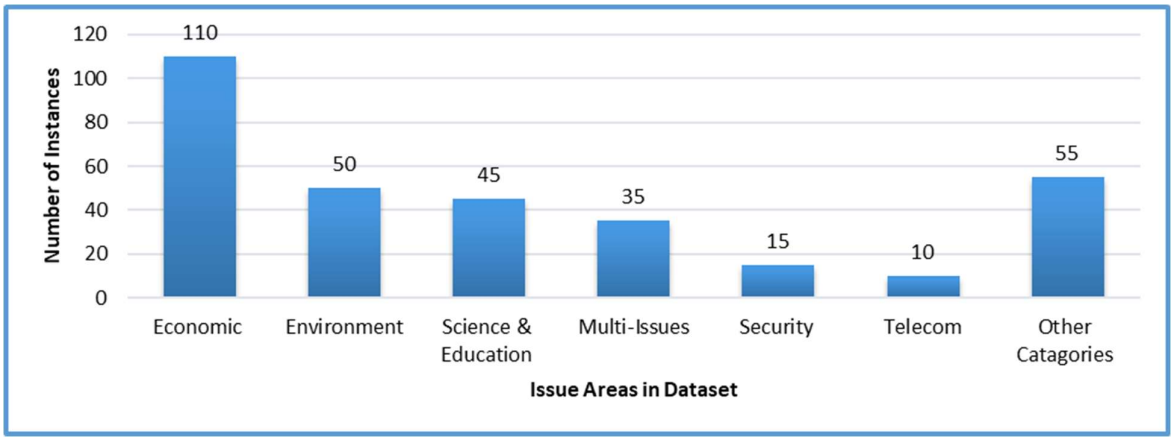

Figure 2: Issue areas distributed in the Twitter dataset

As presented in Figure 2, different issue areas are distributed in Twitter dataset. The issues are provided in horizontal axis with corresponding instances in the vertical axis. The dataset is subjected to rough set representation and then used in deep rough sets model.

Classification method	Classification Rate (%)

	Positive (%)	Negative (%)	Average (%)
Decision Tree	90	74	82
K-NN Classifier	79	59	69
Neural Networks	90	88	89
DNNRS (Proposed)	91.5	92	91.75

Table 2: Shows classification rate when Twitter dataset is used

As presented in Table 2, it is observed that the classification rate for classes such as positive, negative and average is provided for many models including the proposed DNNRS model.

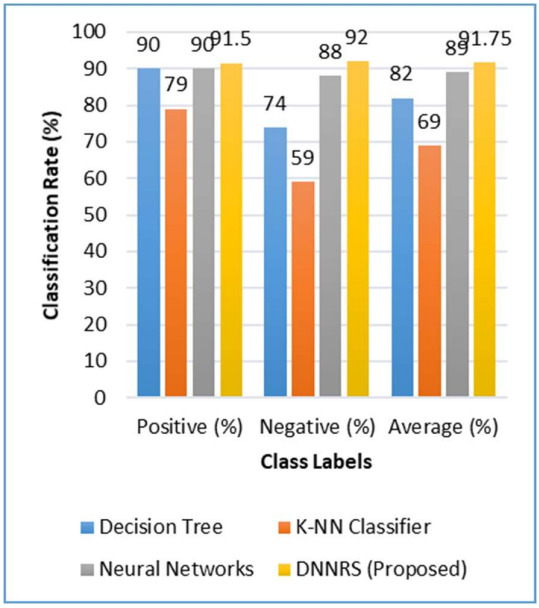

Figure 3: Classification rate comparison on Twitter dataset

As presented in Figure 3, the classification rate of each machine learning model including the proposed deep learning model known as DNNRS is provided. The class labels are showed in horizontal axis while the classification rate is given in vertical axis. The results revealed that the deep rough sets representation has its impact on classification rate. It is observed that the classification rate for each class label revealed that the proposed model shows better performance.

Classification method	Classification Rate (%)		
	Facebook (%)	Wikipedia (%)	Twitter (%)
Decision Tree	82	85	82
K-NN/Rough Sets	69	83	69
Neural Networks	86	86	89
Deep Rough Sets (Proposed)	92	89	91.75

Table 3: Classification rate with multiple datasets

As presented in Table 3, it is observed that classification rate is observed for multiple datasets using different learning models.

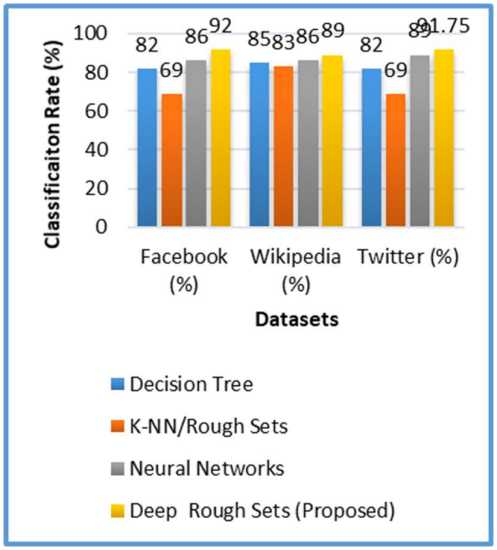

Figure 4: Classification rate comparison for different datasets

As presented in Figure 4, the classification rate of each machine learning model including the proposed deep learning model known as DNNRS is provided for all datasets. The datasets are showed in horizontal axis while the classification rate is given in vertical axis. The results revealed that the deep rough sets representation has its impact on classification rate. It is observed that the classification rate for each class label revealed that the proposed model shows better performance. With Facebook dataset, the proposed model showed 92% classification rate which is higher than other models like Decision Tree, KNN and Neural Networks. In the same fashion, with Wikipedia dataset, the proposed model showed 89% classification rate which is higher than other models like Decision Tree, KNN and Neural Networks. With Twitter dataset also, the proposed model showed 91.75% classification rate which is higher than other models like Decision Tree, KNN and Neural Networks.

5. CONCLUSION AND FUTURE WORK

This paper proposes a novel approach with rough sets based on deep learning architecture. In other words, a deep rough set theory is used to define a deep learning model with multiple decision tables a to realize a decision support system. The proposed deep learning architecture considers each decision table's local properties to arrive at an approximate decision globally. We also proposed an algorithm known as Deep Neural Network on Rough Sets (DNNRS) to realize the proposed deep learning architecture. The ability of the proposed model to handle multiple decisions tables with soft computing and machine learning paves way for solving real world problems. The proposed rough sets based deep learning model has capability that mimics human brain thinking which is suitable in many decision support systems. Empirical study has revealed the significance of the proposed model. Proposed deep learning model achieved highest classification rate with 91.75%. In future, we intend to improve the proposed deep learning model based on rough sets to realize a clinical decision support system in healthcare industry.

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