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Highlights

- Critique of Various Algorithms
- Elimination in 4G Network Call
- Brother of Artificial Intelligence
- Human Learning to Deep Learning

Discovering Thoughts, Inventing Future

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Critique of Various Algorithms for Handwritten Digit Recognition using Azure ML Studio

By Goutham Cheedella

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Keywords: handwritten recognition, digit recognition, azure machine learning studio, neural networks, support vector machines, decision tree, classification.

GJCST-D Classification: I.2.2

CRITIQUEOFVARIOUSALGORITHMSFORHANDWRITTENDIGITRECOGNITIONUSINGAZUREMLSTUDIO

Strictly as per the compliance and regulations of:

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I. Introduction

Handwritten Digit Recognition is probably one of the most exciting works in the field of science and technology as it is a hard task for the machines to recognize the digits which are written by different people. The handwritten digits may not be perfect and also consist of different flavors. And there is a necessity for handwritten digit recognition in many real-time purposes. The widely used MNIST dataset consists of almost 60000 handwritten digits. And to classify these kinds of images, many machine learning algorithms are used. This paper presents an in-depth analysis of accuracies and performances of Support Vector Machines (SVM), Neural Networks (NN), Decision Tree (DT) algorithms using Microsoft Azure ML Studio.

For many years, we are using handwritten digit recognition in several ways, and even though there is much advancement made in the system, there are minute errors in recognizing the digits. Still, we haven't achieved 100% accuracy, and research is going on. Seldom 1% or 2% errors may also lead to inapt results in several real-time applications.

And here, we have used the MNIST dataset for the training and testing of our model. In this dataset, it consists of almost 60000 images which are already normalized and centered. And so each image is of size 28x28, which forms an array size of 784 pixels with values ranging from 0 to 255. Whenever a pixel value is '1', it represents that the background is white, and for black it is '0'.

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II. Implementation

a) A glimpse of the MNIST Dataset

The handwritten digit recognition is a broad research topic which gives an extensive survey of the field, including significant feature sets, learning datasets, and algorithms. The MNIST stands for the Modified National Institute of Standards and Technology dataset. It is a dataset of 60000 small square 28×28 pixel grayscale images of handwritten single digits between 0 and 9.

It helps to train various image processing systems and for training and testing in the field of machine learning. It was created by remixing the samples from NIST's original datasets which stands for the National Institute of Standards and Technology, a unit of the U.S. Commerce Department.

There are several scientific papers on attempts to achieve the lowest error rate as possible. An extended dataset which is similar to MNIST called EMNIST published in 2017, which contains 240000 training images, and 40000 testing images of handwritten digits and characters.

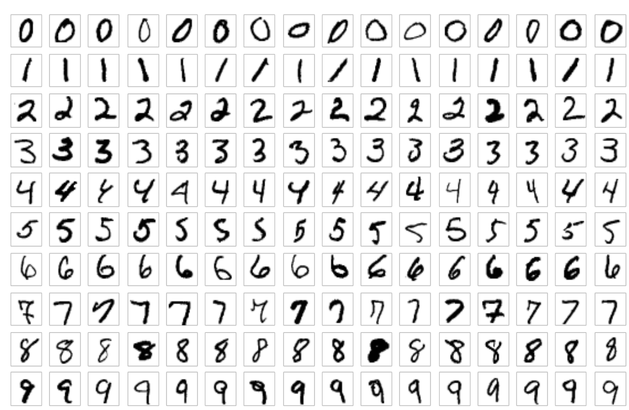

Figure 1: An example featuring MNIST dataset

The dataset used in our experiment in which, training set consists of 60000 images and 10000 images for the test set. Depending on the training and test datasets, the accuracies and performance of the algorithms may vary.

b) Support Vector Machines

Support Vector Machines helps us to find a hyperplane in N-dimensional space (N- the number of features), which classifies the data points distinctly. It is a supervised machine learning model used for classification and regression. In this, the data points get classified applying the concept of the hyper plane. Its dimensions may vary depending upon the number of features.

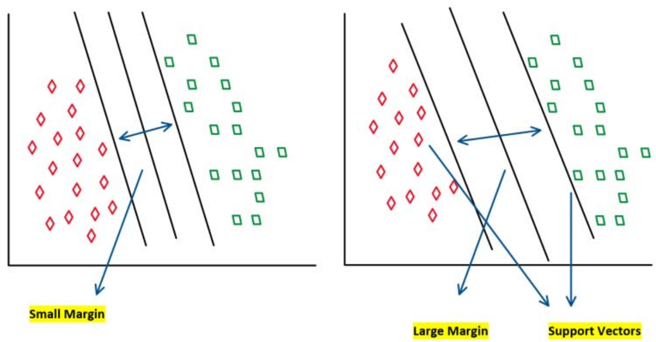

Figure 2: Support Vector Machine Classifier

The separation margin should be of equal distance from the classes. SVM offers notable immeasurable features for the classification problem. Initially, the MNIST dataset gets loaded into the Azure ML studio, and once the data preprocessing gets completed, the model training takes place using the SVM algorithm. Then the labels are predicted for the given inputs. Finally, we attain the accuracy, precision, recall, and F1 scores.

Using the two-class boosted SVM, we got an accuracy of 91% on the MNIST dataset.

In SVM, it's always wise to scale the input data so that the training time becomes less and also the model rendering takes more time if the data is more.
Image of the SVM results

c) Decision Tree Algorithm

These are used successfully in many diverse areas. A Decision Tree mainly consists of three components, such as nodes: test for the value of a particular attribute, Edge/ Branch: outcome of a test and connect to the next node or leaf and leaf nodes/terminal nodes. The Decision Tree forms from the given input data. At long last, the classification procedure through a tree-like structure is consistently natural and interpretable. The two main types of Decision Trees are classification and regression. In this, we are using the Decision Tree for classification as yes/no types where a tree gets built using a process known as binary recursive partitioning. It is an iterative process of splitting the data into partitions and then splitting it up further on each of the branches.

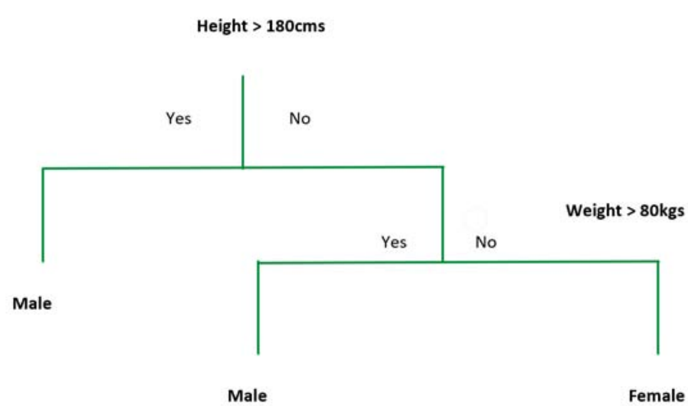

Figure 3: Decision Tree Classifier

The critical point is to use a decision tree to partition the data into cluster regions and empty regions. Initially, load the dataset into the Azure ML Studio, and after the data preprocessing, the model is trained using the two-class boosted decision tree, and then the scores are obtained.

With the use of this classifier, we have achieved an accuracy of 99.5% on the MNIST dataset.

d) Neural Networks

The usage of Neural Networks is found more in pattern recognition and image processing systems. They are multi-layer networks of neurons with non-linear mapping structures. For a set of inputs and a set of the target values, predictions made should match those target values as close as possible. A simple model consists of a connection, which transforms input to output and a neuron that includes a bias term and activation function. A positive weight means an excitatory connection, while negative values mean inhibitory connections. All inputs are transformed and then summed. This activity refers to as a linear combination. Subsequently, an activation function controls the amplitude of the output.

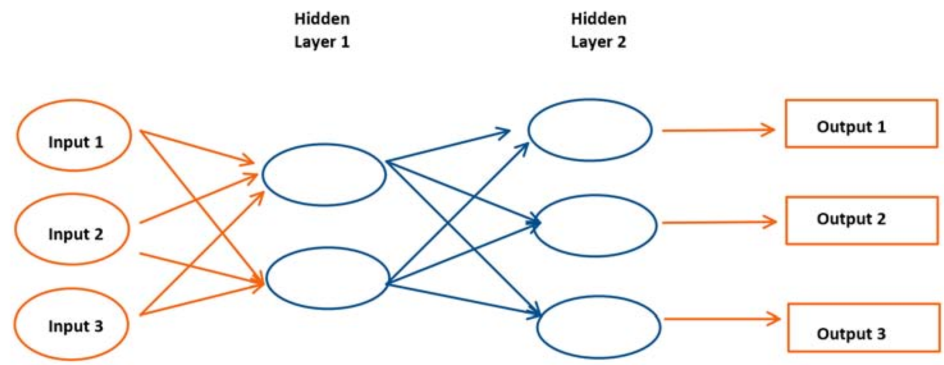

Figure 4: Neural Networks

The complexity of a model increases as the number of hidden layers increases. And so the prediction capability of the model for better performance also increases.

Here we initially load the MNIST dataset into the Azure ML Studio, and then the model is trained using the two-class Neural Networks. Using this, we achieved an accuracy of 99.8% on the MNIST dataset.

III. Experimental Tools

Azure Machine Learning Studio is a collaborative, drag, and drop tool developed by Microsoft Corporation to build, test, and then to deploy predictive analytics solutions of our data. Azure Machine Learning Studio publishes models also as web services that can easily be consumed by custom applications or tools such as Excel.

It is where everything like data science, predictive analytics, our data, and all our cloud resources meet. It is a robust and easy to use platform for deploying several machine learning models. Developing a model using this studio is like an iterative process. As we modify the various functions and their parameters, our results converge until we are satisfied that we have a trained and capable model.

It provides an interactive environment where everything is drag and drops supported to build and iterate on a predictive analysis model quickly. By connecting the required components such as datasets, algorithms, and specific analysis models (score model, train model), we can form an experiment. When the training completes, we can publish it as a web service so that others can access it. The Azure ML Studio allows us to experiment on any kind of dataset to construct a predictive analysis model for any system.

IV. Results and Discussion

The scores obtained can be illustrated using the below table

Type of Algorithm	Support Vector M	Decision Tree	Neural networks
Accuracy	91.0%	99.5%	99.8%
F1 Score	95.2%	99.7%	99.9%
Precision	92.4%	99.6%	99.9%
Recall	98.1%	99.9%	99.9%

Figure 5: Accuracy, F1 Score, Precision and Recall for SVM, Decision Tree and Neural Networks

As can be seen from the above table, Neural Networks has an accuracy of 99.8%, followed by Decision Trees with 99.5% and the last Support vector Machines with 91%.

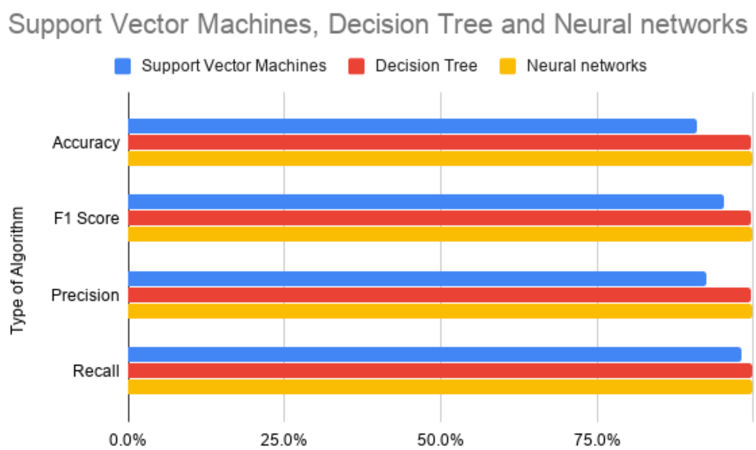

Figure 6: Graph for comparison of algorithms

When we see the other scores rather than accuracy, the highest F1 score is 99.9% for Neural Networks, and the lowest is 95.2% for Support Vector Machines, and the other Decision Tree has 99.7%, which is almost near to the value of Neural Networks.

Similarly, the highest Precision value is for Neural Networks with 99.9%, followed by Decision Trees with 99.6% and the other Support vector machines with 92.4%. Recall values for Neural Networks, Decision Trees, and Support Vector Machines are 99.9%, 99.9%, and 98.1%, respectively. Here the recall values for both Neural Networks and Decision Trees are the same. But when it comes to the overall score, such as Accuracy, F1 Score, Precision, and Recall values, the Neural Networks has scored best when compared to Decision Trees and Support Vector Machines.

V. Conclusion

In this paper, the performances of various algorithms like Support Vector Machines, Decision Trees and Neural Networks have been weighed and analyzed to reveal the best classifier for adequate recognition of handwritten digits using Microsoft Azure Machine Learning Studio. In any recognition process, the important thing is to preprocess the data and then adequately train the model using all necessary measures. Using the Azure Machine Learning Studio, we can do all the processing within less time.

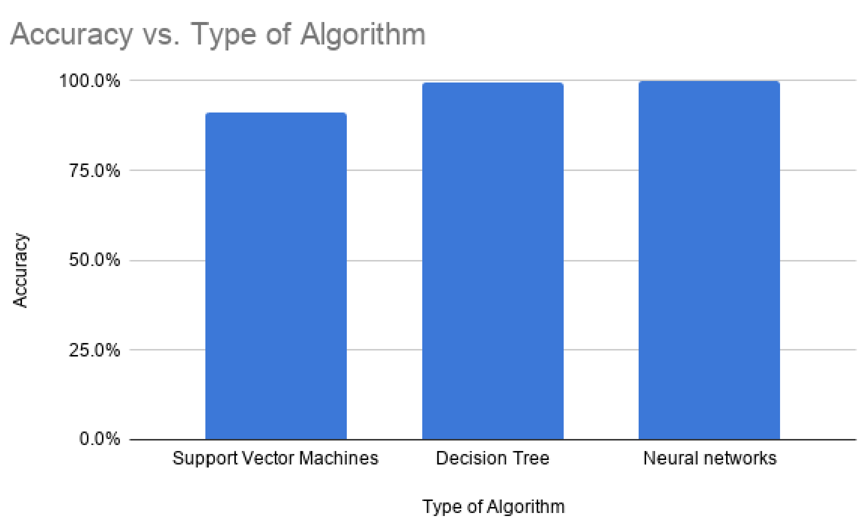

Figure 7: Accuracy vs. type of algorithm

The overall highest accuracy, 99.8%, is achieved by Neural Networks in the recognition process. This paper is an attempt to analyze different models for the recognition process to unveil the best classifier. Therefore, we can conclude that Neural Networks give better performance for handwritten digit recognition.

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Activation Function: Key to Cloning from Human Learning to Deep Learning

By Pranit Gopaldas Shah & Hiral Pranit Shah
Parul Institute of Engineering and Technology

Abstract- Maneuvering a steady on-road obstacle at high speed involves taking multiple decisions in split seconds. An inaccurate decision may result in crash. One of the key decision that needs to be taken is can the on-road steady obstacle be surpassed. The model learns to clone the drivers behavior of maneuvering a non-surpass-able obstacle and pass through a surpass-able obstacle. No data with labels of "surpass-able" and "non-surpass-able" was provided during training. We have development an array of test cases to verify the robustness of CNN models used in autonomous driving. Experimenting between activation functions and dropouts the model achieves an accuracy of 87.33% and run time of 4478 seconds with input of only 4881 images (training + testing). The model is trained for limited on-road steady obstacles. This paper provides a unique method to verify the robustness of CNN models for obstacle mitigation in autonomous vehicles.

Keywords: BC, end-to-end learning, saliency map, computer vision, behavioral cloning, autonomous vehicles, self-driving, obstacle mitigation.

GJCST-D Classification: I.2.6

ACTIVATIONFUNCTIONKEYTOCLONINGFROMHUMANLEARNINGTODEEPLEARNING

Activation Function: Key to Cloning from Human Learning to Deep Learning

Pranit Gopaldas Shah [α] & Hiral Pranit Shah [σ]

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Keywords: BC, end-to-end learning, saliency map, computer vision, behavioral cloning, autonomous vehicles, self-driving, obstacle mitigation.

I. Introduction

Affordability of powerful computational hardware and advances in deep learning techniques has made vision-based autonomous driving an active research focus within the transport industry. There are considerable drawbacks in the techniques to overcome, even though the research worldwide has already taken giant leap. Foremost downside is the inability to explicitly model each possible scenario. Driving needs responding to a large variety of complex environmental conditions and agent behaviors.

End-to-end method and perception-driven method are the two popular vision-based paradigms for self-driving cars. A perception-based method lacks self-learning ability and all features including task plans are manually hand crafted. This is the major disadvantage of perception-based method.

End-to-end Behavior cloning (Off-policy imitation learning) provides an alternative to traditional modular approach by simultaneously learning both perception and control using deep network.

Maneuvering each and every steady on-road obstacle either surpass able or non-surpass-able is cost intensive. Again maneuvering a steady on-road obstacle at high speed involves taking multiple decisions in split seconds. An inaccurate decision may result in crash. One of the key decision that needs to be taken is can the steady on-road obstacle be surpassed.

Clearly, an autonomous driving vehicle successfully navigating through the streets should be able to follow the roadway as well as maneuver only in cases required. If the autonomous vehicle can surpass a steady on-road obstacle without being unstable it must do so. Therefore, we here in propose an improved convolution neural network model. Overall, this research work makes the following contributions:

- Provides evaluation method for popular learning models by defining test cases to mitigate an on-road obstacle.
- Identify, evaluate and validate the configuration producing optimum results by performing combination of activation function and dropout.
- Improve prediction accuracy by validating statistical data with visual saliency map.

The paper has been organized as follows: Section 2 gives an overview of related work done in past and present. Section 3 describes the methodology used. Section 4 Experimental Setup, Results and Discussion. Finally, Section 5 concludes this paper.

II. Related Work

Perception-driven method ad End-to-end method are the two popular vision-based paradigms for self-driving cars. Both the perception and end-to-end methods have been reviewed extensive through literature study and presented here. However, the key aspect of autonomous driving is the problem of object detection itself. Hence in the later part of this section we review our study on object detection in the context of Deep Learning.

a) Perception-driven Learning Methods

Traditional Perception based method has made remarkable achievements, in past decades, in the field of self-driving cars. Several methods of detections have been proposed to generate a description of the local environment. Depending on the technique used current detection research can be broadly classified as shown in Figure 1 below.

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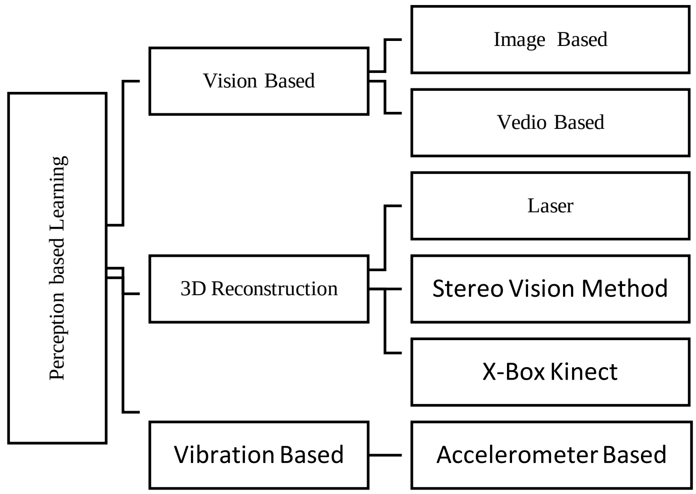


Fig. 1: Perception-driven learning

i. *Vision Based Detection*

Object location through enclosing boxes has been adopted by researchers as a part of object detection task. This bounding box can be anything from a steady road signs, traffic signs, moving cars, moving bicycles, etc. The model is trained with labeled data of objects. The key factor in case of self-driving car is an ability to identify if there is an obstacle and at what distance. It is immaterial to have the exact location of the bounding box.

Kwang Eun An [10] used Deep Convolutional Neural Network (DCNN) for image classification into obstacle/pothole or non-pothole. The method compared Inception_v4, Inception_ResNet_v2, ResNet_v2_152 and MobileNet_v1 for comparison between color and grayscale images. This method is limited in its efficiency in processing single frame of image.

Canny edge detection or Hough transformation area is implemented to locate lane position through many lane detection methods. There are no specific geometric restrictions required to identify uneven lane boundaries in these methods.

ii. *3D Reconstruction*

There are three major approaches for 3D reconstruction of obstacle/pothole each with its own drawback.

1. Chang et al. [19] used a Grid based processing technique. Here a surface receives laser incidents and digitally implements the bounced back pulse to generate a precise. The output was accurate, however this was expensive. Li et al.[20] used infrared laser line projectors, a digital camera and a multi-view coplanar scheme for calibrating the lasers. The method plotted more feature points in the cameras point of view and was much more cost effective.
2. Wang [21] used a series of cameras. This method generated a 3D surface model through a series of 2D images captured. High computation requirement was key backdrop.
3. Xbox Kinect sensor was used by Joubert et al.[22] and Moazzam et al.[23]. The method could not minimize the error and power for computing, even though equipment price was minimized.

iii. *Vibration based detection*

Umang Bhatt [26] combined accelerometer, gyroscope, location and speed data to classify road condition and detect potholes/obstacles. SVM with radial basic function (RBF) kernel was used for road condition classification.SVM and gradient boost were used for pothole/non-pothole classification. Failure attributed includes inability to accurately classify between good and bad road due to insufficient data for all road types. The key backdrop was inability to distinguish between a bump, a manhole or a pothole.

One key takeaway from all the above work done in perception based learning provides proactive data to the driver regarding the obstacle. These methods do not provide any method for routing through obstacle. Again, there is not classification if an obstacle can be surpassed or not.

b) End-to-end Learning Methods

Pomerleau [9] pioneered end-to-end training of neural network to steer a car. In 1989 Pomerleau built the Autonomous Land Vehicle in a Neural Network (ALVINN) system.

In the scenario of autonomous driving one of the key requirement is an ability to identify salient objects.

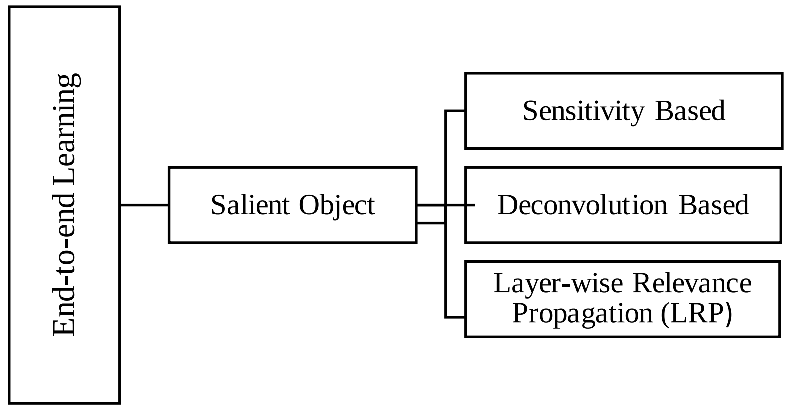


Fig. 2: End-to-end Learning

i. *Sensitivity Based*

After 25 years of advances in data and computational power DAVE-2 in [3] demonstrated the potential of end-to-end learning. A CNN based model introducing PilotNet Network Architecture designed by NVIDIA. The key differentiator for this architecture was its ability to identify salient objects without the need for hand-coded rules and instead learn by observing. However Dave's PilotNet model admits that the convolutional layers were chosen empirically and hence the performance was not sufficiently reliable to provide a full alternative to more modular approaches to off-road driving.

ii. *Deconvolution Based*

Matthew [28] presented a method for mid and high-level feature learning like corners, junctions and object parts. Mattew [28] resolves the two fundamental problems found in image descriptors like SIFT, HOG or edge gradient calculators followed by some histogram or pooling operation. First being invariance to orientation and scale. Secondly a CNN models inefficiency in training each model with respect to input. Visualization available is for one activation per layer.

iii. *Layer-wise Relevance Propagation*

Alexander Binder [29] implemented Layer-wise relevance propagation to compute scores for image pixels and image regions denoting the impact of the particular image region on the prediction of the classifier for one particular test image. Alexander Binder [29] demonstrated controlling the noisiness of the heatmap, however an optimal trade between numerical stability and sparsity/meaningfulness of the heatmap was kept as item for future work.

Salient object based methods does identify the key features that impact the steering angles. However these methods have not been explicitly developed/tested for identifying if an obstacle can be surpassed or not.

To overcome the above mentioned limitations, we propose to perform extensive training and testing for a neural network to clone an obstacle mitigation policy. Even though there is a great deal of work and literature on the task of steering angle prediction, our goal is not to propose yet another method for prediction, but rather provide a different perspective on on-road steady obstacles mitigation model. A model to not only detect an on-road steady obstacle but also to predict the obstacle can be surpassed to avoid unnecessary maneuvering.

III. Methodology

This section provides the details on CNN models used for validation and steps performed on data for accurate prediction.

a) Preprocessing

Network Model continuously predicts the steering angle to clear all test cases with an input of raw pixels incorporating attention in an end-to-end manner. It's important that our experiments and results are independent of car geometry, hence we represent steering command as inverse turning radius r_t^{-1} (r is turning radius at time stamp t). We use inverse to prevent numerical instability, singularity, and smooth transitions through zero from left turns to right turns. The relation between steering angle θ_t and inverse turning radius can be given as

$$\theta_t = f_{Steers}(u_t) = u_t d_w K_s (1 + K_{slip} v_t^2 \quad . \qquad (1)$$

Where θ_t in degree and v_t (m/s) is a steering angle and velocity at time t, respectively. K_s, K_{slip} and d_w are vehicle-specific parameters. K_s is steering ratio between the turn of the steering and the turn of the wheels. K_{slip} represents the relative motion between the front and rear wheels.

b) Data Bias Removal

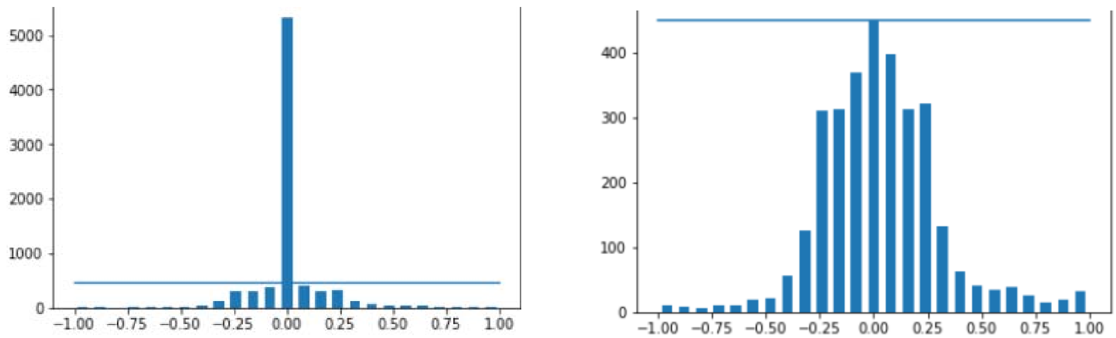


Fig. 3: Left: Data with 5000+ images having '0' steering Right: Non-biased data with sample reduced to 400+ per bin to have a uniformly distributed steering.

The general tendency of every driver is to drive as steady as possible without lot of maneuvering. However in case of behavioral cloning if the driver drives steady during training then all the model will learn is to maintain a zero steering angle. Such a training would generate results bias to zero output. In order to avoid output bias towards a –ve/+ve steering angle driving the training is done for complete track in clockwise and then anticlockwise direction over track. In fact additional recovery training tracks are also done where the car is take off the center lane and then recovered to back. The data bias is removed by trimming samples per bin as shown in Figure 3.

c) Encoder model: Convolution to clone obstacle mitigation behavior

Convolutional Neural Networks (CNN) are adaptations of multi-layer perceptron and are biologically-inspired. In context of self-driving cars, CNNs are able to learn the entire task of lane and road following without manual decomposition into road or lane marking detection, semantic abstraction, path planning and control. The network learns to detect the outline of a road without the need of explicit labels during training. The following research implements variants of the CNN architecture established by NVIDIA for self-driving cars, the PilotNet[3] and DroNet[32].

IV. Experimental Setup, Results and Discussion

This section presents the basic description of experimental setup for data collection, training and testing. We elaborate further on the configuration of hardware and software used. Later we enlist the training cases and test cases for model evaluation and the evaluation criteria. Eventually we enlist the results from our experiment.

Model training and testing is performed in a virtual environment Unity 2017 in the interest of research cost. Other software tools include Visual studio for Unity, Atom, Jupyter Notebook and Anaconda. GitHub for online code repository and Google Colab platform for online code execution. Programming is done in c# and python. Multiple packages including OpenCV, numpy, matplotlib, Keras (model, optimizer, layers), pandas and sklearn are used. Hardware includes my laptop with Intel i5 processor@1.27GHz, 8GB RAM and Intel HD Graphics family with 2GB RAM.

Virtual 3D models of non-surpass-able and surpass-able obstacles are created in unity as shown in Figure 4 below.

Fig. 4: Left: Car model alongside non-surpass-able obstacle.
Right: Car model alongside surpass-able obstacle.

3 Cameras are mounted in front of the model car to capture left, center and right images.

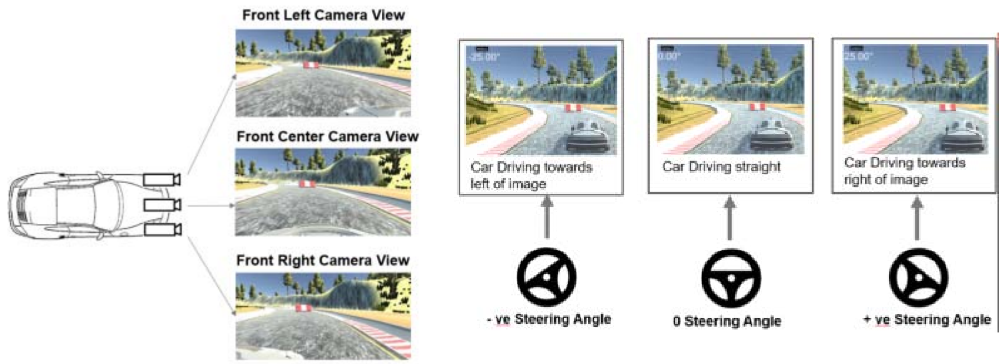


Fig. 5: Left: Front camera to capture images. Right: Steering angle and car driving direction

a) Training and Test cases

Our network model is trained on only 4 cases and is expected to pass 10 test cases based on training. These training cases are to train the network to clone driver's behavior while driving through both non-surpass-able and surpass-able obstacles. Training cases are as listed in Figure 6 below

Fig. 6: Top Left: Training Case-TRC01: The track is empty without any obstacles. The model is trained on this empty track. Top Right: TRC02: The track has a non-surpass-able obstacle on the right of simulated car. The model it trained to maneuver through the obstacle. Bottom Left: TRC03: The track has a surpass-able obstacle in the centre of track. The model it trained to pass through the obstacle. Bottom Right: TRC04: The track has a non-surpass-able obstacle on the left of simulated car. The model it trained to maneuver through the obstacle.

Test case are to verify the robustness of networks ability to learning to maneuver through varied configurations of obstacles. Test cases are as listed in Figure 7 below

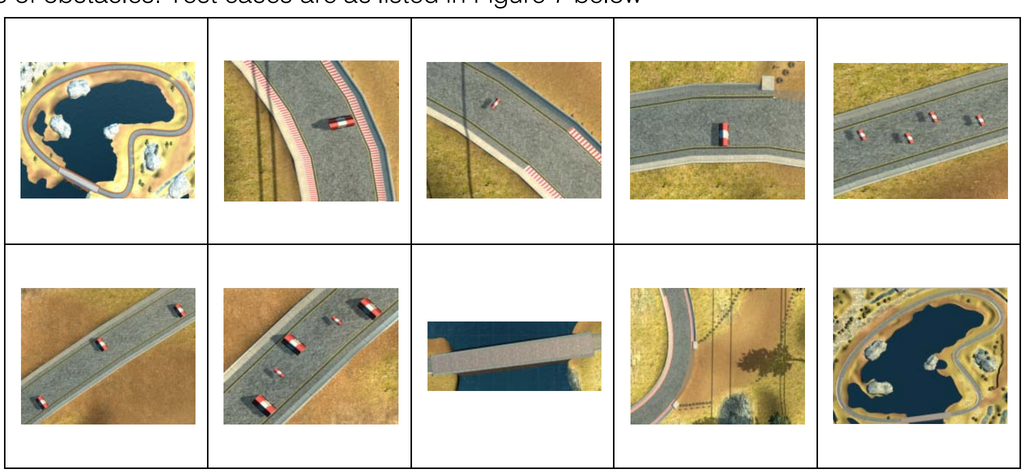


Fig. 7: Starting from Top Left 1st: Test Case-TC01: The track is empty without any obstacles. The model is supposed to drive through the entire track to call it has passes this test case. 2nd:TC02: The track has a non-surpass-able obstacle on the right of simulated car. The model is supposed to maneuver through the obstacle and retain a steady drive to call it has passes this test case. 3rd:TC03: The track has a surpass-able obstacle. The model is supposed to pass through the obstacle with minimum vehicle instability and maintain a steady drive to call it has passes this test case. 4th:TC04: The track has a non-surpass-able obstacle on the left of simulated car. The model is supposed to maneuver through the obstacle and retain a steady drive to call it has passes this test case. 5th:TC05: The track has

an array of multiple surpass-able obstacles. The model is supposed to pass through the obstacles with minimum vehicle instability and maintain a steady drive to call it has passes this test case. Starting Bottom Left 1st:TC06: The model is supposed to maneuver through an array of left and right non-surpass-able obstacles and retain a steady drive to call it has passes this test case. 2nd:TC07: The track has an array of both multiple left and right non-surpass-able and surpass-able obstacles. The model is supposed to pass through surpass-able obstacles and maneuver through the obstacle to call it pass. 3rd:TC08: In this case an unknown bridge, which has a different track, has to be crossed to call this case passes. 4th:TC09: In this case an unknown unpaved path has to be avoided by the model. The model has not been trained for this behavior. 5th:TC10: In model is expected to clear all the obstacles, pass through unknown bridge and unpaved path all in a single stretch.

b) Model Accuracy Calculation

Each model is trained in 4 cases and tested for 10 cases. The model accuracy is defined as follows

Number of test cases model passed: P
Score for a test cases in which model self-recovered: SR
Model Accuracy: MA
Total test cases: T

Number of obstacles correctly maneuvered or surpassed: SR_o
Total maneuverable and surpass-able obstacles: T_o

$$MA = ((P+SR)/T)/100 \quad (2)$$

$$SR = SR_o/T_o \quad (3)$$

c) Dataset Characteristics

Right size of data set is the key to accurate predictable solution. Initial training was started with 30,000 images, however due to resource constraints, we reached an optimal data size of 9970 images that produced reliable results. Zero steering bias images are removed from input images. Data augmentation is performed to increase the data size and accuracy. The final data set is classified using test_train_split functionality in sklearn library. All models are trained using 3904 samples and validated with 977 samples as shown in Table 1 below

Table 1: Data Characteristics for different models

Model	Input Data	Input Data after removing bias		Trainable parameters
		Training Samples	Validation Samples	
DroNet	9930	3904	977	311777
PilotNet	9930	3904	977	252219

This paper represents two deep learning models tested with a combination of activation function and dropout on same database. Table 2 below shows model used, code assigned for ease, configurations used and val_loss achieved. Table 2 below clearly indicated that model P1, PilotNet with elu and No Dropout, achieved the best val_loss of 0.0250.

Table 2: Configuration and val_loss comparison for different models

Model	Code	Configuration	val_loss
DroNet	D1	Dropout + Relu	0.0295
	D2	No Dropout + elu	0.0731
PilotNet	P1	No Dropout+ elu	0.0250
	P2	Dropout + elu	0.0454
	P3	No Dropout + Relu	0.0276
	P4	No Dropout + Sigmoid	0.0934
	P5	No Dropout + Softmax	0.0863

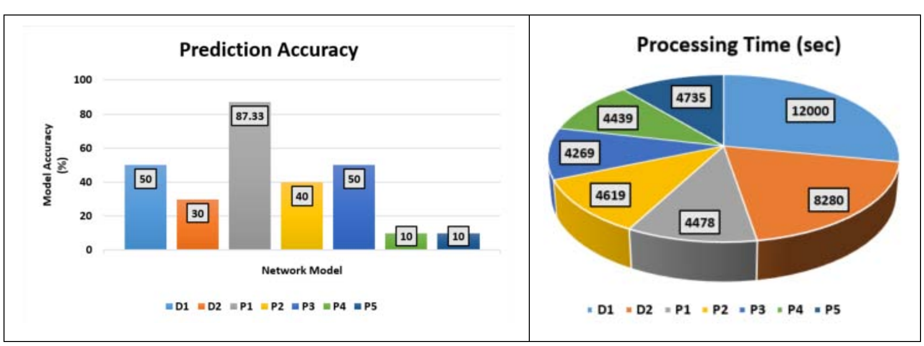
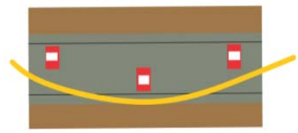
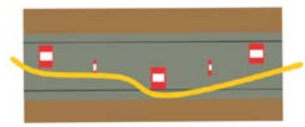


Fig. 8: Left: Prediction Accuracy. Right: Processing time

Figure 8 Left and right shows the prediction accuracy and model running time when using different configurations on two learning models using same dataset. Model P1, PilotNet with elu and no dropout, achieves highest prediction accuracy of 87.33%. Model P4 and P5 has the least accuracy of 10%. The highest accuracy achieved by both DroNet model D1 and D2 are 50% and 30% respectively with heavy processing time of 12000s and 8280s respectively. Model P1 achieves the highest accuracy consuming the processing time of 4478 seconds.

Model P1, PilotNet with elu and no-dropout, performed a self-recovery in test cases 6 and 7 as listed in Table 5 below

Table 3: Path Followed and individual test case accuracy for Model P1

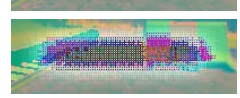
	Test Case 6	Test Case 7
Path Followed		
Description	The model maneuvers 1st, skips 2nd by going off the track and recovers back post skipping 3rd obstacle.	The model maneuvers 1st, pass through 2nd, skips 3rd by going off the track and recovers back post skipping 4th and 5th obstacle.
SR calculation	$SR_o = 1$; $T_o = 3$; $SR_6 = 0.33$	$SR_o = 2$; $T_o = 5$; $SR_7 = 0.4$

Overall Model Accuracy for model P1 is calculated as below

$$MA_{P1} = ((P_{P1}+SR_{P1})/ T)/100$$
$$= ((8 + (0.33+0.4))/10)/100$$
$$= 87.33\%$$

Saliency Map is generated to co-related and validate the statistical results obtained. PilotNet models are taken for saliency mapping for identification of left non-surpass-able, surpass-able and right non-surpass-able obstacles. As depicted in table below model P4 and P5 has failed completely which co-relates with only prediction accuracy of 10%. Model P2 has wrongly detected the saliency for surpass-able obstacle and has not detected the lane boundaries at all. Model P1 perform better than P3 with better saliency map both for obstacles and lanes as depicted in table 6

Table 4: Saliency Map for PilotNet based Models

Model	Non-surpass-able left(alpha=0.004)	Surpass-able (alpha=0.003)	Non-surpass-able right(alpha=0.0045)
P2			
P3			
P1			
P4			
P5			

V. Conclusion

In this paper, we presented and compared two most popular autonomous driving methods including DroNet and PilotNet. We experimented with combinations of different activation functions with-without dropout. The experiment has demonstrated the PilotNet model P1 is able to learn the entire task of non-surpass-able obstacle maneuvering and passing through a surpass-able obstacle. The experiment has provided us with a clear insight into effect of each activation function and dropout on steering angle prediction. PilotNet model P1 has the highest prediction accuracy, lowest val_loss and reasonable processing time with best visual saliency map for obstacles with current dataset. The experiment has clearly concluded that PilotNet, with activation function elu without dropout, outperforms all other models and configurations.

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The system learned to mitigate through an obstacle without the need of explicit surpass-able and non-surpass-able obstacle labeling during training.

In the future work, we would like to optimize PilotNet to improve prediction accuracy. We would also like to introduce a custom-Net that would outperform all current autonomous driving methods.

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Artificial Satisfaction - The Brother of Artificial Intelligence

By Satish Gajawada & Hassan M. H. Mustafa
Indian Institute of Technology Roorkee

Abstract- John McCarthy (September 4, 1927 – October 24, 2011) was an American computer scientist and cognitive scientist. The term "Artificial Intelligence" was coined by him (Wikipedia, 2020). Satish Gajawada (March 12, 1988 – Present) is an Indian Independent Inventor and Scientist. He coined the term "Artificial Satisfaction" in this article (Gajawada, S., and Hassan Mustafa, 2019a). A new field titled "Artificial Satisfaction" is introduced in this article. "Artificial Satisfaction" will be referred to as "The Brother of Artificial Intelligence" after the publication of this article. A new algorithm titled "Artificial Satisfaction Algorithm (ASA)" is designed and implemented in this work. For the sake of simplicity, Particle Swarm Optimization (PSO) Algorithm is modified with Artificial Satisfaction Concepts to create the "Artificial Satisfaction Algorithm (ASA)." PSO and ASA algorithms are applied on five benchmark functions. A comparision is made between the results obtained. The focus of this paper is more on defining and introducing "Artificial Satisfaction Field" to the rest of the world rather than on implementing complex algorithms from scratch.

Keywords: *intelligence, artificial intelligence, satisfaction, artificial satisfaction, new invention, new creation, new area of research, computer science, algorithm, nature inspired computing, bio-inspired computing, john mccarthy, lotfi zadeh.*

GJCST-D Classification: *I.2.m*

ARTIFICIALSATISFACTIONTHEBROTHEROFARTIFICIALINTELLIGENCE

Strictly as per the compliance and regulations of:

Artificial Satisfaction - The Brother of Artificial Intelligence

Satish Gajawada [α] & Hassan M. H. Mustafa [σ]

Abstract- John McCarthy (September 4, 1927 – October 24, 2011) was an American computer scientist and cognitive scientist. The term "Artificial Intelligence" was coined by him (Wikipedia, 2020). Satish Gajawada (March 12, 1988 – Present) is an Indian Independent Inventor and Scientist. He coined the term "Artificial Satisfaction" in this article (Gajawada, S., and Hassan Mustafa, 2019a). A new field titled "Artificial Satisfaction" is introduced in this article. "Artificial Satisfaction" will be referred to as "The Brother of Artificial Intelligence" after the publication of this article. A new algorithm titled "Artificial Satisfaction Algorithm (ASA)" is designed and implemented in this work. For the sake of simplicity, Particle Swarm Optimization (PSO) Algorithm is modified with Artificial Satisfaction Concepts to create the "Artificial Satisfaction Algorithm (ASA)." PSO and ASA algorithms are applied on five benchmark functions. A comparision is made between the results obtained. The focus of this paper is more on defining and introducing "Artificial Satisfaction Field" to the rest of the world rather than on implementing complex algorithms from scratch.

Keywords: intelligence, artificial intelligence, satisfaction, artificial satisfaction, new invention, new creation, new area of research, computer science, algorithm, nature inspired computing, bio-inspired computing, john mccarthy, lotfi zadeh.

I. Definition of Artificial Satisfaction Field

According to the Cambridge English Dictionary, "Satisfaction" is a pleasant feeling that you get when you receive something you wanted or when you have done something you wanted to do (Cambridge, 2020). Artificial Satisfaction (AS) field algorithms are designed by taking "Satisfaction" as inspiration. Research Scientists develop AS field algorithms by imitating "Satisfaction." The simulation of satisfaction of humans to design and develop algorithms will be a part of the "Artificial Human Satisfaction" field. Artificial Satisfaction Field algorithms are created by mimicking the "Satisfaction" of all living beings. Hence "Artificial Human Satisfaction" is a sub-field of the "Artificial Satisfaction" field. Unlike Artificial Intelligence, the focus of this work is on the "Artificial Satisfaction" where consideration is given to the "Satisfaction" of all living beings and not just the satisfaction of humans.

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e-mail: satish.gajawada.iit@gmail.com
Author σ: Banha University, Egypt. Grand Father of Artificial Human Optimization.

II. Billions and Trillions of Opportunities in the new Artificial Satisfaction Field

There is an Excellent Future for Artificial Satisfaction (AS) Field Research Scientists. There are billions and trillions of opportunities in the Artificial Satisfaction field. Some of them are shown below:

1. International Institute of Artificial Satisfaction, Hyderabad, INDIA
2. Indian Institute of Technology Roorkee Artificial Satisfaction Labs, IIT Roorkee
3. Foundation of Artificial Satisfaction, New York, USA.
4. IEEE Artificial Satisfaction Society
5. ELSEVIER journals in Artificial Satisfaction
6. Applied Artificial Satisfaction – A New Subject
7. Advanced Artificial Satisfaction – A New Course
8. Invited Speech on "Artificial Satisfaction" in world-class Artificial Intelligence Conferences
9. A Special Issue on "Artificial Satisfaction" in a Springer published Journal
10. A Seminar on "Recent Advances in Artificial Satisfaction" at Technical Festivals in colleges
11. International Association of Artificial Satisfaction
12. Transactions on Artificial Satisfaction
13. International Journal of Artificial Satisfaction
14. International Conference on Artificial Satisfaction
15. www.ArtificialSatisfaction.com
16. B.Tech in Artificial Satisfaction
17. M.Tech in Artificial Satisfaction
18. Ph.D. in Artificial Satisfaction
19. Post Doc in Artificial Satisfaction
20. IBM the Artificial Satisfaction Labs
21. To become "Father of Artificial Satisfaction" field.

III. Artificial Intelligence

The following is the definition of Artificial Intelligence according to Investopedia shown in double quotes as it is:

"Artificial intelligence (AI) refers to the simulation of human intelligence in machines that are programmed to think like humans and mimic their actions. The term may also be applied to any machine that exhibits traits associated with a human mind such as learning and problem-solving" (Investopedia, 2020).

IV. Literature Review

There are lakhs of researchers who are working in Artificial Intelligence. But there is no single researcher who worked in Artificial Satisfaction field to date. This work shows the World's First Artificial Satisfaction method. For the sake of completeness, articles (Al-Awami, A.T.; Zerguine, A.; Cheded, L.; Zidouri, A.; Saif, W., 2011), (Al-Shaikhi, A.A., Khan, A.H., Al-Awami, A.T. et al, 2019), (Anita, Yadav A., Kumar N., 2020), (C. Ciliberto, M. Herbster, A.D. Ialongo, M. Pontil, A. Rocchetto, S. Severini, L. Wossnig, 2018), (Deep, Kusum; Mebrahtu, Hadush, 2011), (Dileep, M. V., & Kamath, S., 2015), (Gajawada, S., 2016), (Gajawada, S., and Hassan Mustafa, 2019a), (Gajawada, S., & Hassan Mustafa., 2019b), (Gajawada, S., & Hassan Mustafa., 2020), (H Singh, MM Gupta, T Meitzler, ZG Hou, KK Garg, AMG Solo, LA Zadeh, 2013), (Imma Ribas, Ramon Companys, Xavier Tort-Martorell, 2015), (Kumar, S., Durga Toshniwal, 2016), (Martínek, J., Lenc, L. & Král, P, 2020), (M. Mitchell, 1998), (P Kumar, A Mittal, P Kumar, 2006), (S Chopra, R Mitra, V Kumar, 2007), (S Das, A Abraham, UK Chakraborty, A Konar, 2009), (S Dey, S Bhattacharyya, U Maulik, 2014), (Whitley, D, 1994), (W. Hong, K. Tang, A. Zhou, H. Ishibuchi, X. Yao, 2018) and (Zhang, L., Pang, Y., Su, Y. et al, 2008) show research articles under Artificial Intelligence field.

V. The Artificial Satisfaction Algorithm

This section explains Artificial Satisfaction Algorithm (ASA). Figure 1 shows ASA. Line number 1 initializes all the particles. Second line sets iterations to zero. In lines 4 to 11, the local best of each particle and global best of all particles are updated. The random numbers generated and Satisfaction Probability are used to group particles into either "Satisfied Beings" or "UnSatisfied Beings". Satisfied Beings have the potential to move in search space because of their satisfaction. Hence in lines, 14 to 17 position and velocity of Satisfied Particle are updated. On the other hand, UnSatisfied Beings cannot move in the search space themselves because of their dissatisfaction. The random numbers generated and Help of Satisfied People Probability are used to classify UnSatisfied Beings into two groups. Either they will receive support from Satisfied Beings or not. Hence in lines 20 to 23, UnSatisfied Beings update position and velocity because they receive help from Satisfied Beings. As shown in line number 25, UnSatisfied Beings without receiving any help from Satisified Beings cannot move in search space. Line number 29 increments iterations variable by 1. The execution reaches back to line number 4 if the termination condition is false. The next iteration starts, and execution continues similar to the current iteration. If the termination condition is reached in line number 30, then execution stops, and the optimal value is returned.

```
All particles are initialized
generations (or iterations) = 0
do
    for each particle i do
        If ( fitness_x_particle < particle_x_best_fitness ) then
            particle_x_best  = input variable at fitness_x_particle
        end if
        if ( particle_x_best_fitness < global_best_all_particles_fitness ) then
            global_best_all_particles = input variable at particle_x_best_fitness
        end if
    end for
    for each particle i do
        if ( generate_random_number (0,1) < SatisfactionProbability ) then // Satisfied Being
            for each dimension d do
                velocity_i,d = weight*velocity_i,d +
                        Constant_1*generate_random_number(0,1)*(local_best_i,d – position_i,d)
                        + Constant_2*generate_random_number(0,1)*(global_best_d – position_i,d)
                position_i,d = position_,d + velocity_i,d
            end for
        else // UnSatisfied Being
            if ( random(0,1) < HelpOfSatisfiedPeopleProbability) then // UnSatisfied Being with Help
                for each dimension d do
                    velocity_i,d = weight*velocity_i,d +
                            Constant_1*generate_random_number(0,1)*(local_best_i,d – position_i,d)
                            + Constant_2*generate_random_number(0,1)*(global_best_d – position_i,d)
                    position_i,d = position_i,d + velocity_i,d
                end for
            else // Unsatisfied Being without help does nothing

            end if
        end if
    end for
    generations (iterations) = generations (iterations) + 1
while ( termination_condition not reached is true)
```

Figure 1: Artificial Satisfaction Algorithm (ASA)

VI. Results

The benchmark functions are taken from article (Gajawada, S., and Hassan Mustafa, 2019a). The ASA and PSO are applied on 5 benchmark functions shown in figure 2 to figure 6.

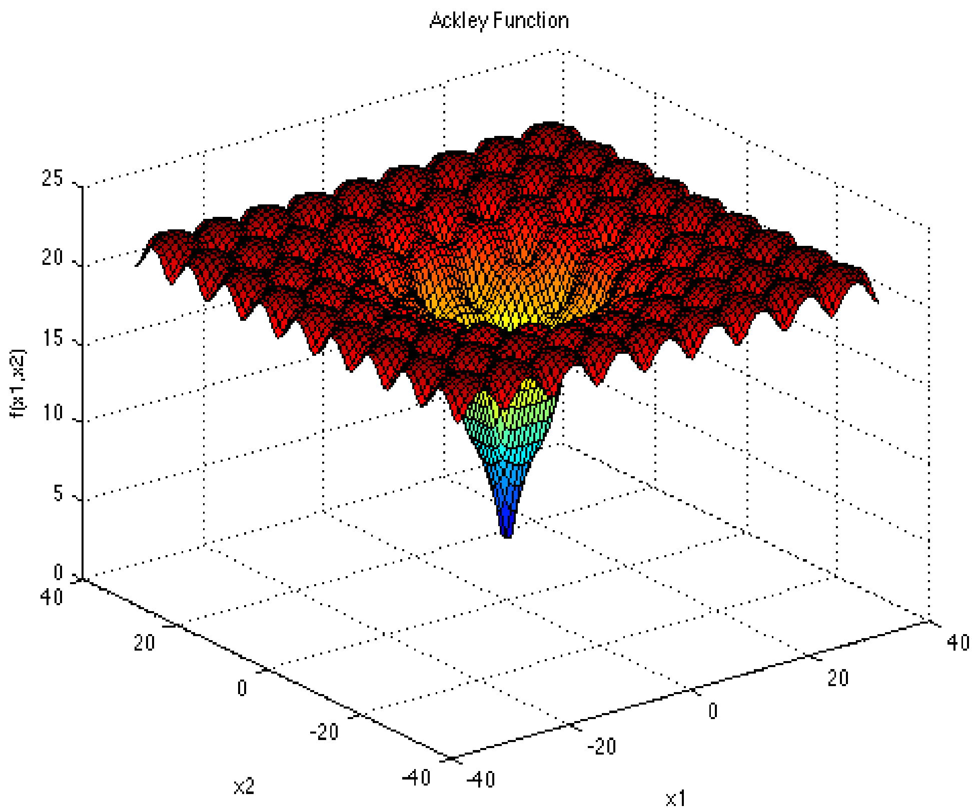

Figure 2: Ackley Function

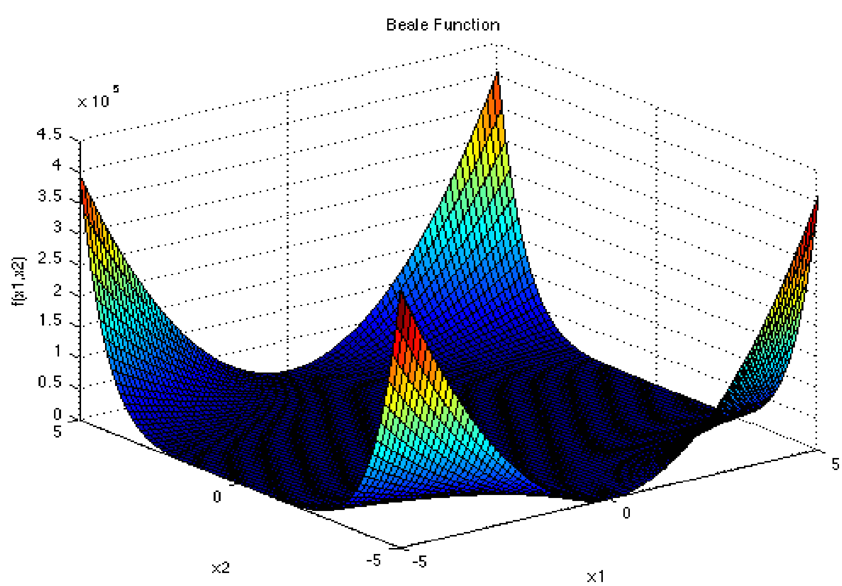

Figure 3: Beale Function

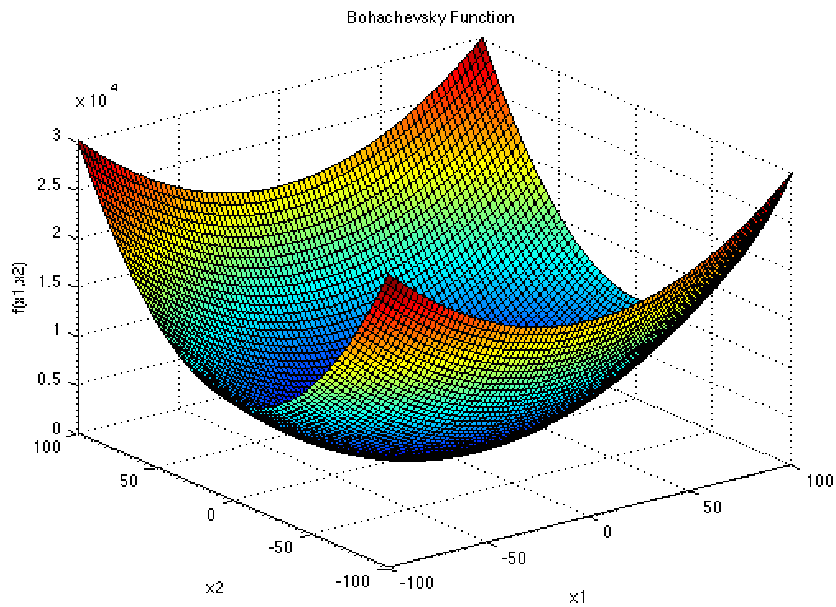

Figure 4: Bohachevsky Function

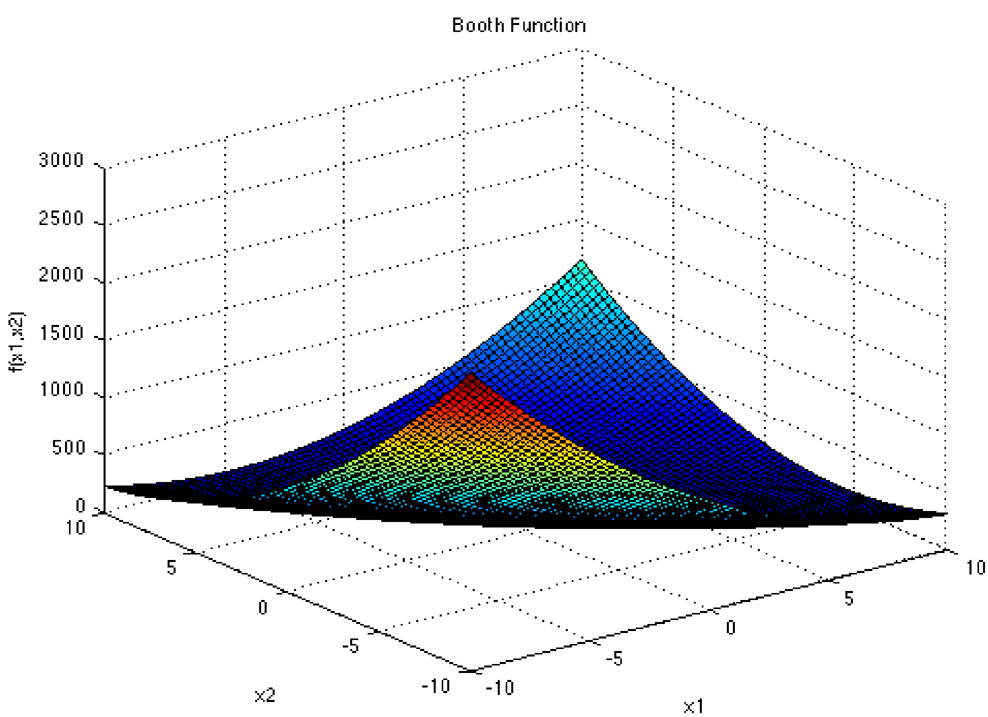

Figure 5: Booth Function

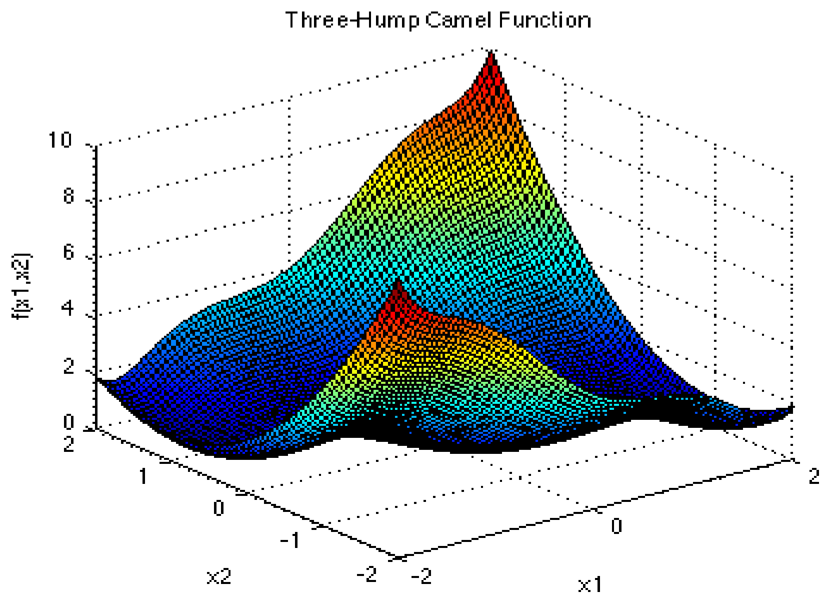

Figure 6: Three-Hump Camel Function

Table 1 shows the results obtained. Green represents performed well. Red represents not performed well. Blue represents performed between well and not well. From Table 1, we can see that all cells are green in color which means the PSO algorithm and developed ASA performed well on all benchmark functions.

Table 1: Obtained Result

Benchmark Function / Algorithm	Artificial Satisfaction Algorithm (ASA)	PSO Algorithm
Ackley Function		
Beale Function		
Bohachevsky Function		
Booth Function		
Three-Hump Camel Function		

VII. Conclusions

A new field titled "Artificial Satisfaction" is defined and introduced in this article. The World's First algorithm under the Artificial Satisfaction field is designed and developed in this article. Results show that proposed ASA and PSO algorithms performed well on all benchmark functions. There is a difference between three recently introduced new research fields titled "Artificial Human Optimization (AHO)" (Gajawada, S., 2016), "Artificial Soul Optimization (ASO)" (Gajawada, S., & Hassan Mustafa., 2019b), "Artificial God Optimization (AGO)" (Gajawada, S., & Hassan Mustafa, 2020) and "Artificial Satisfaction". AHO, ASO, and AGO are three new fields under Artificial Intelligence. But the "Artificial Satisfaction" field is a separate field like "Artificial Intelligence" and not a sub-field of Artificial Intelligence. There are billions and trillions of opportunities under the Artificial Satisfaction field. The FUTURE will be very bright for Artificial Satisfaction Field Research Scientists and Students.

Acknowledgments

Thanks to everyone (and everything) who directly or indirectly helped us to reach the stage where we are now today.

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Author's Profile:

1. *Scientific Excellence*
   a) Satish Gajawada's Research Project is featured by NASA Astrophysics Data System. Website address - {https://ui.adsabs.harvard.edu/abs/2019arXiv190312011G/abstract}
   b) His Research Project is indexed in AGRIS (maintained by the Food and Agriculture Organization of the United Nations (FAO)).

2. *Research Grants*
   a) One of his research projects "Missing Value ..." has been partially funded by a research grant received from IBM Corporation as part of the IBM Shared University Research Award (IBM SUR Award).
   b) Received invitation for a fully-funded Summer INTERNSHIP project in 2009 (at 21 years of age) from Telecom Sud Paris, Cedex, France.

3. *Contribution to Humanities and Social Sciences, Economics and Philanthropy*
   a) He is the Creator of "Smile Theory of Everything" published at the International Conference on History and Society Development, Thailand.
   b) He is a KindSpringer. He added 1767+ Kind Acts to the world. Currently have 13927+ Karmabucks. Given Away 285310+ Karmabucks. He got the award titled "Community Member of the Week" (3 times) out of one lakh plus Kind Springers. He got

awards like "Beautiful Spirit Award," "Kindness King," "Super Hero of Kindness," etc.

4. *Terms Coined under Artificial Intelligence*

a) He coined the terms "Artificial Human Optimization," "Artificial Soul Optimization," and "Artificial God Optimization,". These are three new branches founded by him under Artificial Intelligence.

5. *Outstanding Achievements*

a. World's First Research Scientist to propose new Fields under Artificial Intelligence through research articles.
b. Satish Gajawada is called “Father of Artificial Human Optimization Field” by few experts for his valuable contribution to the new field titled “Artificial Human Optimization (AHO).”
c. He received a SALUTE and APPRECIATION from the IEEE chair, Dr. Eng. Sattar B. Sadkhan for his numerous achievements within the field of science.
d. He got "5 out of 5" for "Contribution to Existing Knowledge" and "Evidence Supports Conclusion" for his article "Artificial God Optimization - A Creation" published at Computer and Information Science, Canada.
e. Published 25 research articles by the age of 30 years.
f. AI Today Science Magazine published his work.
g. He is the member of EST Singapore.
h. Search the phrase “father of Artificial Human Optimization” on "Google Search Engine" and it displays content related to him.
i. He is the member of ARIA conference which will be held at Switzerland in 2020.

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Artificial Intelligence Assisted Consumer Privacy and Electrical Energy Management

By Raziq Yaqub & Sadiq Ahmad
Alabama A & M University

Abstract- Smart metering infrastructure brings unique benefits for Utility Companies as well as consumers, however, massive consumer data collected and transmitted by the smart meters have raised consumers' privacy concerns. This paper presents a novel solution that is based on Artificial Intelligence Agent that continuously computes the gap between "Average Daily Demand" and "Instantaneous Demand" of a consumer, and allows the Battery Banks to discharge just enough to fill the gaps and eliminate kinks in the energy usage graph to mask the energy usage. This novel approach offers several benefits, such as, it conceals the utility usage patterns and thus ensures privacy, eliminates excessive discharging and charging of batteries that lifts operational constraints of the batteries, employs scheduling that renders utility bill reduction as an add-on.

Keywords: AI, smart metering, privacy, scheduling, virtual power bank, adjusted-average daily demand.

GJCST-D Classification: I.2.1

ARTIFICIALINTELLIGENCEASSISTEDCONSUMERPRIVACYANDELECTRICALENERGYMANAGEMENT

Strictly as per the compliance and regulations of:

Artificial Intelligence Assisted Consumer Privacy and Electrical Energy Management

Raziq Yaqub [α] & Sadiq Ahmad [σ]

Abstract- Smart metering infrastructure brings unique benefits for Utility Companies as well as consumers, however, massive consumer data collected and transmitted by the smart meters have raised consumers' privacy concerns. This paper presents a novel solution that is based on Artificial Intelligence Agent that continuously computes the gap between "Average Daily Demand" and "Instantaneous Demand" of a consumer, and allows the Battery Banks to discharge just enough to fill the gaps and eliminate kinks in the energy usage graph to mask the energy usage. This novel approach offers several benefits, such as, it conceals the utility usage patterns and thus ensures privacy, eliminates excessive discharging and charging of batteries that lifts operational constraints of the batteries, employs scheduling that renders utility bill reduction as an add-on.

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I. Introduction

Smart metering of electrical utilities is a promising technology. On the one hand, it enables consumers to manage the consumption efficiently, and on the other, the Utility Companies to manage the production competently [1]. Though the technology is beneficial for both, the consumers have a major privacy concern [2,3]. It is because the massive data that flows from Smart Meter at consumer premises to the Utility Company [4-6] corresponds to consumer's utility usage patterns and may reveal his privacy. For example, if the households are in the home or not, what times they are away; what appliances they use, and when, who has high-tag appliances, what times they watch TV, and even what TV channel they watch [7]. Another type of privacy invasion can be with users of Plug- in Electric Vehicles (EV) where the charging data can be used to identify travel routines [8]. The concern is even more serious for businesses, whose energy consumption patterns can disclose important business operation information to the competitors [9]. Thus there is a need for a system that could mask consumption patterns, to assure consumer privacy.

Several methods have been proposed in the literature to provide security and privacy to Smart Meter users. For example, reference [2] proposes a cryptography-based Time of Use protocols for preserving privacy. Though the encryption can provide data security, but not consumer privacy, as it encrypts the data, but cannot hide the energy consumption patterns. Reference [1] proposes to add noise of special threshold to the data signal that moves from the consumer end to the Utility Company. The major drawback of this system is that the amount of noise and the inter symbol interference (ISI), depending upon medium, may result in a total loss of signal, i.e. loss of useful data. Reference [10] uses a battery that sits in the middle of a consumer and the Utility Company. It draws energy from an Electric Utility Company at a constant rate and continuously feeds all the household loads at all times. Thus the battery masks all the real-time energy usage. Though the solution is promising, the drawback is that a battery always supplies the loads constantly. This requires a battery to be of quite a big capacity so that it could power a whole house at all times, which may be cost-prohibitive. The solution proposed in [11] is vague, as it does not show (a) how to calculate the capacity of each load for each residential consumer, (b) the solution mandates customization to each residential consumer as it requires to calculate the capacity of each load at each home. Further, just scheduling, without knowing the utility company's peak rates and load factor cannot provide cost-saving in the energy bills. Thus the claims made are unrealistic.

Though Smart metering infrastructure brings unique benefits for Utility Companies as well as consumers, massive consumer data collected and transmitted by the smart meters have raised consumers' privacy concerns. This paper presents a novel solution that employs Artificial Intelligence Techniques to continuously compute the gap between "Average Daily Demand" and "Instantaneous Demand" of a consumer, and thus allows the Battery Banks to discharge just enough to fill the gaps and eliminate kinks in the energy usage graph, and thus to masks the energy usage. The accuracy of computing the Adjusted-average Daily Demand, holds a critical value in this approach. The higher the accuracy of Adjusted-average Daily Demand, the lesser the need for charging/discharging of the Battery Banks. To accomplish this, an Artificial Intelligence-based agent plays a vital role.

The approach not only overcomes the above-noted shortcomings but also offers several benefits, such as, it conceals utility usage-patterns that ensures privacy, does not require higher capacity batteries and eliminates excessive charging/discharging of batteries that lifts the operational constraints of the batteries,

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employs scheduling that renders utility bill reduction as an add-on feature. Employs existing communication technologies such as e.g. 4G/5G, and Wi-Fi. In addition to the above-noted benefits, the proposed approach is economically as well technically viable as the installation of Battery Banks in residential, commercial, and industrial markets is becoming a norm due to the huge EV market, micro-grids, and home/community energy storage systems [12].

The rest of the paper is organized as follows. Section II presents the proposed solution, Section III presents simulation results, Section IV economic viability, and Section V concludes the work.

II. Description of Proposed Solution

We propose an Artificial Intelligence assisted consumer privacy and energy management system. The schematic design of the proposed Artificial Intelligence Agent (AI-Agent) that is the brain of the whole architecture, is shown in figure 1.

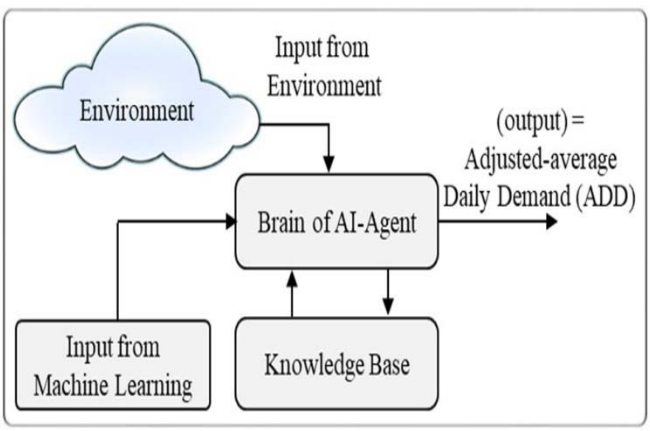

Figure 1: Design Schematic of AI-Agent

The AI-Agent is a mini-computer, designed to achieve an explicit goal of "Consumer Privacy" and "Energy Management". The brain of the AI-Agent receives critical information through the environment, machine learning algorithm, and its knowledge base. It processes this information and makes intelligent decisions after any given sequence of percepts, and provides output. The Structure of Intelligent Agents can be viewed as the "System Architecture" and the "System Program". The system architecture consists of the following entities that an agent executes on, and is shown in figure 2.

1. Energy-sources Tracker and Selector (ETS)
2. Battery Banks that may comprise of Dedicated Battery Banks, and Electric Vehicle (EV) Battery Banks
3. Task Completion Register (TCR)
4. Consumer's Smart Appliances (CSA)
5. Remote Applications Servers (RAS) that comprise of Utility Servers, and Weather Servers.

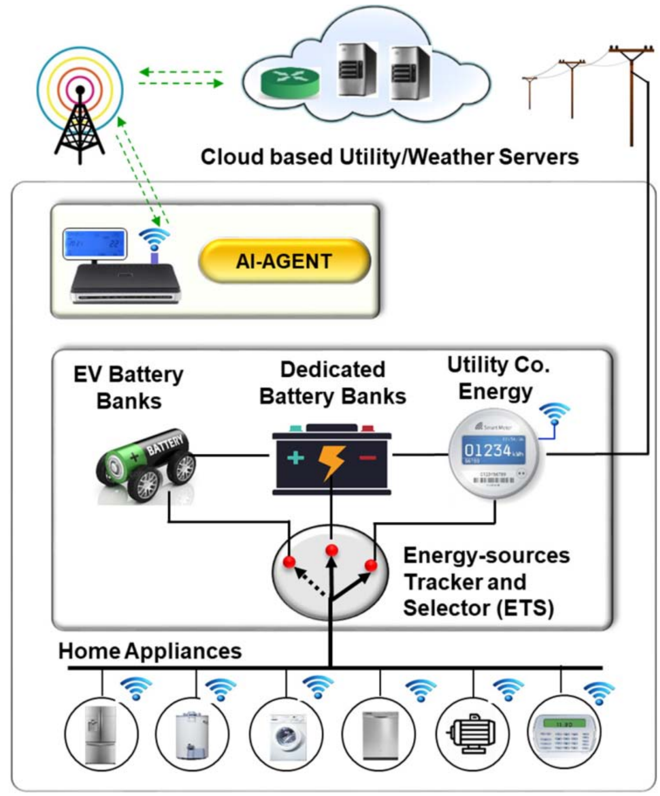

Figure 2: Artificial Intelligence based system architecture

The Agent Program is an implementation of an agent function and is shown in the flowchart of Figure 3. It receives information from the above-noted entities and consequently makes intelligent decisions to maximize the expected value of the objective function. While explaining the agent functions below, the above entities are elucidated.

The AI-Agent is packaged and installed at the consumer's premises. It performs multiple tasks. It acquires system variables from the (a) Utility Server, (b) Weather Server, (c) Consumer's Smart Appliances, (d) Task Completion Register, (e) Energy-sources Tracker and Selector, and (f) Graphical User Interface. The AI-Agent receives the information from the Utility Server and the Weather Server either through 4G/5G technologies, or the smart meter as explained in [14]. The AI-Agent receives the information from the Consumer's Smart Appliances through Wi- Fi technologies, and from its subsystems, i.e. the Task Completion Register, the Energy-sources Tracker and Selector, and the Graphical User Interface over Bluetooth/Wi-Fi or internally wired communication interfaces.

As depicted in figure 3, the AI-Agent communicates and receives information from the Utility Server the forecasted load factor, and the complex tariff information for the next 24-hour on a daily basis through a Cloud. The Cloud network consists of a set of servers available to many users over the Internet. Utility companies are shifting to the cloud technology as it will save utility significant hardware and software purchasing costs. Also, it would provide the utility company to leverage data sharing and analysis. To address the Cybersecurity-related concerns such as unauthorized access to the cloud, the security policies are in place, or the data communication may be one way only, i.e. from the Cloud to AI-Agent. Though a two-way communication will have its numerous benefits.

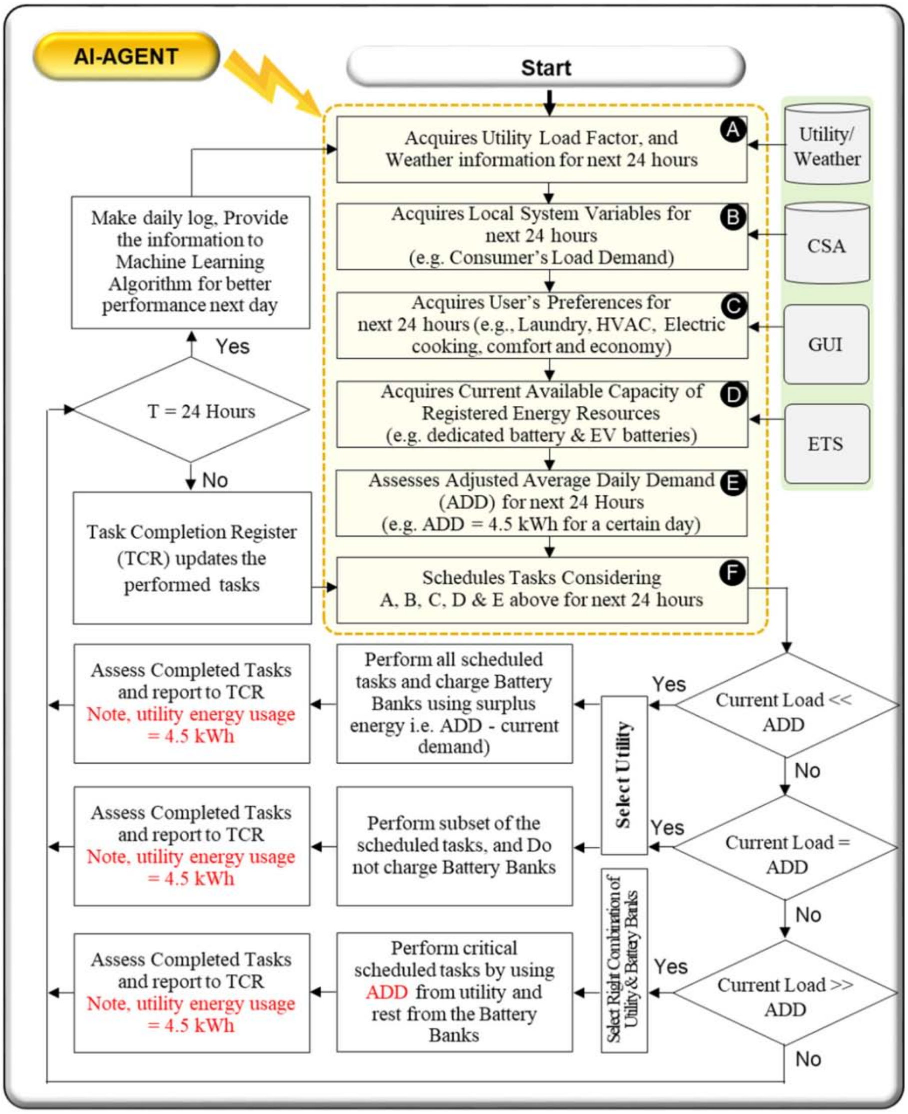

Figure 3: AI-Agent based Consumer Privacy & Energy Managment

AI-Agent communicates and receives information from the Weather Server, it acquires forecasted weather information, such as temperature, humidity, rain, sun, etc. for the same 24 hours for the consumer's location. AI- Agent uses the real-time prevailing weather information in making smart decisions while scheduling the daily tasks, such as laundry, dishwashing, and setting the optimal values of various thermostats of water heater, air conditioner, refrigerator, etc.,

AI-Agent communicates and receives information from the Consumer's Smart and IP addressable Appliances that include home appliances such as, washer/dryer, dishwasher, boiler/water heater, air conditioner, refrigerator, etc., and other devices such as home security systems, and the user's calendar, etc. to detect the user's presence at home and adjust thermostat levels for air conditioning, water heater, and refrigerator, etc. accordingly.

AI-Agent receives information from the Graphical User Interface (GUI). Graphical Use Interface is integrated with AI-Agent. The consumer uses a Graphical User Interface to input his preferences. These preferences relate to tasks' priority, convenience, comfort, and financial affordability. (e.g., the desired temperature ranges of hot water, refrigerator, air-conditioning, preferred time or priority for washing clothes, or dishes, etc.). The consumer may enter these parameters once and save them. The user may feed the parameters using the touchpad, voice recognition, or through a mobile App.

AI-Agent communicates and receives information from the Energy-sources Tracker and Selector. It keeps a track record of the available energy sources and their status. Based on the command received from the AI-Agent, it selects the right combination of sources from the pool of available sources. The available sources in the pool, as shown in Figure 1, are Utility Company, Dedicated Battery Banks, and EV-Battery Banks when the EV(s) are parked in the consumer's garage, etc. EV-Battery Banks can be drained to meet the household energy demand, and top up again later when energy is surplus. Since EV adoption rate has increased exponentially recently, the EV-Battery Banks assumption will be a reality in the years to come [15, 16].

AI-Agent communicates and receives information from the Task Completion Register. Task Completion Register monitors the appliances' task completion status, pending tasks status, and consequently makes a daily log. The Task Completion Register continuously acquires this information from the appliances and updates the AI-Agent.

Based on the parameters acquired from the Utility Server, the Weather Server, the Consumer's Smart Appliances, the Graphical User Interface, the Energy-sources Tracker and Selector, and the Task Completion Register, the AI- Agent computes the Adjusted-average Daily Demand (ADD). Traditionally, the Adjusted-average Daily Demand is calculated by the total energy used over a year divided by 365 days. However, our AI-Agent calculates it by totaling the energy rating and usage duration (kWh) of each consumer appliance that is scheduled by the scheduler for that day.

Scheduling is performed by the AI-Agent by comparing and contrasting the daily load factor and daily complex tariff information received from the Utility Server, consumer preferences and priorities, and prevailing weather conditions, etc. The AI-Agent schedules the daily tasks in a manner that less energy is consumed when the Utility Company has peak demand (and the tariff is high), and as maximum as possible loads/appliances (such as boiler heating, washing, drying, charging Battery Banks, etc.) are operated when the Utility Company has off-peak demand (and the tariff is low). This keeps the overall utility consumption at a low cost.

Though the AI-Agent performs careful scheduling, the things may not go as scheduled. For example, the user may override his own preferences knowingly or unknowingly, and/or may turn on the lights/devices/appliances unexpectedly or randomly. Thus despite careful and intelligent scheduling, the actual prevailing load conditions may be different than what planned. Thus another key job of the AI-Agent is to continuously compute the gap between Adjusted-average Daily Demand and the current/prevailing actual load and directs Energy-sources Tracker and Selector to select the appropriate energy source in such a way that Utility Company always continues to provide Adjusted-average Daily Demand, and any positive gap between the Current Load and the Adjusted- average Daily Demand is covered by charging the Battery Banks, and any negative gap between the Current Load and the Adjusted-average Daily Demand is covered by discharging the Battery Banks. Since the Battery Banks is used to cover up the gap only, our solution eliminates the excessive discharging and charging of batteries that lifts several operational constraints off the batteries. Thus computing the Adjusted-average Daily Demand accurately carries vital importance. The gap analysis is performed by the AI-Agent as discussed below in the following three scenarios:

Scenario 1: If the CURRENT LOAD IS LESS THAN ADJUSTED-AVERAGE DAILY DEMAND, the AI-Agent selects the Utility Company from the pool of available sources to perform all scheduled tasks and uses the surplus energy (i.e. Adjusted-average Daily Demand minus Current Load) to charge the Battery Banks. Thus in this scenario, Utility Company acts as a "source" for feeding the appliances, as well as, charging Battery Banks. As an example to illustrate this scenario, suppose the current load in a given hour is 3kW and the Adjusted-average Daily Demand is 4.5kW, the AI-Agent selects Utility Company to perform all scheduled tasks and uses the surplus energy (i.e. 4.5kW minus 3kW = 1.5kW) to charge Battery Banks.

Scenario 2: If the CURRENT LOAD IS EQUAL TO ADJUSTED-AVERAGE DAILY DEMAND, it again selects Utility Company from the pool of available sources, perform all scheduled tasks, and since, there is no surplus energy (i.e. Adjusted-average Daily Demand minus current load = 0), Utility energy is used to feed all the appliances, and not for charging the Battery Banks. For example, if the current load in a given hour is 4.5kW and the Adjusted-average Daily Demand is also 4.5kW, AI-Agent selects Utility to perform the scheduled tasks only and does not charge the Battery Banks at all.

Scenario 3: If the CURRENT LOAD IS GREATER THAN ADJUSTED-AVERAGE DAILY DEMAND, it selects Utility Company and Battery Banks (Dedicated ones and/or EV-Battery Banks if available) to feed the scheduled loads. Under this scenario, since the existing load is greater than the Adjusted-average Daily Demand, Utility energy is used to feed some of the appliances whereas the Battery Banks to feed the rest of the load. For example, if the current load in a given hour is 7.5kW and the Adjusted-average Daily Demand is 4.5kW, AI-Agent selects Utility to feed the appliances that add up to 4.5 kW and selects the Battery Banks to feed the remaining 3kW load.

Thus, no matter whatever the current load is, the AI-Agent intelligently selects the available energy resources in such a way that Utility Company always continues to provide Adjusted-average Daily Demand, and any gap between Adjusted-Average Daily Demand and the Current Load is covered either discharging the Battery Banks or charging the Battery Banks. This strategy eliminates the excessive discharging and charging of batteries. Also, the higher the accuracy of the Adjusted-average Daily Demand, the lesser will be the frequency and depth of charging/discharging of the Battery Banks. This concept is further elaborated after explaining Figures 3 and 4.

Figure 4 shows the hourly demand of a hypothetical consumer on a certain day. The AI-Agent computed the Adjusted-average Daily Demand = 4.5kW for that day, which is represented by a blue/thick dotted line at 4.5kW of Y-axis in the Figure. The graph also shows that the consumer load is (a) less than the Adjusted-average Daily Demand for a sum of 16 hours (i.e. from 12:00 AM to 10:30 AM, from 11:30 AM to 02:00 PM, and from 09:00 PM to 12:00 A.M) and (b) greater than the Adjusted-average Daily Demand for the 7-hour duration (i.e. from 02:00 PM to 09:00 P.M.).

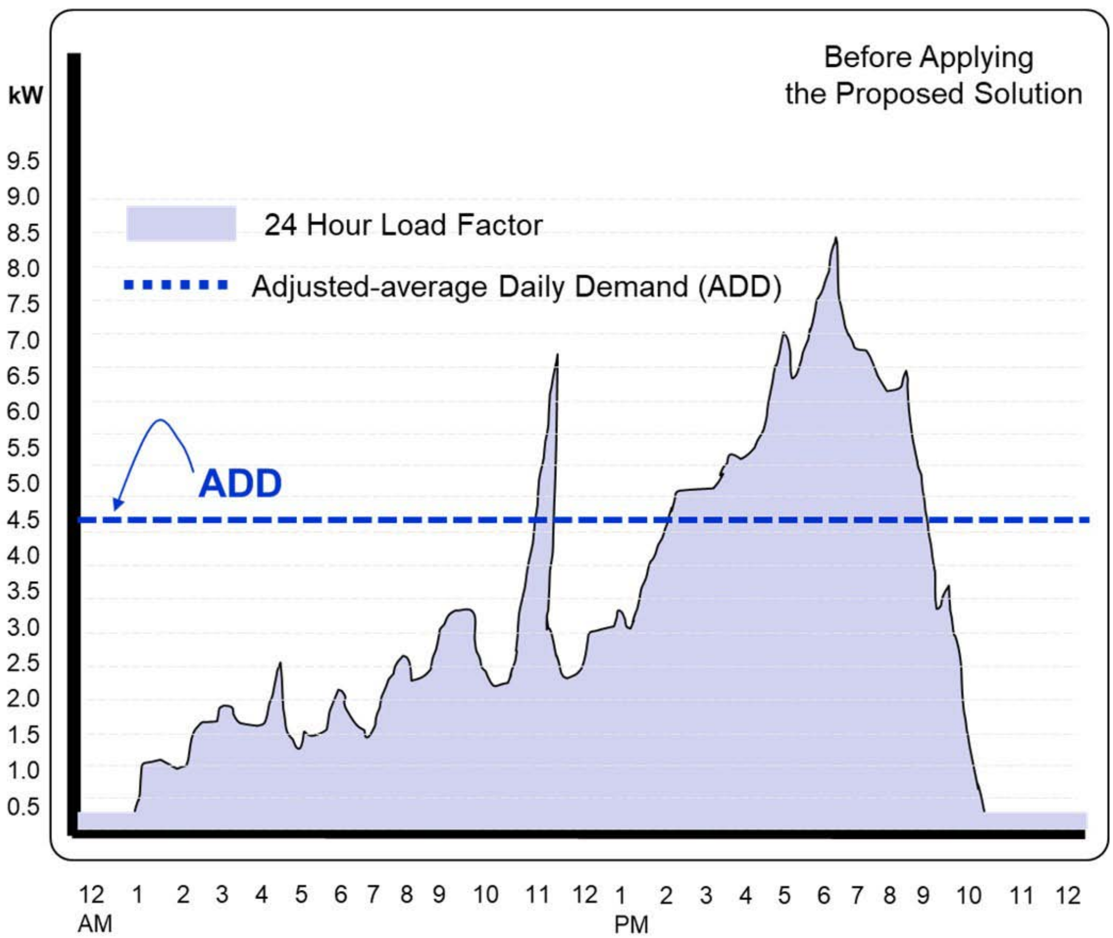

Figure 4: 24-Hour Load Factor, and Adjusted Average Daily Demand of an Imaginary Consumer before Applying the Proposed Solution

Figure 5 tries to depict the scheduling as well as the above noted three scenarios. The first peak demand of 7kW occurs for 15 minutes (i.e. 10:50 AM–11:05 AM and is shown in green color), and the second peak demand of 9kW for 4 hours (i.e. from 04:30 PM–08:30 PM and is shown in green color). The AI-Agent schedules the load smartly, i.e. it slashes the 15-minute peak (7kW-4.5kW= 2.5kW) and moves to 07:00 AM (see green color), and slashes the 4-hour peak (9kW - 4.5kW= 4.5kW) and move it to 10:00 PM–01:00 AM (see green color).

For scenario 1 and 2, the AI-Agent selects the Utility Company only to feed the (a) base scheduled load/appliances (see the load shown in sky blue color, below dotted line see) (b) the rescheduled load/appliances (see the load shown in green color under the dotted line) and (c) charge Battery Banks (the load shown in yellow color, below dotted line) for 16-hour duration (i.e. for the intervals from 12:00 AM to 10:30 AM, from 11:30 AM to 02:00 PM, and from 09:00 PM to 12:00 AM). Thus it is clear that the AI-Agent selects the Utility Company to feed during the intervals,

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the load is less than the Adjusted-average Daily Demand).

For Scenario 3 AI-Agent selects both, the Utility Company and the Battery Banks for the interval the load is greater than the Adjusted-average Daily Demand. AI-Agent selects the Utility Company to feed appliances load equivalent to 4.5 kW (sky blue color) and Battery Banks to feed surplus load equivalent to 1.5 kW for 7-hour duration i.e. from 02:00 PM to 09:00 P.M (see red color).

From Figure 5 graph we can infer that the Battery Banks were discharged for the 7-hour duration (red color). Thus the Battery Banks have to provide 1.5 x 7 = 10.5kWh/day. Considering 90% depth of discharge, the Battery Banks are recommended to have a rating of about 12kWh. The Figure also shows that the Battery Banks are charged for 7 hours at about a maximum of 2.5kW and for 8 hours at about a maximum of 1.5kW. Thus the duration and rating are quite enough to get the Battery Banks fully charged.

To avoid over-charging or under-charging of Battery Banks, the AI-Agent has to carefully compute the value of Adjusted-average Daily Demand every day very carefully. For a scenario, when the daily demand is low, the AI- Agent adjusts the Adjusted-average Daily Demand at a lower level (e.g. let's say 2kW, instead of 4.5kW), conversely, for a scenario when the daily demand is high, the AI-Agent adjusts the Adjusted-average Daily Demand at a higher level (e.g. let's say 6.5kW, instead of 4.5kW). Thus AI-Agent attempts to avoid a situation where Batteries become fully charged or under-charged, and the Utility energy ends-up adding the kinks to the Adjusted-average Daily Demand, hence defeating the masking effect.

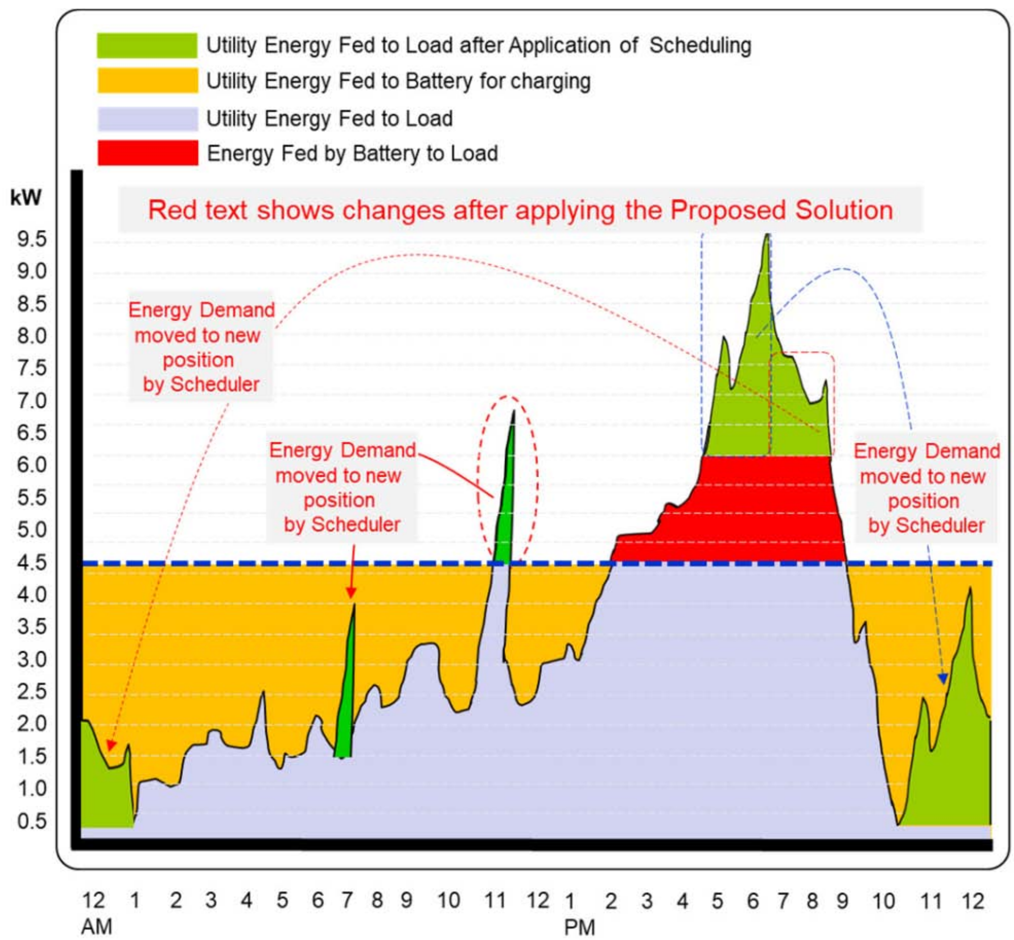

Figure 5: 24-Hour Load Factor, and Average Demand of an Imaginary Consumer after Applying the Proposed Solution

The algorithm, finally, calculates the cycle time. If it is not reached to 24-Hour, the loop returns to the step of acquiring the system variables again. Otherwise, the Task Completion Register makes a daily log, inputs it to AI- Agent, and the machine learning algorithm. The AI-Agent calculates a new Adjusted-average Daily Demand for the next day.

III. Simulation Results

As explained in section II, the higher the accuracy of the Adjusted-average Daily Demand, the lesser will be the frequency and need for charging/discharging the Battery Banks. Thus computing the Adjusted-average Daily Demand accurately carries vital importance. The AI-Agent prudently performs this job by acquiring real-time information from several entities including remote cloud-based servers, local servers, and machine-learning algorithm. We developed a MATLAB program to design the AI-Agent. The snapshot of the program is presented in Figure 9. Figures 5, 6, and 7 present the simulation results.

Figure 6 shows that when the proposed algorithm is not applied at all, the red graph (representing consumer's current load) fluctuates a lot over a 24-hour day. Thus there is neither privacy nor cost saving.

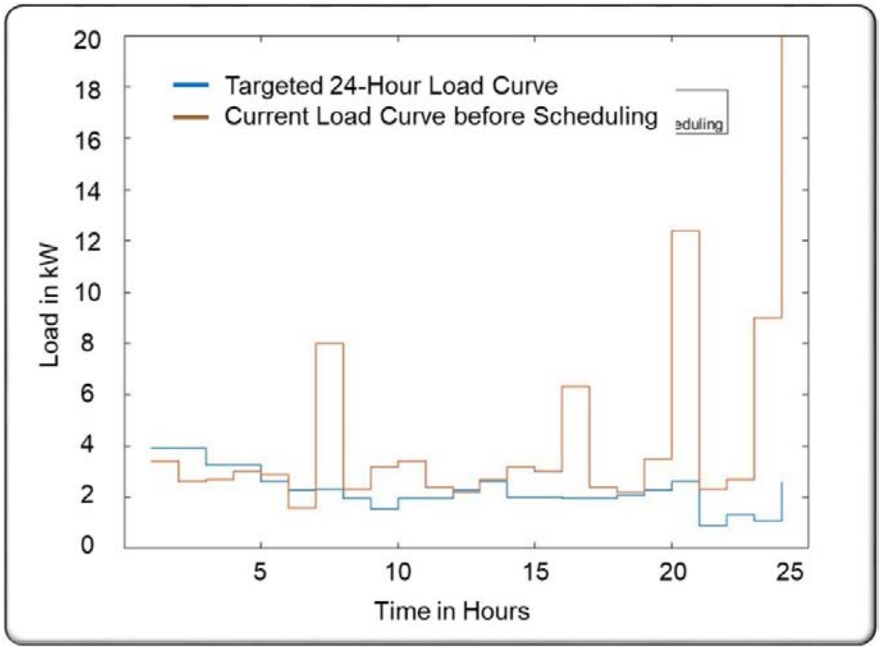

Figure 6: Current Load before Applying the Proposed Solution

Figure 7 shows the effect of AI-Agent's scheduling and reveals that scheduling reduces several kinks in the blue line, thus bringing saving in the utility bills, however, it does not mask the user privacy.

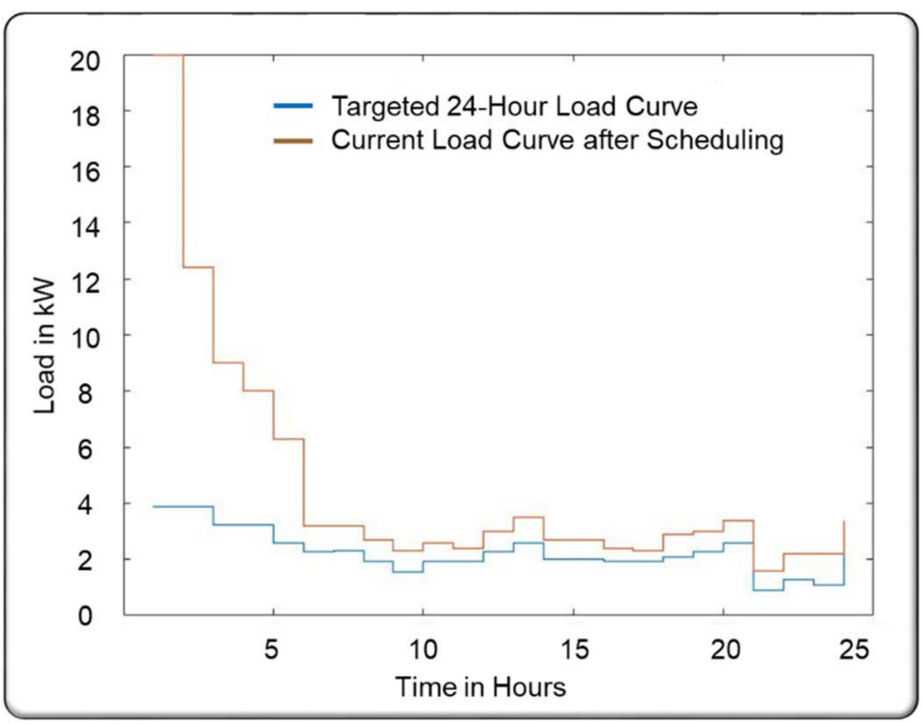

Figure 7: Load Curve after Applying Scheduling only

Figure 8 shows the effect of AI-Agent's gap analysis and reveals that the step of gap analysis eliminates all the kinks, thus masking the consumer's usage pattern completely, as shown by the yellow line. Thus the beauty of the proposed solution is that it manages user privacy, as well as, energy.

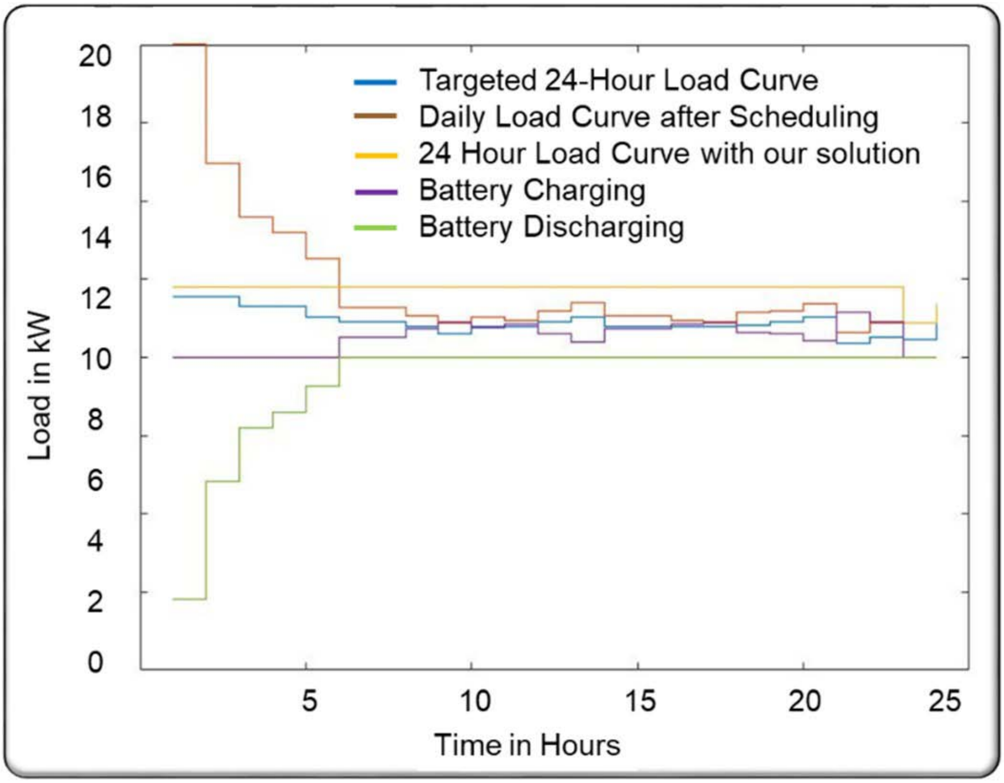

Figure 8: Load Curve After Applying Proposed Solution

IV. Validity and Economic Viability of the Proposal

Industry outlook shows that the global lithium-ion battery market is expected to reach USD 93.1 billion by 2025 [15] [12]. The driving forces behind this huge market are EVs, micro-grids grids, and home storage systems due to significant growth in the solar industry. References [15-16] show that EV adoption rate has become exponential recently, thus the assumption of Dedicated Battery Banks and EV-Battery Banks in every home will be a reality in the years to come, thus the proposed approach is implementable practically.

Reference [17] shows that the operation cost of a lithium-ion storage device is about $0.10 (10 cents) per kW, per cycle (calculated by dividing the upfront cost by the number of cycles these batteries can be used for). For our proposed system that requires about 10 kWh battery, and needs charging/discharging once a day for an average house, the operation cost comes out to be about $365 per year. On the other hand, our proposed scheduling step offers about a 25% reduction in utility bills, as evident from our work in [13]. If we assume that the average residential utility bill $125 per month or $1500 per year. The cost reduction through scheduling will be about $375 that offset the cost of having a privacy feature. Further [17] also shows that ESS batteries set a goal of $100 per kWh capital cost for the batteries that can run for many thousands of cycles. References [18-20] also indicate that the cost of operating such storage devices is declining rapidly. The math points to batteries that eventually cost a few cents per kWh. Thus the proposed approach is viable economically as well.

V. Conclusion

This paper presents a novel solution that offers several features, such as it (a) masks consumers' utility usage data to conceal their utility usage patterns, thus preserves privacy, (b) offers scheduling that conserves energy, thus renders cost reduction in the utility bill, and also evens out the cost of Dedicated Battery Banks (c) it continuously computes gap between "Adjusted-average Daily Demand" and "Current Load" of a household and allows the battery to discharge only to fill the gaps, consequently eliminates the excessive discharging and charging of batteries, thus it lifts constraints on charging-discharging rates and temperature regulations, (d) is user-friendly, simple to implement, and efficient. Though we considered a residential user as an example in this paper, nothing prevents it to be used in industrial or commercial settings as well.

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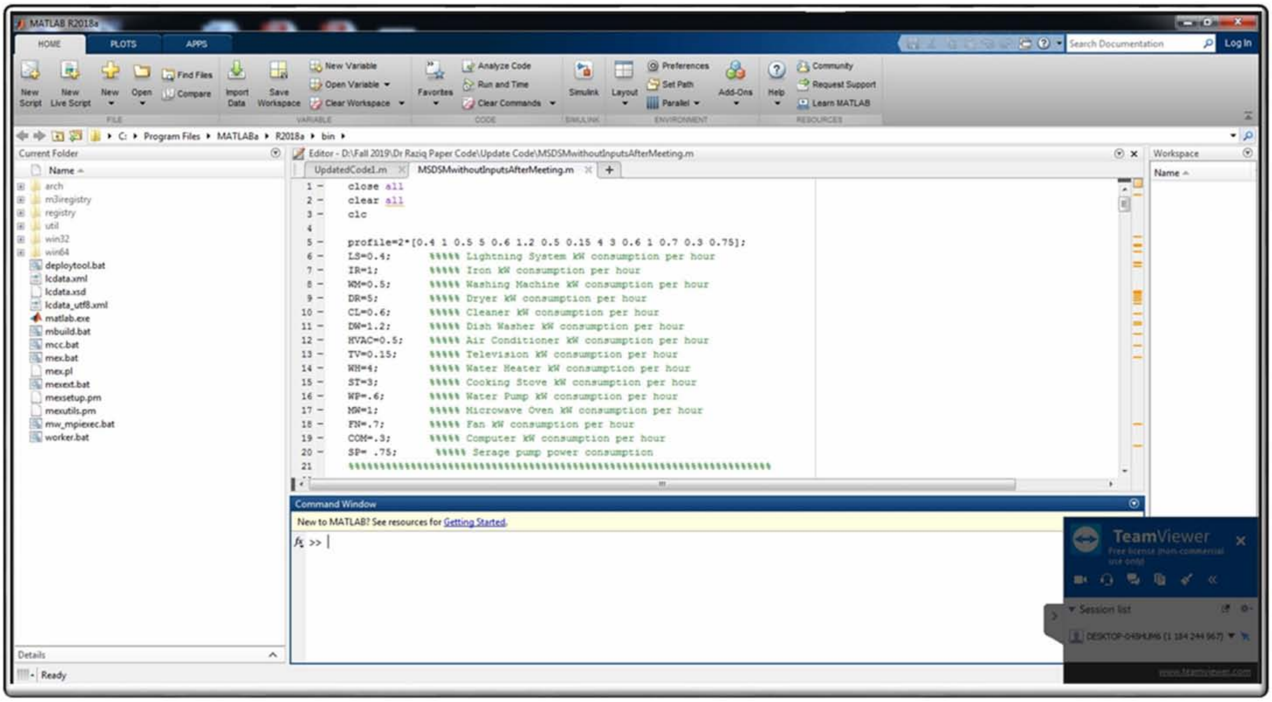

Figure 9: Snapshot of MATLAB Computer Algorithm

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Uncertainty and Congestion Elimination in 4G Network Call Admission Control using Interval Type-2 Intuitionistic Fuzzy Logic

By Uduak Umoh, Imo Eyoh, Etebong Isong & Andy Inyang
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Abstract- The management and control of the global growth and complex nature of wireless Fourth Generation (4G) Networks elicits the need for Call Admission Control (CAC). However, CAC faces the challenge of network congestion, thereby deteriorating the network Quality of Service (QoS) due to inherent imprecision and uncertainties in the QoS data which leads to difficulties in measuring some objective and constraints of QoS using crisp values. Previous researches have shown the strength of Interval Type-2 Fuzzy Logic System (IT2FLS) in coping adequately with linguistic uncertainties. Intuitionistic fuzzy sets (IFSs) have indicated their ability to further reduce uncertainty by handling conflicting evaluation involving membership (M), non-membership (NM) and hesitation. This paper applies the Interval Type-2 Intuitionistic Fuzzy Logic System (IT2IFLS) in solving CAC problem in order to achieve a better QoS in 4G Networks.

Keywords: call admission control, quality of service, fourth generation (4G) network, fuzzy logic, intuitionistic, logic.

GJCST-D Classification: I.5.m

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Strictly as per the compliance and regulations of:

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Abstract- The management and control of the global growth and complex nature of wireless Fourth Generation (4G) Networks elicits the need for Call Admission Control (CAC). However, CAC faces the challenge of network congestion, thereby deteriorating the network Quality of Service (QoS) due to inherent imprecision and uncertainties in the QoS data which leads to difficulties in measuring some objective and constraints of QoS using crisp values. Previous researches have shown the strength of Interval Type-2 Fuzzy Logic System (IT2FLS) in coping adequately with linguistic uncertainties. Intuitionistic fuzzy sets (IFSs) have indicated their ability to further reduce uncertainty by handling conflicting evaluation involving membership (M), non-membership (NM) and hesitation. This paper applies the Interval Type-2 Intuitionistic Fuzzy Logic System (IT2IFLS) in solving CAC problem in order to achieve a better QoS in 4G Networks. Intuitionistic inference system, Gaussian membership function and defuzzification are applied to obtain the crisps output. The study also implements Type-1 Fuzzy Logic (T1FL) and IT2FLSfor comparison purposes. The experiments are conducted using artificially generated datasets and apply four matrices for performance evaluation. Results of experimental analyses indicate a superior control with IT2IFLS over IT2FLS and T1FLS. The proposed IT2IFLS-CAC also outperforms its counterparts with the same datasets due to the presence of additional degrees of freedom in the MF, NMF and hesitation indexes. Also, increase level of fuzziness in IT2IFLS provides a more accurate and promising approximation compared with IT2FLS and T1FLS in handling CAC control problem. The system is expected to improve the utilization of network resources as well as keeping satisfactory QoS levels.

Keywords: call admission control, quality of service, fourth generation (4G) network, fuzzy logic, intuitionistic, logic.

I. Introduction

In recent years, wireless communication is changing and growing rapidly in the world. Due to its tremendous growth and complex nature, it has been challenging to manage and control the demands and complexities associated with this vast network such as Fourth Generation (4G) Network. In telecommunications, 4G is the Fourth Generation of cellular wireless standards succeeding 3G and the 2G families of standards [1]. In 2008, the ITU-R organization specified the IMT- Advanced (International Mobile Tele-communications Advanced) requirements for 4G standards, setting peek speed requirements for the 4G service at 100 Mbit/s for high mobility communication (such as trains and cars) and 1Gbit/s for low mobility communication (such as pedestrians and stationary users).

Mobile network users in our society today strive to get the best service there is, and this has caused a migration of users to the 4G network as it provides better and improvement of services when compared to its predecessors. As the demand for better call and data services increases, there are changes and tremendous growth in 4G wireless network communications worldwide which cause the network to become complex and difficult to manage and control. Due to the influx of users on this network, network service providers can only satisfy a limited amount of traffic, thus causing network congestion. Congestion occurs when the network is overwhelmed with more service requests that it can accommodate, thus, causing delays, dropped and blocked calls. Congestion is a big contributing factor in the deterioration of QoS in a network.

In order to control and manage such complex4G Networks and still maintain good QoS, Call Admission Control (CAC) is necessary. CAC is a mechanism whose main purpose is to decide, at the time of call arrival whether a new call should be admitted. For example, a new call is accepted only if Quality of Service (QoS) constraints are fulfilled without affecting the QoS constraints of the existing calls in the network [2]. However, the CAC faces the challenge of network congestion which is a big contributing factor in the deterioration of QoS in a Network. This is because some objectives and constraints of QoS are often hard to be measured using crisp values due to the inherent imprecision and uncertainties in the QoS data.

Several methods have been used to improve QoS across 4G networks. These methods include Markov models, queuing models and expert systems, [3] [4] [5] [6] [7]. In recent years, the knowledge of fuzzy systems has been employed to solve QOS problems

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because of its ability to make decisions from vague and imprecise information [8] [9].

Fuzzy Logic (Type-1 Fuzzy logic) (T1FL) is a form of multivalued logic derived from fuzzy set theory to deal with reasoning that is approximate [10][11]. The five stages involved in the development of a T1FL system are, fuzzy mathematical model, fuzzification of quantities, composition of fuzzy sets, composition of fuzzy relations and defuzzification of quantities. It has been established that T1FLSs have had great success in many real-world applications, but research has also shown that there are limitations in the ability of T1FLS to model and minimize the effect of uncertainties due to the fact that its membership grade is itself crisp [12] [13]. The solution to this problem is an extension of the T1FLS to type-2 fuzzy logic systems (T2FLS) by [14].

The T2FLS is derived from type-2 fuzzy set (T2Fswhich allows us to handle linguistic uncertainties. T2Fs, a fuzzy relation of higher type has been regarded as one way to increase the fuzziness of a relation by increased ability to handle inexact information in a logically correct manner [15]. The T2FSs allow for linguistic grades of membership, assisting in knowledge representation and also offer improvement on inference [16]. The structure of T2FLS is similar to it type-1 counterpart with additional unit called type-reduction. Type-reduction algoritims such as iterative Karnik-Mendel (KM)[17] algorithm, Wu-Mendel algorithm [18], etc can be explored to perform type-reduction.

Generally, because of the computational complexity of using a general T2FLS, an Interval type-2 fuzzy logic (IT2FL) which is quite practical and a special case of T2FS with a manageable computational complexity is designed by[13]. The extended version of type-1 defuzzification operation technique is usually applied on T2FSs case of the IT2FLS to obtain a T1FS at the output. The T1FS so obtained becomes a type-reduced set which is a collection of the outputs of all of the embedded T1FLSs [17]. IT2FLs are complementary fuzzy sets which provide degree of membership (DoM) value of an element in a given set where the degree of non-membership (DoNM)value is equal to one take away the DoM value. However, IT2FLsmay not cope adequately with real-life situations because most often human beings are hesitant in specifying about set descriptions in terms of MF and NMF as such fuzzy sets theory may not be appropriate to deal with such problem, and hence IFS theory suffices.

Intuitionistic logic was introduced by [19] as logic for Brouwer's intuitionistic mathematics, [20] applied more generally to constructive mathematics (logic). It is mostly described as classical logic without the principle of excluded middle (⊢A∨¬A) or the double negation rule (¬¬ A⊢ A) [21]. Atanassov [22] extended the concept of Zadeh's fuzzy sets to intuitionistic fuzzy sets (IFSs) as a generalization of fuzzy sets which determines both a DoM and a DoNM in dealing with uncertainty and vagueness. Fuzzy sets provide DoM of an element in a given set where the DoNM is equal to one take away the DoM, whereas, the intuitionistic fuzzy sets being a higher order fuzzy set can handle both a DoM and a DoNM. The membership function (MF) and non-membership functions (NMF) representation of attributes to handle uncertainty are more or less independent of each other, thus providing a better way to express uncertainty. The presence of non-membership or hesitation index in fuzzy sets gives more allowance to represent imprecision and uncertainty adequately in dealing with many real-world problems [23]. The concept of IFS is extended to interval valued intuitionistic fuzzy sets (IVIFS) as membership and non-membership functions in the interval [0,1] called IT2IFLSs with degrees of membership as intervals can give better result in some applications than the T1FLSs and T2FLS [24] [25] [26] [27] [28]. (the highlighted refs. are not in order and please let the student confirm the rest that they match).

In this paper, we apply an IT2IFLS to model uncertain data for call admission control in 4G networks. It is a type of fuzzy logic controller that incorporates the experience of human experts in making appropriate decisions to handle uncertainty and congestion control in 4G Networks. This paper is motivated by the ability of IT2IFLS to handle imprecision and vagueness more accurately and make better decisions due to its ability to consider membership and non- membership of an element and expert's factor of hesitation.

To the best knowledge of the authors, there is currently no work in the literature where IT2IF set is applied in a fuzzy logic inference system in handling call admission control problem in 4G Networks in order to improve the QoS. Decision is made based on the information in the traffic contract and the condition of the network. T1FL and IT2FL are also implemented for the purpose of comparison. MAD, MAPE, MSE AND RMSE performance measures are applied in order to measure the performance and utilization of the proposed system. The paper employs system analysis and design and object design tools in the development of the system Matlab, Intellij, MySQL Intellij, MySQL and the java programming language are employed in implementing the system.

The rest of the paper is presented as follows: In section 2, an overview of IFS, T2IFS and IT2IFS are defined. In section 3, IT2IFLS is designed. We present our results in Section 4, and conclude in section 5.

II. Related Work

The related work is concerned about the different researches which deal with CAC in improving QoS in mobile networks and also the different methods and characteristics that are explored in this paper.

Call Admission Control (CAC)

CAC is an important decision making tool which is employed to provide the needed QoS by controlling access to the network resources [29]. Maintaining QoS parameters such as signal quality, packet delay, loss rate, call blocking and dropping thresholds are required for efficient admission control in mobile multimedia networks [30]. The CAC can decide to either accept or block the new request depending on the available network resources and on network load conditions for a needed connection type. Fundamentally, a new request is accepted if the available resources are adequate to meet the QoS requirements for this new connection without violating the QoS of the request that has already been accepted, otherwise the call is rejected. Many researchers have applied several techniques including fuzzy logic to deal with CAC in order to improve QoS across 4G networks.

Mahesh et al., (2014) [2] applied soft computing technique in surveying call admission control in wireless networks. Congestion control mechanism is modeled with fuzzy logic [31]. Shen and Mark [32] proposed a call admission control in wideband CDMA cellular networks by using fuzzy logic. Sonmez et al., [33] studied a fuzzy-based congestion control for wireless multimedia sensor networks. [30], carried out a comparative study of CAC in mobile multimedia networks using soft computing paradigms. Metre et al., [34] surveyed soft computing techniques for Joint Radio Resource Management (JRRM). Mallapur et al., [35] developed a fuzzy based bandwidth allocation scheme for temporary borrowing of bandwidth from existing connections in order to accommodate newly arrival call connections. Chen and Chang [36] designed a fuzzy Q-Learning admission control for WCDMA/WLAN heterogeneous networks with multimedia traffic. Ramesh et al., [37] designed a fuzzy neural model for call admission control in multi class traffic based next generation wireless networks (NGWNs). Lawal et al. [6] carried out a survey on call admission control schemes in LTE Networks where the algorithms are grouped into CAC with Pre-emption, Resource Reservation (RR), Resource Degradation (RD), Delay Awareness (DA) or Channel Awareness (CA). The study further discussed the operational procedure, strengths and weaknesses of each scheme. G. Mali [38] designed a fuzzy based vertical handoff -decision controller for future networks. [39] [40] employed IT2FL to model connection admission control (CAC) in fourth generation (4G) networks to improve quality of service (QoS). The study applied Karnik–Mendel (KM) and Wu-Mendel (WM) algorithms for computing the centroid and to derive inner and outer- bound sets for the type-reduced set of IT2FS. The results indicate that IT2FLS-CAC using WU approach achieves minimal call blocking probability and provides better performance in CAC decision making with IT2FLS-CAC than IT2FLS-CAC using KM and IT1FLS methods.

Interval Type-2 Fuzzy Set (IT2FS)

According to [41], IT2FS, is characterized by,

$$\tilde{A} = \{((x,u), \mu_{\tilde{A}}(x,u)) \mid \forall\, x\ \in X, \forall\, u\ \in J_x \subseteq\ [0,1 \qquad (1)$$

where *x* is the *primary variable* with a domain *X* and *u*∈*U* is the *secondary variable* with domain Jx at each *x*∈*X*. Jx is the primary membership of x and the secondary grades of all equal 1 [42]. The uncertainty about the union of all the primary memberships is called *footprint of uncertainty* (FOU) as shown in (2) and Figure 1 respectively.

$$\mu_{\tilde{A}}(x,u) = 1, FOU\ (\tilde{A}) = \bigcup_{\forall x \in X} J_x =$$

$$\{(x,u) : u\ \in Jx\ \subseteq\ [0,1]\} \qquad (2)$$

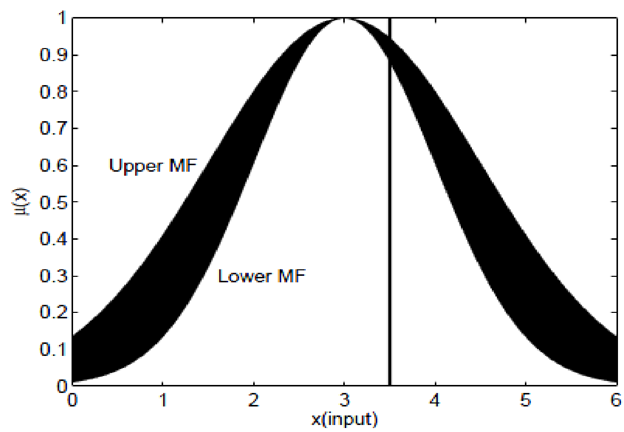

Fig. 1: Interval Type-2 Fuzzy set [41]

Where the *upper membership function (UMF) and lower membership functions (LMF)* are represented as,

$$\text{UMF} = \bar{\mu}_{\tilde{A}}(x) \equiv \overline{FOU\ (\tilde{A})} \quad \forall x \in X \qquad (3)$$

$$\text{LMF} = \underline{\mu}_{\tilde{A}}(x) \equiv \underline{FOU\ (\tilde{A})}\ \ \forall x \in X \qquad (4)$$

$$J_x = \{(x,u) : u \in [\underline{\mu}_{\tilde{A}}(x), \bar{\mu}_{\tilde{A}}(x)]\} \qquad (5)$$

The MFs of IT2FS are twice T1MFs bounded by the FOU in (3) and (4) and $J_x$is an interval set. The set theory operations of union, intersection and complement are applied to compute IT2FSs.

Type-1 Intuitionistic Fuzzy Set (T1IFS)

Definition 1: According to [22]given a non- empty set , an intuitionist fuzzy setA^* in X is an object having the form:

$$A^* = \{(x, \mu_{A^*}(x), \mathcal{V}_{A^*}(x)) : x\ \in X)\} \qquad (6)$$

where the function $\mu_{A^*}(x) : \rightarrow [0,1]$ defines the degree of membership and $\mathcal{V}_{A^*}(x)$: X → [0,1] defines the degree of non-membership of element $x\ \in X$.

Definition 2: for every element, $x\ \in X$, $0 \leq\ \mu_{A^*}(x) + \mathcal{V}_{A^*}(x) \leq 1$ holds. Then

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$$\mathcal{V}_{A^*}(x) = 1 - \mu_{A^*}(x) \quad (7)$$

The set A is a fuzzy set [19].

Definition 3: For every common fuzzy subset A on X, intuitionistic fuzzy indexin A^* (degree of hesitancy or uncertainty) of the element x in A for every T2IFS is defined as in (8)

$$\pi_{A^*}(x) = 1 - (\mathcal{V}_{A^*}(x) + \mu_{A^*}(x)) \quad (8)$$

Type-2 Intuitionistic Fuzzy Set (T2IFS)

According to [26], a T2IFS is characterized by T2 membership function (MF) and non-membership functions (NMF) of defined as:

$$\mu_{\tilde{A}^*}(x, u) : u \,\epsilon J_x^{\mu} \subseteq [0,1] \text{ (MF)} \quad (9)$$

and

$$\mathcal{V}_{\tilde{A}^*}(x, u) : u \,\epsilon J_x^{v} \subseteq [0,1] \text{ (NMF)} \quad (10)$$

Where J_x^{μ} is the primary MF and J_x^{v} is the primary NMF of element in (x, u) defined in (11) and (12).

$$J_x^{\mu} = \{(x, u) : u \,\epsilon \left[\underline{\mu}_{\tilde{A}*}(x), \bar{\mu}_{\tilde{A}*}(x)\right]\} \quad (11)$$

$$= \quad J_x^{v} = \{(x, u) : u \,\epsilon \left[\underline{v}_{\tilde{A}*}(x), \bar{v}_{\tilde{A}*}(x)\right] \quad (12)$$

$$\tilde{A}* =$$

$$\{(x, u) : \bar{\mu}_{\tilde{A}*}(x, u), \bar{v}_{\tilde{A}*}(x, u), | \,\forall\, x \epsilon \,\mathrm{X}, \forall u \,\epsilon\, J_x^{\mu}, \forall u \,\epsilon\, J_x^{v}\} \quad (13)$$

Where $0 \leq (\bar{\mu}_{\tilde{A}*}(x,u)) \leq 1$ and $0 \leq (\bar{v}_{\tilde{A}*}(x,u)) \leq 1$, $\forall u \,\epsilon\, J_x^{\mu}$ and $\forall u \,\epsilon\, J_x^{v}$ conforms to $0 \leq \bar{\mu}_{\tilde{A}*} + \bar{v}_{\tilde{A}*} \leq 1$. When the secondary MFs, $\bar{\mu}_{\tilde{A}*}(x,u)$=1, and secondary NMFs, $\bar{v}_{\tilde{A}*}(x,u)$ = 1, a T2IFS translates to an IT2IFS as shown in Figure 2. Where, x and u are the primary and secondary variables respectively.

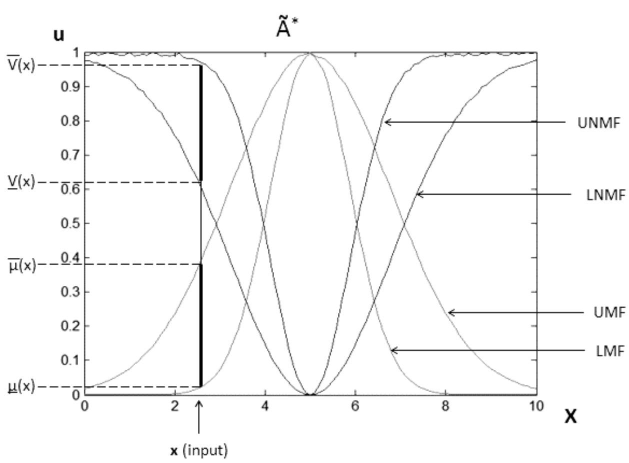

Fig. 2: An IT2 Intuitionistic Gaussian MF and NMF of IT2IFS [26]

Interval Type-2 Intuitionistic Fuzzy Set (IT2IFS)

An IT2IFS, $\tilde{A}*$, is characterized by bounding MFs and NMFs respectively where $0 \leq \bar{\mu}_{\tilde{A}*}(x) + \underline{v}_{\tilde{A}*}(x) \leq 1$ as defined in (14) and (15)[43].

$$\text{IT2 MFs} = \bar{\mu}_{\tilde{A}*}(x), \underline{\mu}_{\tilde{A}*}(x) \quad (14)$$

$$\text{IT2 NMFs} = \bar{v}_{\tilde{A}*}(x), \underline{v}_{\tilde{A}*}(x) \quad (15)$$

For each $x \in X$, we have the IF-index or hesitancy degree as an outcome of an expert's uncertainty about the degree of M and NM as defined in [44]. There are two IF-indexes; the center IF-index and variance IF-index as seen in (16 - 18) [45].

$$\pi_c(x) = \max(0, (1 - (\mu_{\tilde{A}*}(x) + v_{\tilde{A}*}(x)))) \quad (16)$$

$$\bar{\pi}_{var}(x) = \max(0, (1 - (\bar{\mu}_{\tilde{A}*}(x) + \underline{v}_{\tilde{A}*}(x)))) \quad (17)$$

$$\underline{\pi}_{var}(x) = \max(0, (1 - (\underline{\mu}_{\tilde{A}*}(x) + \bar{v}_{\tilde{A}*}(x)))) \quad (18)$$

Such that $0 \leq \pi_c(x) \leq$ and $0 \leq \pi_{var}(x) \leq 1$

An IT2IFS, is fully bounded by two T1 MFs and two T1 NMFs as upper MF, $\bar{\mu}_{\tilde{A}*}$ and lower MF, $\underline{\mu}_{\tilde{A}*}(x)$ (14) and upper NMF, $\bar{v}_{\tilde{A}*}(x)$, and lower NMF, $\underline{v}_{\tilde{A}*}(x)$ (15) which define the footprints of uncertainty (FOUs) of a T2FS. The upper MF is a subset with maximum membership grade of FOU while the lower MF is a subset with minimum membership grade of FOU and both the MF and NMFs of the IT2FS are combined into M and NM FOUs respectively to handle the uncertainty about IT2FS as shown in Figure 1 and (19 - 20) as the primary M and NM respectively [26].

$$FOU_{\mu}(\tilde{A}^*) = \cup_{\forall x \in X}[\underline{\mu}_{\tilde{A}*}(x), \bar{\mu}_{\tilde{A}*}(x) \quad (19)$$

$$FOU_{\mu}(\tilde{A}^*) = \cup_{\forall x \in X}[\underline{v}_{\tilde{A}*}(x), \bar{v}_{\tilde{A}*}(x) \quad (20)$$

Interval Type-2 Intuitionistic Fuzzy Logic System (IT2IFLS)

The IT2IFLS is the hybridization of IT2FL and Intuitionistic Logic (IL) tools to deal adequately with uncertainty and vagueness associated with real world problem. The structure of IT2IFLS is similar to IT2FL with the following components: intuitionistic fuzzification unit, intuitionistic rule base, intuitionistic fuzzy inference engine and intuitionistic composition/defuzzification processes respectively. Figure 3 gives the structure of IT2IFL which is a modification of the work done in [40].

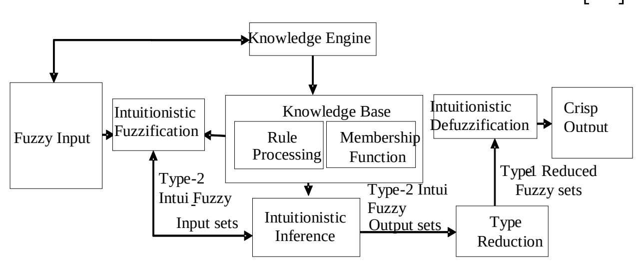

Fig. 3: The structure of IT2IFL [40]

Fuzzification process is carried out by converting intuitionistic fuzzy inputs and fuzzified into input IT2IF sets by mapping a numeric input vector x into an IT2IFS, Here, each element of the MFs and NMFs is assigned membership grade (degree of membership) in each IT2IFS division. The study considers IT2I Gaussian MF and NMFs with a fixed center (mean) and uncertain width (deviation) because it is suitable for a highly dynamic system and has the advantage of being smooth at all points as define in (21-24) respectively (Eyoh et al, 2017).

$$\bar{\mu}_{ik}\ (x_i) = exp\ (-\frac{(x_i - c_{ik})^2}{2\bar{\sigma}_{2,ik}^2}) * (1 - \pi_{c,ik}(x_i)) \quad (21)$$

$$\underline{\mu}_{ik}\ (x_i) = exp\ (-\frac{(x_i - c_{ik})^2}{2\underline{\sigma}_{1,ik}^2}) * (1 - \pi_{c,ik}(x_i)) \quad (22)$$

$$\underline{v_{ik}}\ \ (x_i) = (1 - \underline{\pi}_{var,ik}(x_i)) - \underline{\mu}_{ik}\ (x_i) \quad (23)$$

$$\underline{v_{ik}}((x_i) = (1 - \underline{\pi}_{var,ik}(x_i)) - \bar{\mu}_{ik}\ (x_i) \quad (24)$$

Where, $\pi_{c,ik}(x)$is the IF-index of center and$\pi_{var,ik}$ is the IF-index of variance. The premise parameters, $\bar{\sigma}_{2,ik}$, $\underline{\sigma}_{1,ik}$ and $\pi_{c,ik}(x), \pi_{var,ik}$define the M and NM grades of each element of and are combined to give FOUs.

Intuitionistic Fuzzy Rule (IFR)

IT2IFLS Mamdani's fuzzy rule syntax is similar to that of IT2FL rule and is expressed in (25) and (26-(27) for both MF and NMFs

R_kIF x_i is $\tilde{A}*_{ik}$ and,., and x_p is $\tilde{A}*_{pk}$ then y_k is $\tilde{B}*_{pk}$ (25)

R_k^{μ}IF x_i is $\tilde{A}*_{ik}^{\mu}$ and,., and x_p is $\tilde{A}*_{pk}^{\mu}$ then y_k is $\tilde{B}*_{pk}^{\mu}$ (26

R_k^{v}IF x_i is $\tilde{A}*_{ik}^{v}$ and,., and x_p is $\tilde{A}*_{pk}^{v}$ then y_k is $\tilde{B}*_{pk}^{v}$ (27)

Where $\tilde{A}*_{ik}\ (x), \ldots, \tilde{A}*_{pk}\ (x)$are IT2IFSfor i = 1,…, $p$are the antecedents;y is the consequent of the *lth* rule of IT2FLS. $\tilde{A}*_{ik}^{\mu}$ and$\tilde{A}*_{ik}^{v}$are the MFs and NMF of the antecedent of IT2IFLS part assigned of the *i*th input x_i, The $\tilde{B}*_{pk}^{\mu}$ and $\tilde{B}*_{pk}^{v}$ are the MFs and NMF of the consequent part assigned to the output MF, y_k^{μ} and outputs NMFs, y_k^{v}respectively

Intuitionistic Fuzzy Inference

There are two general fuzzy inference mechanisms based on their characterization and the evaluation of the output. They include; Mamdani and Takagi -Sugeno-Kang (TSK) fuzzy inference engines. The Mamdani fuzzy inference is adopted in this paper because it proves to be more intuitive. In IT2IFLS, Mamdani fuzzy inference approach evaluates the rules in a rule base against IT2IF input set from fuzzification to produce IT2IF output set by the composition of MFs output, and NMFs output . Then the firing strength of the *pth* rule of the fired M/ and NM values for both the upper and lower bounds are computed (28) and (29-32) respectively.

$$\widetilde{F^k}(x') = [\underline{f_k^{\mu}}(x'), \overline{f_k^{\mu}}(x'), \underline{f_k^{v}}(x'),\ \overline{f_k^{v}}\ (x')]$$

$$= [\underline{f_k^{\mu}}, \overline{f_k^{\mu}}, \underline{f_k^{v}}, \overline{f_k^{v}}] \quad (28)$$

$$\underline{f_k^{\mu}} = \underline{\mu}_{\hat{A}_{1k}}(x_1) * \underline{\mu}_{\hat{A}_{2k}}(x_2) * \ldots * \underline{\mu}_{\hat{A}_{pk}}(x_p) \quad (29)$$

$$\overline{f_k^{\mu}} = \bar{\mu}_{\hat{A}_{1k}}(x_1) * \bar{\mu}_{\hat{A}_{2k}}(x_2) * \ldots * \bar{\mu}_{\hat{A}_{pk}}(x_p) \quad (30)$$

$$\overline{f_k^{v}} = \bar{v}_{\hat{A}_{1k}}(x_1) * \bar{v}_{\hat{A}_{2k}}(x_2) * \ldots * \bar{v}_{\hat{A}_{pk}}(x_p) \quad (31)$$

$$\underline{f_k^{v}} = \underline{v}_{\hat{A}_{1k}}(x_1) * \underline{v}_{\hat{A}_{2k}}(x_2) * \ldots * \underline{v}_{\hat{A}_{pk}}(x_p) \quad (32)$$

Where $\widetilde{F^k}(x')$ is the antecedent of *kth*. $\mu_{\hat{A}_{pk}}$ and $v_{\hat{A}_{pk}}$ are the degrees of membership and non-membership for i=1,…, p.

Intuitionistic Defuzzification

The crisp output, y is computed using the composition of M and NM outputs. Although there are several techniques available in the literature for the defuzzification of the final crisp output, the study employs TSK method in[45][46] to compute the IT2IFLS final crisp output as presented in (33) and (34) and the M and NM fired strength are evaluated using (34)-(36) respectively.

$$(-\beta)\ \sum_{k=1}^{P} \tilde{f}_k^{\mu} y_k^{\mu} + (1 - \beta) \sum_{k=1}^{P} \tilde{f}_k^{v} y_k^{v} \quad (33)$$

$$y = \frac{(1-\beta)\sum_{k=1}^{P}(\underline{f_k^{\mu}} + \overline{f_k^{\mu}}) y_k^{\mu}}{\sum_{k=1}^{M} \underline{f_k^{\mu}} + \sum_{k=1}^{P} \overline{f_k^{\mu}}} + \frac{\beta \sum_{k=1}^{P}(\underline{f_k^{v}} + \overline{f_k^{v}}) y_k^{v}}{\sum_{k=1}^{P} \underline{f_k^{v}} + \sum_{k=1}^{P} \overline{f_k^{v}}} \quad (34)$$

Where,

$$\tilde{f}_k^{\mu} = \frac{\underline{f_k^{\mu}} + \overline{f_k^{\mu}}}{\sum_{k=1}^{P} \underline{f_k^{\mu}} + \sum_{k=1}^{P} \overline{f_k^{\mu}}} \quad (35)$$

and

$$\tilde{f}_k^{v} = \frac{(\underline{f_k^{v}} + \overline{f_k^{v}})}{\sum_{k=1}^{P} \underline{f_k^{v}} + \sum_{k=1}^{P} \overline{f_k^{v}}} \quad (36)$$

The parameter $\beta$is a user defined parameter which specifies the contribution of the M and NM values in the final output such that$0 \leq \beta <= 1$. If $\beta = 0$, the outputs of the IT2IFLS are determined using MF else if $\beta = 1$, only the NM will contribute to the system's output.

III. Research Methodology

Uncertainty and Congestion Elimination in 4G Networks CAC using IT2IFL.

The main goal of this paper is to apply the interval type-2 intuitionistic fuzzy Logic (IT2IFL) in solving call admission control problem in order to achieve a better QoS in 4G Networks. The model of the proposed system is shown in Figure 4 and the components of the system include; knowledge engine (which provides both the structured and unstructured information required by the system), intuitionistic fuzzifier, knowledge base, intuitionistic defuzzifier. The knowledge base processes both the fuzzy rules and the membership functions.

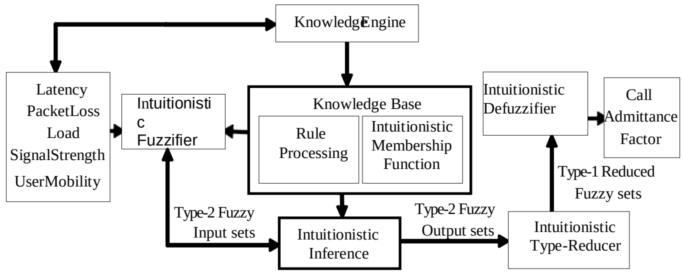

Fig. 4: The IT2IFL- CAC model for Uncertainty and Congestion Elimination in 4G Networks

The IT2IF inference system takes the following five parameters, *Latency (LA)*, *Packet Loss (PL)*, *Load (LD)*, *Signal Strength (SS)* and *User Mobility (UB)* as inputs. The system explores the Mamdani inference method [47] for both membership and nonmembership functions evaluation. The intuitionistic fuzzy values of the *LA, PL, LD, SS* and *UB* are intuitionistically fuzzified and passed to the intuitionistic fuzzy inference engine where rules are applied to these values.The output of the inference engine is passed to the output processing unit and finally the defuzzified crisp value (Call Admittant Factor (*CAF*)) is obtained.

The algorithm for the steps in modeling CAC intuitionistic fuzzy controller is summarized in the Figure 5.

1. Begin
2. IFIS := Create intuitionistic fuzzy inference system
3. Define linguistic values of input variables; *LA, PL, LD, SS, UB*
4. Define linguistic values of output variable *CAF*
5. LA_value := Read Latency value
6. PL_value := Read Packet Loss value
7. LD_value := Read Load value
8. SS_value := Read Signal Strength value
9. UB_value := Read User Mobility value
10. [Low Medium High] := Find degree of MF for LA_value
11. [NLow NMedium NHigh] := Find degree of NMF for LA_value
12. [Low Medium High] := Find degree of MF for PL_value
13. [NLow NMedium NHigh] := Find degree of NMF for PL_value
14. [VeryLow Low High VeryHigh] := Find degree of MF for LD
15. [NVeryLow NLow NHigh NVeryHigh] := Find degree of NMF for LD_value
16. [Weak Medium Strong]:= Find degree of MF for SS_value
17. [NWeak NMedium NStrong] := Find degree of NMF for SS_value
18. [Low Medium High]:= Find degree of MF for UM_value
19. [NLow NMedium NHigh] := Find degree of NMF for UM_value
20. [Poor Fair Good Excellent]:= Find degree of MF for UM_value
21. [NPoor NFair NGood NExcellent] := Find degree of NMF for UM_value
22. Compute appropriate intuitionistic fuzzy logic rules to get degree of truth for output variable *CAF*
23. Apply defuzzification model to get crisp value of *Call Admittant Factor (CAF).*
24. Show final *CAF*

Fig. 5: Algorithm for CAC Intuitionistic Fuzzy System

Intuitionistic Fuzzifier - CAC for Uncertainty and Congestion Elimination in 4G Networks

The paper designs an intuitionistic fuzzy - CAC system for elimination of uncertainty and congestion control in 4G Networks for improving QoS. The universe of discourse is defined for our linguistic variables in Table 1. From Figure, 4, firstly, intuitionistic fuzzification is performed on the values of five QoS control input variables, namely: the *LA, PL, LD, SS* and *UB* respectively.

Table 1: Fuzzy Inputs Universe of Discourse

Input Variables And Their Universe Of Discourse					
LA(%)	PL	SS (dBm)	LD (%)	UM (m/s)	CAF
[0 ,100]	[0 , 5]	[-100,-80]	[0 , 100]	[0,6	[0 , 1]

Equations 21 – 24 are applied for the Gaussian membership function evaluation for both MF and NMF for all the input and output attributes as presented in sections (a)-(e) respectively. The IT2IFLS IF-index for

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center and variance are determined for the five parameters based on (16) – (18) respectively. By putting the values of the five input variables (LA, PL, LD, SS and UB) in the MF and NMFs of LA, PL, LD, SS and UB respectively, we obtain the fuzzified values. Tables 2 - 6 show the matrixes values of MF, NMF and hesitancy for the five input parameters of CAC process respectively. The MF and NMF of the output variable (CAF) of our IT2IFL system is evaluated.

a) Membership and non-membership function for Latency

$$\mu_L(x, [6.5\,, 4.5], [20.0\,, 20.0]) = e^{\frac{-1}{2}\left(\frac{x-[20.0,20.0]}{[6.5\,,4.5]}\right)^2} = [\overline{\mu}_{\tilde{A}_{im}}, \underline{\mu}]$$

$$\mu_l = \underline{\mu_l} \text{ and } v_l = 1 - \overline{\mu}_l$$

$$\mu_M(x, [10.5\,, 8.5], [50.0\,, 50.0]) = e^{\frac{-1}{2}\left(\frac{x-[50.0\,,50.0]}{[10.5\,,8.5]}\right)^2}$$

$$\mu_M = \underline{\mu_M} \text{ and } v_M = 1 - \overline{\mu}_M$$

$$\mu_H(x, [6.5\,, 4.5], [80.0\,, 80.0]) = e^{\frac{-1}{2}\left(\frac{x-[80.0\,,80.0]}{[6.5\,,4.5]}\right)^2}$$

$$\mu_H = \underline{\mu_H} \text{ and } v_H = 1 - \overline{\mu}_H$$

b) Membership and non-membership function for Packet Loss

$$\mu_L(x, [0.8\,, 0.6], [0.0\,, 0.0]) = e^{\frac{-1}{2}\left(\frac{x-[0.0\,,\ 0.0]}{[0.8\,,\ 0.6]}\right)^2}$$

$$\mu_L = \underline{\mu_L} \text{ and } v_L = 1 - \overline{\mu}_L$$

$$\mu_M(x, [0.45\,, 0.35], [2.5\,, 2.55]) = e^{\frac{-1}{2}\left(\frac{x-[2.5\,,\ 2.5]}{[0.45\,,\ 0.35]}\right)^2}$$

$$\mu_M = \underline{\mu_M} \text{ and } v_M = 1 - \overline{\mu}_M$$

$$\mu_H(x, [0.8\,, 0.6], [5.0\,, 5.0]) = e^{\frac{-1}{2}\left(\frac{x-[5.0\,,\ 5.0]}{[0.8\,,\ 0.6]}\right)^2}$$

$$\mu_H = \underline{\mu_H} \text{ and } v_H = 1 - \overline{\mu}_H$$

c) Membership and non-membership function for Load

$$\mu_{VL}(x, [7.0\,, 5.0], [20.0\,, 20.0]) = e^{\frac{-1}{2}\left(\frac{x-[20.0\,,\ 20.0]}{[7.0\,,\ 5.0]}\right)^2}$$

$$\mu_{VL} = \underline{\mu_{VL}} \text{ and } v_{VL} = 1 - \overline{\mu}_{VL}$$

$$\mu_L(x, [8.0\,, 6.0], [40.0\,, 40.0]) = e^{\frac{-1}{2}\left(\frac{x-[40.0\,,\ 40.0]}{[8.0\,,\ 6.0]}\right)^2}$$

$$\mu_L = \underline{\mu_L} \text{ and } v_L = 1 - \overline{\mu}_L$$

$$\mu_H(x, [7.0\,, 5.0], [60.0\,, 60.0]) = e^{\frac{-1}{2}\left(\frac{x-[60.0\,,\ 60.0]}{[7.0\,,\ 5.0]}\right)^2}$$

$$\mu_H = \underline{\mu_H} \text{ and } v_H = 1 - \overline{\mu}_H$$

$$\mu_{VH}(x, [7.0\,, 5.0], [80.0\,, 80.0]) = e^{\frac{-1}{2}\left(\frac{x-[80.0\,,\ 80.0]}{[7.0\,,\ 5.0]}\right)^2}$$

$$\mu_{VH} = \underline{\mu_{VH}} \text{ and } v_{VH} = 1 - \overline{\mu}_{VH}$$

d) Membership and non-membership function for Signal Strength

$$\mu_W(x, [1.7\,, 1.2], [-95.0\,, -95.0]) = e^{\frac{-1}{2}\left(\frac{x-[-95.0\,,-95.0]}{[1.7\,,\ 1.2]}\right)^2}$$

$$\mu_W = \underline{\mu_W} \text{ and } v_W = 1 - \overline{\mu}_W$$

$$\mu_M(x, [1.7\,, 1.2], [-90.0\,, -90.0]) = e^{\frac{-1}{2}\left(\frac{x-[-90.0\,,-90.0]}{[1.7\,,\ 1.2]}\right)^2}$$

$$\mu_H = \underline{\mu_H} \text{ and } v_H = 1 - \overline{\mu}_H$$

$$\mu_S(x, [1.7\,, 1.2], [-85.0\,, -85.0]) = e^{\frac{-1}{2}\left(\frac{x-[-85.0\,,-85.0]}{[1.7\,,\ 1.2]}\right)^2}$$

$$\mu_S = \underline{\mu_S} \text{ and } v_S = 1 - \overline{\mu}_S$$

e) Membership and non-membership function User Mobility

$$\mu_L(x, [0.8\,, 0.6], [0\,, 0]) = e^{\frac{-1}{2}\left(\frac{x-[0\,,\ 0]}{[0.8\,,\ 0.6]}\right)^2}$$

$$\mu_L = \underline{\mu_L} \text{ and } v_L = 1 - \overline{\mu}_L$$

$$\mu_M(x, [0.7\,, 0.5], [3\,, 3]) = e^{\frac{-1}{2}\left(\frac{x-[3\,,\ 3]}{[0.7\,,\ 0.5]}\right)^2}$$

$$\mu_H = \underline{\mu_M} \text{ and } v_M = 1 - \overline{\mu}_M$$

$$\mu_H(x, [0.8, 0.6], [6\,, 6]) = e^{\frac{-1}{2}\left(\frac{x-[6\,,6]}{[0.8\,,\ 0.6]}\right)^2}$$

$$\mu_H = \underline{\mu_H} \text{ and } v_H = 1 - \overline{\mu}_H$$

Table 2: Membership, Non-membership and Hesitancy Values Matrix for Latency (LA)

Fuzzy Set	Crisp Input					
	10	20	40	60	80	100
L	[0.08, 0.7, 0.22]	[1.0, 0.0, 0.0]	[0.0, 0.9992, 0.008]	[0.0, 1.0, 0.0]	[0.0, 1.0, 0.0]	[0.0, 1.0, 0.0]
M	[0.0, 0.0993, 0.0007]	[0.020, 0.9831, 0.0149]	[0.506, 0.3646, 0.0149]	[0.506, 0.3646, 0.0149]	[0.020, 0.9831, 0.0149]	[0.0, 1.0, 0.0]
H	[0.0,1.0, 0.0]	[0.0, 1.0, 0.0]	[0.0, 1.0, 0.0]	[0.001, 0.9912, 0.0087]	[1.0, 0.0, 0.0]	[0.001, 0.9912, 0.0087]

Table 3: Membership, Non-membership and Hesitancy Values Matrix for Packet Loss (PL)

Fuzzy Set	CRISP INPUT					
	0	1	2	3	4	5
L	[1.0, 0.0, 0.0]	[0.2494, 0.5422, 0.2085]	[0.0039, 0.9561, 0.0401]	[0.0, 0.9991, 0.0009]	[0.0, 1.0, 0.0]	[0.0, 1.0, 0.0]
M	[0.0, 1.0,	[0.001,0 .9961,	[0.3604, 0.4606, 0. 1790]	[0.3604, 0.4606,	[0.001, 0.9961,	[0.0, 1.0,

	0.0]	0.0038]		0.1790]	0.0038]	0.0]
H	[0.0, 1.0, 0.0]	[0.0,1.0, 0.0]	[0,0.991, 0.0009]	[0.0039, 0.9561, 0.0041]	[0.2494, 0.5422, 0.2085]	[1.0, 0.0, 0.0]

Table 4: Membership, Non-membership and Hesitancy Values Matrix for Load (LD)

Fuzzy Set	10	30	50	70	90
VL	[0.1352, 0.6396, 0.2251]	[0.1352, 0.6396, 0.2251]	[0, 0.999, 0.0001]	[0.0, 1.0, 0.0]	[0.0, 1.0, 0.0]
L	[0, 0.9991, 0.0009]	[0.2494, 0.5422, 0.2085]	[0.2494, 0.5422, 0.2085]	[0, 0.9991, 0.0009]	[0.0, 1.0, 0.0]
H	[0.0, 1.0, 0.0]	[0.0, 1.0, 0.0]	[0, 0.999, 0.0001]	[0.1353, 0.6396, 0.2251]	[0.0, 0.9999, 0.0001]
VH	[0.0, 1.0, 0.0]	[0.0, 1.0, 0.0]	[0, 0.999, 0.0001]	[0.1353, 0.6396, 0.2251]	[0.1353, 0.6396, 0.2251]

Table 5: Membership, Non-membership and Hesitancy Values Matrix for Signal Strength (SS)

Fuzzy Set	Crisp Inputs				
	-96	-94	-90	-85	-82
W	[0.7066, 0.1589, 0.1345]	[0.7066, 0.1589, 0.1345]	[0.002, 0.9689, 0.0131]	[0.0, 1.0, 0.0]	[0.0, 1.0, 0.0]
M	[0.0, 0.9980, 0.0020]	[0.0039, 0.9372, 0.00589]	[1.0, 0.0, 0.0]	[0.002, 0.9868, 0.0131]	[0.0, 1.0, 0.0]
S	[0.0, 1.0, 0.0]	[0.0, 1.0, 0.0]	[0.002, 0.9868, 0.0131]	[1.0, 0.0, 0.0]	[0.0044, 0.7893, 0.1668]

Table 6: Membership, Non-membership and Hesitancy Matrix for User Mobility

Fuzzy Set	Crisp Input				
	1	2	3	4	5
L	[0.2494, 0.5422, 0.2085]	[0.0039, 0.9561, 0.0040]	[0.00, 0.9991, 0.0009]	[0.0, 1.0, 0.0]	[0.0, 1.0, 0.0]
M	[0.0003, 0.9831, 0.0165]	[0.1353, 0.6396, 0.2251]	[1.0, 0.0, 0.0]	[0.1353, 0.396, 0.225]	[0.0003, 0.9831, 0.0165]
H	[0.0, 1.0, 0.0]	[0.0, 1.0, 0.0]	[0.000, 0.991, 0.0009]	[0.0039, 0.9561, 0.0040]	[0.2494, 0.5422, 0.2085]

Intuitionistic Fuzzy Rules (IFR) - CAC for Uncertainty and Congestion Elimination in 4G Networks.

Intuitionistic fuzzy rules are defined in the work based on (25). Fuzzy rules for the MF and NMFs are defined respectively based on and (26-27). Rules are defined based on human expert opinion. There are 243 rules defined for the IT2IFLS and parts of the rules are presented Table 7 for simplicity. In the IT2FLS, the rule base part re enclosed with five antecedents *(LA, PL, SS, LD, UM)*.

Table 7: Intuitionistic Fuzzy Rules (IFR)

S/N	Latency	Packet Loss	Load	Signal Strength	User Mobility	CAF
1	L	L	VL	W	H	EXCELLENT [1.0,0.0]
2	H	H	VH	S	L	FAIR [1.0, 0.0]
3	H	H	VH	S	L	FAIR [1.0, 0.0]
4	L	M	VL	W	H	EXCELLENT [1.0, 0.0]
5	L	H	VL	W	H	GOOD [0.3, 0.8]
6	L	L	VL	W	H	EXCELLENT [1.0, 0.0]
7	L	M	VL	W	H	GOOD [0.3, 0.8]
8	L	H	VL	W	H	GOOD [1.0, 0.0]
9	M	L	VL	W	H	GOOD [0.3, 0.8]
10	M	M	VL	W	H	GOOD [1.0, 0.0]
11	M	H	VL	W	H	GOOD [1.0, 0.0]
12	H	L	VL	W	H	GOOD [1.0, 0.0]
13	H	M	VL	W	H	GOOD [1.0, 0.0]
14	H	H	VL	W	H	FAIR [0.32, 0.71]
15	H	L	VL	W	H	GOOD [1.0, 0.0]
16	H	M	VL	W	H	FAIR [0.32, 0.71]
17	H	H	VL	W	H	FAIR [1.0, 0.1]
18	L	M	L	M	M	EXCELLENT [1.0, 0.0]
19	L	H	L	M	M	GOOD [0.3, 0.8]
20	L	M	L	M	M	GOOD [0.3, 0.8]
21	L	H	L	M	M	GOOD [1.0, 0.0]
22	M	M	L	M	M	GOOD [1.0, 0.0]
23	M	H	L	M	M	GOOD [1.0, 0.0]
24	H	M	L	M	M	GOOD [1.0, 0.0]
25	H	H	L	M	M	FAIR [0.32, 0.71]
26	H	M	L	M	M	FAIR [0.32, 0.71]
27	H	H	L	M	M	FAIR [0.9, 0.22]
28	L	H	H	S	L	GOOD [0.3, 0.8]
29	L	M	H	S	L	EXCELLENT [1.0, 0.0]
30	L	M	H	S	L	GOOD [0.3, 0.8]
31	L	H	H	S	L	GOOD [1, 0.1]
32	M	M	H	S	L	GOOD [1, 0.1]
33	M	H	H	S	L	GOOD [1.0, 0.0]
34	H	M	H	S	L	GOOD [1.0, 0.0]
35	H	H	H	S	L	FAIR [0.32, 0.71]

36	H	M	H	S	L	FAIR [0.32, 0.71]
37	H	H	H	S	L	FAIR [1, 0.1]
38	L	L	VH	W	H	GOOD [1, 0.1]
39	L	M	VH	W	H	GOOD [1, 0.1]
40	L	H	VH	W	H	FAIR [0.32, 0.71]
41	L	L	VH	M	M	GOOD [0.3, 0.8]

Intuitionistic Fuzzy Inference Mechanism (IFIM) for IT2IFL-CAC

In IT2IFLS, the IFIM is applied and the appropriate IF- THEN type intuitionistic fuzzy rules in the knowledge base is activated using Mamdani inference method in (28).The M and NM interval of each of the crisp input is computed and then the firing strength of the *pth* rule of the fired M/NM values for both the upper and lower bounds are calculated. The fired rules are combined and the input IT2FSs and output IT2FSs are mapped by computing unions and intersections of type-2 sets, as well as compositions of type-2 relations for the MFs and NMFs using (29)–(32) respectively.The main idea is to determine the effect of the five input parameters *(Latency, Packet Loss, Load, Signal Strength and User Mobility)*in the antecedent partsuch that a concise representation of the system's behavior which is *Call Admittant Factor (CAF)*in this case is produced in the consequent part.

For example, given the crisp input vector, v = [20, 2, 50, -94, 2] their degree of M and NM are calculated from respective Gaussian MFs and the fuzzified values for the five input parameters and is presented in Table 8. Evaluating rules 20, 22, 30, 32, 45 against the IFS yields the firing level as shown in Table 9.

Table 8: Fuzzified Values with crisp vector of [20, 2, 50, -94, 2]

Latency $[\overline{\mu}^1, \underline{\mu}^1, \overline{v}^1, \underline{v}^1]$	PacketLoss $[\overline{\mu}^2, \underline{\mu}^2, \overline{v}^2, \underline{v}^2]$	Load $[\overline{\mu}^3, \underline{\mu}^3, \overline{v}^3, \underline{v}^3]$	Signal Strength $[\overline{\mu}^4, \underline{\mu}^4, \overline{v}^4, \underline{v}^4]$	Mobility $[\overline{\mu}^5, \underline{\mu}^5, \overline{v}^5, \underline{v}^5]$
μL[1.0,1.0, 0.0, 0.0]	μL [0.037, 0.0422,0.9578, 0.9963]	μVL [0.000,0.0001, 0.9999, 1.000]	μW [0.6116,0.7280, 0.2720, 0.3884]	μL[0.0037,0.0422, 0.9578, 0.9963]
μM[0.0019, 0.0166, 0.9834, 0.9981]	μM [0.2959, 0.4429, 0.5571, 0.7041]	μL [0.1974,0.3624, 0.6376, 0.8026]	μM [0.036,0.0591,0.9409, 0.9964]	μM[0.1649,0.2793, 0.7207, 0.8951]
μH[0.0,0.0, 1.000, 1.000]	μH [0.0,0.0, 0.9991, 1.000]	μH [0.1352,0.3601, 0.6399, 0.8648]	μS [0.0,0.0, 1.0, 1.0]	μH[0.0,0.0, 1.0, 1.0]
		μVH[0.000,0.000, 0.9999, 1.000]		

Table 9: Firing Level on Rule Evaluation of 20, 22, 30, 32, 45 against the IFS

Rule No.	Firing Interval	Consequent
R20	$[\underline{f}_1^{\mu}, \overline{f}_1^{\mu}, \underline{f}_1^{v}, \overline{f}_1^{v}] =$ = [0.001443,0.00006331, 0, 0]	$[y_1^{\mu}, y_1^{v}]$ = GOOD $[0.3, 0.8]$
R22	$\left[\underline{f}_2^{\mu}, \overline{f}_2^{\mu}, \underline{f}_2^{v}, \overline{f}_2^{v}\right] =$ = [2.7420e-06, 1.0567e-06,0.4956, 0.2404]	$[y_2^{\mu}, y_2^{v}]$ = GOOD [1.0, 0.0]
R30	$[\underline{f}_3^{\mu}, \overline{f}_3^{\mu}, \underline{f}_3^{v}, \overline{f}_3^{v}] =$ = [0.0, 0.0, 0.0, 0.0]	$[y_3^{\mu}, y_3^{v}]$ = GOOD [0.3, 0.8]
R32	$[\underline{f}_4^{\mu}, \overline{f}_4^{\mu}, \underline{f}_4^{v}, \overline{f}_4^{v}] =$ = [0.0, 0.0, 0.5966, 0.3405]	$[y_4^{\mu}, y_4^{v}]$ = GOOD [1, 0.1]
R45	$[\underline{f}_5^{\mu}, \overline{f}_5^{\mu}, \underline{f}_5^{v}, \overline{f}_5^{v}] =$ = [2.0987e-10, 6.5133e-08, 0.6874, 0.4722]	$[y_5^{\mu}, y_5^{v}]$ = FAIR [0.32, 0.71]

Intuitionistic Defuzzification

The study adapts TSK method to compute the IT2IFLS final crisp output using (33) - (36) respectively. For our illustration, the crisp output, y is computed using the composition of member and non membership output values with the value β and P at 0.5 and 5.

$$(1 - \beta)\sum_{k=1}^{P}\left(\underline{f_k^{\mu}} + \overline{f_k^{\mu}}\right)y_k^{\mu} = 2.2977e - 4$$

$$\sum_{k=1}^{P}\underline{f_k^{\mu}} + \sum_{k=1}^{P}\overline{f_k^{\mu}} = 0.0015$$

$$\beta\sum_{k=1}^{P}\left(\underline{f_k^{v}} + \overline{f_k^{v}}\right)y_k^{v} = 0.4585$$

$$\sum_{k=1}^{P}\underline{f_k^{v}} + \sum_{k=1}^{P}\overline{f_k^{v}} = 2.8327$$

$$y = 0.3151$$

Hence, given the crisp input vector v = [20, 2, 50, -94, 2] for LA, PL, LD, SS and UM, the Call Admittance Factor (CAF) produced is 0.3151 or 31.51% fair quality of service influence on the 4G network. This indicates that based on the level of influence of the five input variables on the output parameter, the IT2IFLS gives a CAF with 31.51% possibility.

The output of the system is described mathematically using (37).A threshold is set to categorize the level of system order to constrain the limits of acceptance values. A threshold is a value of a metric that should cause an alert to be generated or management action to be taken (Ramkumar and Mandalika, 2010). In this work, a threshold of 50% and above indicates that network resources are available hence; a call can be accepted into the network. Therefore, in regard the output of "CAF = 31%", the call will be blocked i.e. not accepted into the network.

$$Output = \begin{cases} POOR: & if\ \ output \leq 25\% \\ FAIR: & if\ \ 25\% < output \leq 50\% \\ GOOD: & if\ 50\% < \ output \leq 75\% \\ EXCELLENT: & if\ \ output > 75\% \end{cases} \quad (37)$$

For the purpose of comparison and testing of the utilization of our work, we employ the following performance measures: Mean Absolute Difference (MAD), Mean Absolute Percentage Error (MAPE), Mean Squared Error (MSE) and Root Mean Squared Error (RMSE) to measure our experimental results. The performance metrics are defined in (38) to (41) respectively.

$$MAD = \frac{1}{N}\sum_{i=1}^{n}|y^x - y| \quad (38)$$

$$MAPE = \frac{1}{N}\sum_{i=1}^{n}|y^x - y|\ /y^x \quad (39)$$

$$MSE = \frac{1}{N}\sum_{i=1}^{N}(y^x - y)^2 \quad (40)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y^x - y)^2} \quad (41)$$

Where y^x is desired output, y is the computed output and N is the number of data items respectively.

IV. Results and Discussion

The paper applies the IT2IFL model for uncertainty elimination and congestion control in 4G Networks call admission control. The system uses 4G network admission control quality of service indicators (variables) which are, Latency, Packet Loss, Load, Signal Strength and user Mobility to model their effects on Call Admittance Factor (CAF). The model employs intuitionistic fuzzifier based on a Gaussian membership function approach for membership function evaluation with intuitionistic width (variance) and center (mean) membership and non-membership for the input vectors respectively. Mamdani Fuzzy Inference is used to infer knowledge from the rule base where the output of each IF-THEN rule is an Intuitionistic fuzzy set. The inference engine returns a crisp set using the composition of the membership and the non-membership functions through defuzzification process. The system is developed using Java software development toolkit (SDK), Intellij Intergrated Development Environment (IDE), MySQL (Structured Query Language), etc.

The system is simulated with different sets of selected input values from the input parameters and the output (CAFs) are produced as results. Sample results of the application are shown in Figures 6 to 9 respectively. Parts of the results obtained from applying different IT2IFLS to the admission control process to eliminate uncertainty and control congestion in order to guarantee efficient QoS are presented in Table 10. Tables 11 give the results of the comparison of IT2IFLS with IT2FLS and T1FLS in CAC. Table 12 shows the results of performance evaluation of the application of the three approaches, IT2IFLS, IT2FLS and T1FLS in call admission control in 4G Network respectively. Figures 10 shows the graphs of Tables 10 forIT2IFLSand Figures 11 and 12 represent the graphs of the resuls of applying IT2FLS and T1FLSrespectively. Figure 13 shows the graph of the results of comparison of the three approaches. The horizontal x-axis of the graphs presents the sample input dataset for the five input parameters (LA, PL, LD, SS and UM). While the computed output values being the Call Admittant Factor (CAF) are displayed on the vertical y-axis of the graphs respectively.

Table 10: Results of IT2IFL-CAC for Uncertainty and Congestion Elimination in 4G Networks

S/N	LA	PL	LD	SS	UM	IT2IFLS (CAF)
1	70	3.0	65	-86	1.0	0.8518
2	20	2	50	-94	2	0.3151

3	25	3.6	29	-92	5.5	0.7123
4	20	3.75	73	-92	5.0	0.3245
5	75	3.6	29	-92	5.5	0.6848
6	26	3.75	30	-92	5.5	0.4356
7	65	4.0	52	-85	1.5	0.6045
8	20	4.0	73	-85	2.0	0.6341
9	90	4.0	73	-85	2.0	0.4418
10	65	5.0	90	-91	4.55	0.3456
11	40	2.0	50	-70	3.0	0.5889
12	65	4.0	80	-95	4.0	0.9632
13	20	5.0	65	-80	1.0	0.6353
14	80	3.5	45	-75	2.5	0.6372
15	55	4.5	35	-75	3.0	0.9436
16	70	5	50	-95	3.0	0.6847
17	70	3	30	-95	3	0.7344
18	5	4	20	-95	3	0.6341
19	80	4	20	-80	3	0.5908
20	45	3	19	-81	2.7	0.3032

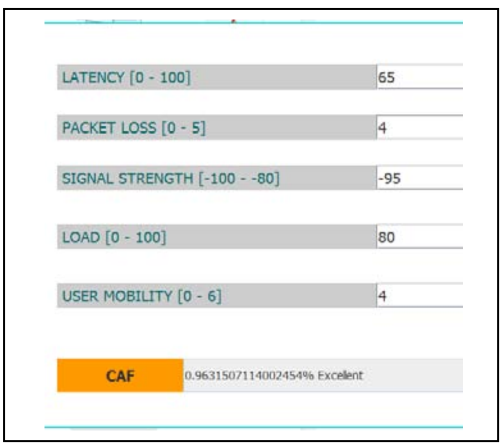

Fig. 6: The Result of IT2IFLS-CAC with input values of LA=65, PI=4, LD=80, SS=-95 and UB=4

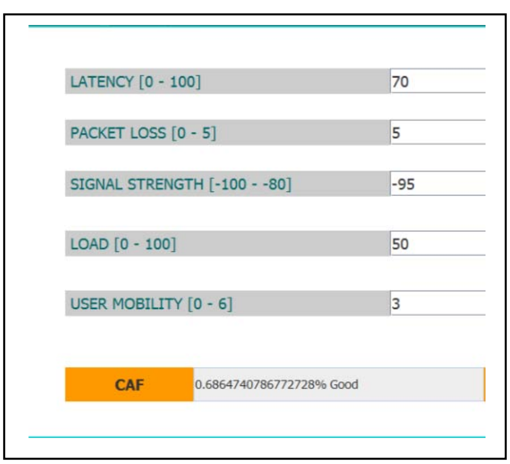

Fig. 7: The Result of IT2IFLS-CAC with input values of LA=70, PI=5, LD=50, SS=-95 and UB=3

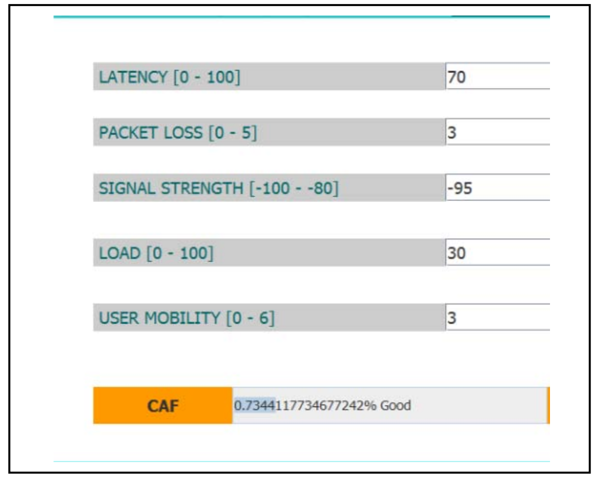

Fig. 8: The Result of IT2IFLS-CAC with input values of LA=70, PI=3, LD=30, SS=-95 and UB=3

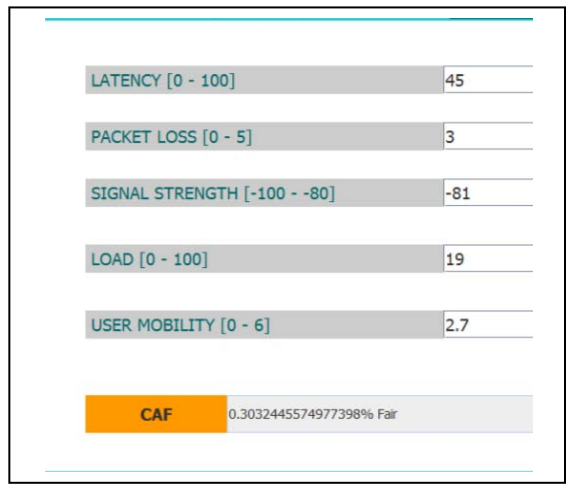

Fig. 9: The Result of IT2IFLS-CAC with input values of LA=45, PI=3, LD=19, SS=-81 and UB=2.7

Table 11: Results of comparison of IT2IFL, IT2FLS and T1FLS-CAC for Uncertainty and Congestion Elimination in 4G Networks

S/N	LA	PL	LD	SS	UM	T1FLS (CAF)	IT2FLS (CAF)	IT2IFLS (CAF)
1	70	3.0	65	-86	1.0	0.7912	0.8283	0.8518
2	20	2	50	-94	2	0.2134	0.2574	0.3151
3	25	3.6	29	-92	5.5	0.5952	0.6715	0.7123
4	20	3.75	73	-92	5.0	0.2503	0.3050	0.3245
5	75	3.6	29	-92	5.5	0.6122	0.6637	0.6848
6	26	3.75	30	-92	5.5	0.3947	0.4120	0.4356
7	65	4.0	52	-85	1.5	0.5272	0.5493	0.6045
8	20	4.0	73	-85	2.0	0.5821	0.6133	0.6341
9	90	4.0	73	-85	2.0	0.3982	0.4196	0.4418
10	65	5.0	90	-91	4.55	0.2766	0.3026	0.3456

11	40	2.0	50	-70	3.0	0.3948	0.4248	0.5889
12	65	4.0	80	-95	4.0	0.8238	0.8938	0.9632
13	20	5.0	65	-80	1.0	0.5433	0.6033	0.6353
14	80	3.5	45	-75	2.5	0.4701	0.5501	0.6372
15	55	4.5	35	-75	3.0	0.766	0.8066	0.9436
16	70	5	50	-95	3.0	0.6202	0.6623	0.6847
17	70	3	30	-95	3	0.6733	0.7149	0.7344
18	5	4	20	-95	3	0.5421	0.6252	0.6341
19	80	4	20	-80	3	0.4691	0.534	0.5908
20	45	3	19	-81	2.7	0.1356	0.2515	0.3032

Table 12: RMSE Comparison of IT2IFL, IT2FL and IT1FLS in Call Admission Control in 4G Network

	Mean	Variance	MAD	MAPE	MSE	RMSE
T1FLS	0.04967	0.02359	0.04534	47.7214	0.00157	0.01254
IT2FLS	0.05401	0.02007	0.04099	43.1488	0.00134	0.01157
IT2IFLS	0.06079	0.01577	0.03439	36.1972	0.00105	0.01025

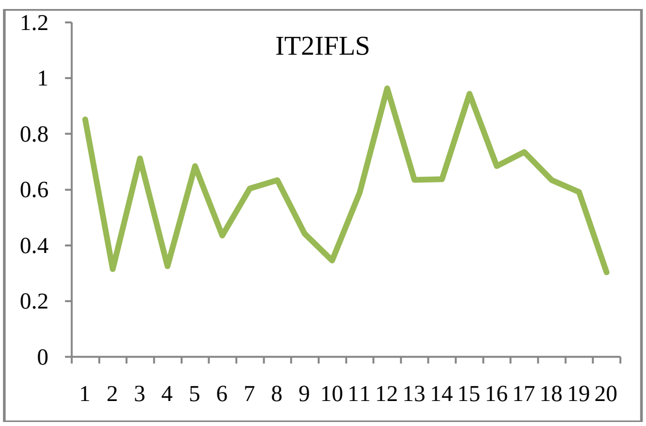

Fig. 10: Graph of IT2IFLS-CAC CAC for Uncertainty and Congestion Elimination in 4G Networks

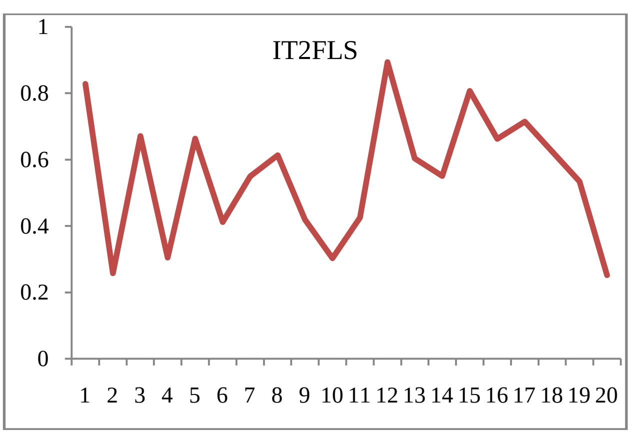

Fig. 11: Graph of IT2FLS-CAC CAC for Uncertainty and Congestion Elimination in 4G Networks

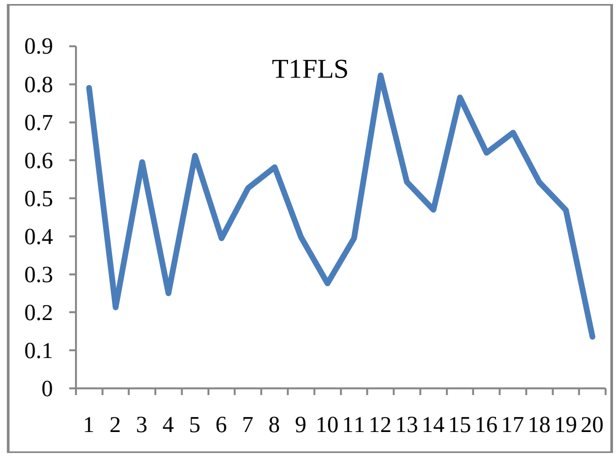

Fig. 12: Graph of T1FLS-CAC CAC for Uncertainty and Congestion Elimination in 4G Networks

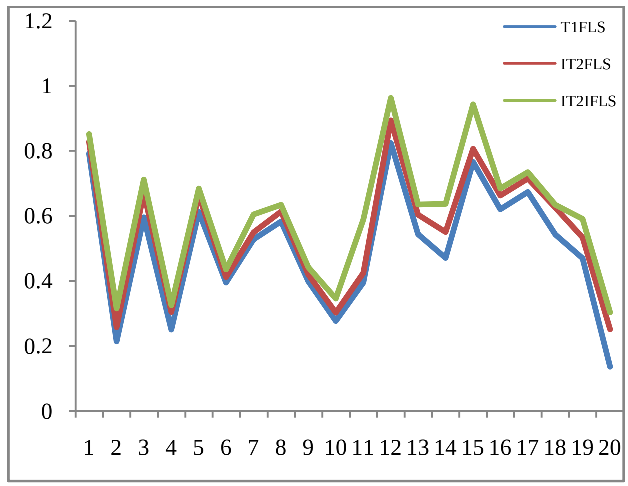

Fig. 13: Graph of comparison of IT2IFLS, IT2FLS and T1FLS CAC for Uncertainty and Congestion Elimination in 4G Networks

From Figures 6, it is observed that when the input values of moderate latency of 65%, moderate packet loss of 4%, high load of 80%, weak signal strength of -95dBm and moderate user mobility of 4m/s are selected and applied in the IT2IFLS-CAC system, the result yields approximately 96% excellent call admittant factor possibility. This indicates that the network has excellent resources to admit/accept the call into the network. From Figure 7, the result of IT2IFLS-CAC with input values of LA=70, PI=5, LD=50, SS=-95 and UB=3 gives a good call admittance factor of 68% based on the level of influence of the input on the output. This indicates that the network has good resources to admit/accept the call into the network. Figure 8, shows that with the input values of LA=70%, PI=3, LD=30%, SS=-95dBm and UB=3m/s, the results show that a 73% good call admittance based on the level of influence of the inputs on the output. This indicates that resources are available and the call is admitted into the network with a good QoS. With input values of LA=45%, PI=3, LD=19, SS=-81dBm and

UB=2.7m/s, the result in Figure 9 shows a poor call admittance factor of 30% based on the level of influence of the input on the output. This indicates that the network does not have enough resources to admit the call i.e. the call is not accepted into the network.

From Tables 10 and 12it is observed that the result of IT2IFLS outperforms IT2FLS and T1FL on the same set of input parameters values. Example 1, with 20% Low Latency and 2% low packet loss, and 50% Low load, -94 low signal strength and 2% moderate user Mobility, 31.51(32%) fair CAF is achieved using IT2IFLS approach against 25.74(26%) fair and 0.2134(21%) poor CAF with IT2FL and T1FLS methods. Example 2, with 80% high Latency and 3.5% moderate packet loss, and 45% Low load, -94dBm low signal strength and 2.5m/s moderate user Mobility, 0.6372(64%) good CAF is achieved using IT2IFLS approach against good CAF IT2FL with 0.5501(55%) possibility and 0.4706(47%) fair CAF with T1FLS method. From Figure 10, it is generally observed that approximately 100% excellent optimal value in terms of QoS demands and overall network performance is achieved using the three approaches with 55% medium latency, 4.5% high packet loss, 35% low load, -75strong signal strength and 3.0m/s moderate user mobility factor. While approximately 70% good optimal quality of service demands and overall performance of the 4G network is accomplished using IT2IFLS, IT2FLS and T1FLS with 25% low latency, 3.6% high packet loss, 29% very low load, -92 strong signal strength and 5.5m/s high user mobility factors respectively. Generally, it noticed that an average of 35% poor quality of service demands and poor overall performance of the 4G network is accomplished using IT2IFLS, IT2FLS and T1FLS with 25% low latency, 3.6% high packet loss, 29% very low load, -92 strong signal strength and 5.5m/s high user mobility factors respectively.

Considering the entire dataset, it is generally observed that the network exhibits 20% excellent, 47% good, 33% fair and 0% poor performance with respect to IT2IFLS against IT2FLS with 20% excellent, 40% good, 40% fair and 0% poor performance and T1FLS with 20% excellent, 26.7% good, 47% fair and 6.7% poor performance in uncertainty and congestion elimination in 4G Networks for improve QoS. From the above result, it can be deduced that on the same sets of data, the three approaches exhibit same level of optimal excellent performance. While our system outperforms it counterparts in achieving 47% good performance against 40% and 26.7% respectively in handling uncertainty and congestion control in 4G network. However, there is an indication that T1FLS has produced 47% fairest performance compared to IT2IFLS and IT2FLS generally. This is an indication that in some cases, where the system is less noisy, classical F1LS achieve the fairest performance to the IT2IFLS and IT2FLS counterparts.

The result of the measurement and evaluation of IT2IFLS-CACdeveloped system using VARIANCE, MAD, MAPE, MSE and RMSE for the purpose of comparison and testing of the experimental results for utilization against IT2FLS and T1FLS are presented in Table 13. From Table 13, it is observed that, our model, IT2IFLS gives the least VARIANCE of 0.01577 against IT2FLS with 0.02007 and T1FLS with 0.02359 respectively. From the table, it is also noted that, the MAD performance measure shows the lowest error rate of 0.03439 with IT2IFLS as it outperforms IT2FLS and T1FL with error rates of 0.04099 and 0.04534 respectively. Performance evaluation with MAPE gives the least percentage error of approximately 36% with IT2IFLS as it outperforms IT2FLS and T1FL with the approximate percentage error of error of 43% and 48% respectively From the same table, it is also indicated that IT2IFLS outperforms both classical IT2FLS and IFLS in terms of the MSE test with error rates of 0.00105 against 0.00134 and 0.00157respectively. Also, it is interesting to observe from the table that RMSE performance measure applied in the work gives the least error rate of 0.01025 with IT2IFLS as it outperforms IT2FLS with error rate of 0.01157and T1FL with error rate of 0.01254 respectively.

From the results of the five performance indicators applied in the study, it is generally observed that MSE gives the least error rate followed by RMSE. The least MSE and RMSE in IT2IFLS compared with IT2FLSand T1FL is as a result of the presence of additional degrees of freedom in the NMF and hesitation indexes. It is observed that the lower the error, the better the performance of the technique. Also, the increase in the level of fuzziness in IT2IFLS gives a more accurate and promising approximation and a significant performance improvement compared to IT2FLS and T1FL approaches in handling CAC control problem. This way our Fuzzy system behaves more humanly as it can cater for the situations where an expert cannot give sufficient knowledge about a criterion or parameter. The system is expected to improve the utilization of network resources as well as keeping satisfactory QoS levels.

V. Conclusion

The paper uses the IT2IFLS call admission control (CAC) approach for uncertainty elimination and congestion control for guaranteed QoS in 4G mobile Networks in order to improve the system performance. Also, the study implements IT2FLS and T1FLS CAC for the purpose of comparison. The system is able to determine the effect of input variables, latency, packet loss, load, signal strength and user mobility in the antecedent part and a concise representation of the system's behavior which is call connection is produced in the consequent part. We have shown that IT2FLS-CAC outperforms IT2FLS and T1FLS on the same set of input parameters values. From the study, it is shown that

IT2IFLS-CAC gives a better and more accurate performance than IT2FLS and T1FL. This is as a result of the presence of additional degrees of freedom in the NMF and hesitation indexes. Also, as shown in the Table 13, IT2IFLS approach exhibits superior performance with MSE and RMSE on test data than IT2FLS and T1FLS respectively. The IT2IFLS approach exhibits most superior performance with MSE in all cases. Particularly, the study has been able to show that an IT2IFLS for call admission control is able to preserve all the qualities of an IT2IFLS for call admission control of congestion and has the ability to still cope with adequately with uncertainty in the packet delay measurements in 4G networks. The IT2IFLS has indicated its ability to further reduce uncertainty by handling conflicting evaluation involving membership (M) non-membership (NM) and hesitation and the capacity to cope with more imprecision thereby modeling imperfect and imprecise knowledge better than IT2FLS and T1FLS. In the future, we aim to employ triangular membership functions and TSK fuzzy inference in the design of IT2IFLS for CAC in 4G networks. Also, we intend to learn and optimize the parameters of the membership and non membership functions of IT2IFLS-TSK for a better performance by using learning tools such as gradient descent (GD), decoupled extended Kalman filter (DEKF), particle swarm optimization (PSO), flower pollination algorithm, etc and compare results with our system.

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Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Deep Loving - The Friend of Deep Learning

By Satish Gajawada & Hassan M. H. Mustafa
Indian Institute of Technology Roorkee

Abstract- Artificial Intelligence and Deep Learning are good fields of research. Recently, the brother of Artificial Intelligence titled "Artificial Satisfaction" was introduced in literature [10]. In this article, we coin the term “Deep Loving”. After the publication of this article, "Deep Loving" will be considered as the friend of Deep Learning. Proposing a new field is different from proposing a new algorithm. In this paper, we strongly focus on defining and introducing "Deep Loving Field" to Research Scientists across the globe. The future of the "Deep Loving" field is predicted by showing few future opportunities in this new field. The definition of Deep Learning is shown followed by a literature review of the "Deep Loving" field. The World's First Deep Loving Algorithm (WFDLA) is designed and implemented in this work by adding Deep Loving concepts to Particle Swarm Optimization Algorithm. Results obtained by WFDLA are compared with the PSO algorithm.

Keywords: deep learning, deep loving, artificial intelligence, artificial satisfaction, artificial mothers, swarm intelligence, artificial mother optimization, artificial human optimization, artificial soul optimization, artificial god optimization.

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Contribution of Authors:

1. Direct Contribution: Satish Gajawada and Hassan M. H. Mustafa contributed directly, completely, and equally to this article.

I. Definition of Deep Loving Field

Just like Mothers in real-world solve real problems, Artificial Mothers (in Deep Loving Field) move in the search space for solving optimization problems. In Deep Loving, we imitate mothers in the real space. In the Artificial Human Optimization field [6-7], Artificial Soul Optimization field [8], and Artificial God Optimization field [9], the basic entities in search space are Artificial Humans, Artificial Souls, and Artificial Gods respectively. Similarly, the basic entities in the Deep Loving Field are Artificial Mothers. Whenever we think of the term "Mother," the Deep Love that each mother shows towards their family, children, etc. comes to mind. Hence the name "Deep Loving Field" is given to the field when Artificial Mothers in search space are imitating Mothers in real-world to solve optimization problems. Instead of naming the field as "Artificial Mother Optimization," a better name "Deep Loving" is chosen by us.

Author α: Indian Institute of Technology Roorkee, Independent Inventor and Scientist, The Creator of Artificial Satisfaction Field, Inventor of Artificial Soul Optimization and Artificial God Optimization Fields, Founder and Father of Artificial Human Optimization Field, Inventor of Deep Loving Field. e-mail: satish.gajawada.iit@gmail.com
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II. Infinite Opportunities in the New Deep Loving Field

There are INFINITE OPPORTUNITIES for Artificial Intelligence field Research Scientists in Deep Loving Field. Some of them are shown below:

1. International Conference on Deep Loving (ICDL 2020)
2. IEEE TRANSACTIONS on Deep Loving (IEEE TDL 2025)
3. International Workshop on Deep Loving, Harvard University, 2050
4. B.Tech Thesis on Deep Loving, IIT Roorkee, the Year 2075
5. IBM Deep Loving Research Labs, IBM Italy
6. Applied Deep Loving - A New Course
7. Advanced Deep Loving Course, IIT Mumbai
8. M.Tech in Deep Loving Field
9. International Institute of Deep Loving, Greece
10. Ph.D. Thesis on Deep Loving, Stanford University
11. Invited Talk on Deep Loving at Google R&D Conference, USA
12. Foundation of Deep Loving, Germany
13. International Association of Deep Loving, China
14. Deep Loving team at Microsoft Research and Development
15. YouTube videos on Deep Loving by Samsung R&D Team
16. Springer Journals on Deep Loving Field
17. Elsevier Book on Deep Loving Field
18. A Course by Deep Loving Experts on Coursera
19. Presentation on Deep Loving Field at Technical Festivals in Singapore Colleges
20. IBMSUR Award for Deep Loving Field Professor at IIT Hyderabad
21. To become a Scientist in Deep Loving Field.

III. Deep Learning

According to Wikipedia, the definition of Deep Learning is shown below in double-quotes as it is:

"Deep Learning is part of a broader family of machine learning methods based on Artificial Neural Networks with representation learning. Deep Learning architectures such as deep neural networks, Deep belief networks, recurrent neural networks, and convolutional neural networks have been applied to many fields including computer vision, machine vision, etc" [1].

Hence from the definition, it is clear that Deep Learning is related to Brain-Inspired Computing.

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IV. Literature Review

There are many Deep Learning papers published in the literature. But there is not even a single paper which is based on Deep Loving. The World's First Deep Loving method is created in this article. For the sake of completeness, references [2] to [5] show Deep Learning articles. You can easily find references for Deep Learning on websites like deeplearning.net. We just showed four references for Deep Learning for completeness.

V. World's first Deep Loving Algorithm (wfdla)

Figure 1 shows the World's First Deep Loving Algorithm (WFDLA). This section explains WFDLA. All Artificial Mothers are initialized, and the iteration count is set to zero in the beginning. Lines 2-5 find local best, global best, local worst, and global worst of all Artificial Mothers. If Artificial Mother is affected by coronavirus, then there are two possibilities. Either Artificial Mother receives help from others or not. If Artificial Mother is affected by a coronavirus and receives help from others, then she can move in search space and updates Velocity and Position. If Artificial Mother is affected by a coronavirus and doesn't receive help from others, then she is halted and cannot move in search space. Hence, Velocity and Position are not updated. If Artificial Mother is not affected by coronavirus, then she can move in search space and updates Velocity and Position. Figure 1 is shown below:

```
1)    Initialize all Artificial Mothers. Set Iteration Counter to 0.
2)    Find local best of all Artificial Mothers
3)    Find global best of all Artificial Mothers
4)    Find local worst of all Artificial Mothers
5)    Find global worst of all Artificial Mothers
6)    for each Artificial Mother do
7)        if (Random_Number_Generated < CoronavirusProbability) then
8)              if ( Random_Number_Generated < HelpProbability) then
9)                   Update Velocity of Artificial Mother
10)                  Update Position of Artificial Mother
11)           else
12)                // Mothers affected by coronavirus without help does nothing
13)           end if
14)     else
15)           Update Velocity of Artificial Mother
16)           Update Position of Artificial Mother
17)     end if
18)   end for
19)   Update Iteration Counter
20)   if (termination_condition_reached is not true) then
21)     go to line number 2
22)   end if
```

Figure 1: World's First Deep Loving Algorithm (WFDLA)

VI. Results

The ASA algorithm in [10], and WFDLA designed in this paper are MATHEMATICALLY equal. In [10] it was shown that both ASA and PSO algorithms performed well on all benchmark functions. Hence due to MATHEMATICAL EQUALITY, both WFDLA and PSO performed well on all benchmark functions.

VII. Conclusions

A new field titled "Deep Loving" is invented in this work. A new algorithm titled "World's First Deep Loving Algorithm (WFDLA) is designed, and results show that both PSO and WFDLA methods performed well on all benchmark functions. There are INFINITE OPPORTUNITIES in Deep Loving Field. Some interesting opportunities in Deep Loving Field are shown for Deep Learning and Artificial Intelligence Research Scientists and Students. As our focus in this paper is very strong on defining and introducing Deep Loving Field, we just added Deep Loving concepts to the PSO algorithm and created WFDLA for the sake of simplicity. We request Deep Learning and Artificial Intelligence field Experts to invent new Deep Loving algorithms from scratch rather than modifying existing algorithms like PSO.

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Set Theoretic Rajan Transform and its Properties

By G. Prashanthi, G. Sathya, Manish Prateek & E. G. Rajan
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Abstract- In this paper, we describe the formulation of a novel transform called Set Theoretic Rajan Transform (STRT) which is an extension of Rajan Transform (RT). RT is a coding morphism by which a number sequence (integer, rational, real, or complex) of length equal to any power of two is transformed into a highly correlated number sequence of same length. STRT was introduced by G. Sathya. In STRT, RT is applied to a sequence of sets instead of sequences of numbers. Here the union (U) is analogous to addition (+) operation and symmetric difference (~) is analogous to subtraction (-). This transform satisfies some interesting set theoretic properties like Cyclic Shift Invariance, Dyadic Shift invariance, Graphical Inverse Invariance. This paper explains in detail about STRT and all of its set theoretic properties.

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Set Theoretic Rajan Transform and its Properties

G. Prashanthi [α], G. Sathya [σ], Manish Prateek [ρ] & E. G. Rajan [ω]

Abstract- In this paper, we describe the formulation of a novel transform called Set Theoretic Rajan Transform (STRT) which is an extension of Rajan Transform (RT). RT is a coding morphism by which a number sequence (integer, rational, real, or complex) of length equal to any power of two is transformed into a highly correlated number sequence of same length. STRT was introduced by G. Sathya. In STRT, RT is applied to a sequence of sets instead of sequences of numbers. Here the union (U) is analogous to addition (+) operation and symmetric difference (~) is analogous to subtraction (-). This transform satisfies some interesting set theoretic properties like Cyclic Shift Invariance, Dyadic Shift invariance, Graphical Inverse Invariance. This paper explains in detail about STRT and all of its set theoretic properties.

I. Introduction

In STRT, given a sequence of sets X(n) of length N, which is a power of two, first it is divided into the first half and the second half each consisting of (N/2) points so that the following holds good :

G(j)=X(i)UX(i+(N/2)); 0≤j≤(N/2); 0≤i≤(N/2)
H(j)=X(i)~X(i-(N/2)); 0≤j≤(N/2); 0≤i≤(N/2)

Now each (N/2) –point segment is further divided into two half's each consisting of (N/4) points so that the following holds good:

G1(k)=G(j)UG(j+(N/4)); 0≤k≤(N/4); 0≤j≤(N/4)
G2(k)=G(j)~G(j-(N/4)); 0≤k≤(N/4); 0≤j≤(N/4)
H1(k)=H(j)UH(j+(N/4)); 0≤k≤(N/4); 0≤j≤(N/4)
H2(k)=H(j)~H(j-(N/4)); 0≤k≤(N/4); 0≤j≤(N/4)

This process is continued till no more division is possible. The total number of stages thus turns out to be log2N. Then the signal flow graph for STRT of length eight would be of the form shown in the Fig. 1.

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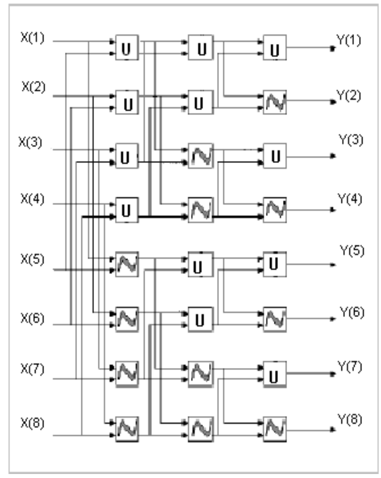

Fig. 1: Signal Flow graph of STRT

Unlike RT, duality doesn't hold good in STRT. If X(n) is a set sequence of length N=2k, k>0 then its Set Theoretic Rajan Transform is denoted by Y(k). Consider a set sequence X(1)={1,2}, X(2)={3,4,6}, X(3)={4,5}, X(4)={1,5}, X(5)={1,4,5}, X(6)={3,4,5}, X(7)={2,6}, X(8)={1,4,6}. Then STRT is computed as follows.

Input set sequence	Stage #1	Stage #2	Stage #3 STRT spectrum
{1,2}	{1,2,4,5}	{1,2,3,4,5,6}	{1,2,3,4,5,6}
{3,4,6}	{3,4,5,6}	{1,3,4,5,6}	{2,3}
{4,5}	{2,4,5,6}	{1,6}	{1,3,6}
{1,5}	{1,4,5,6}	{1,3}	{3,6}
{1,4,5}	{2,4,5}	{2,4,5,6}	{2,4,5,6}
{3,4,5}	{5,6}	{4,5,6}	{2}
{2,6}	{2,4,5,6}	{6}	{4,6}
{1,4,6}	{4,5,6}	{4}	{4,6}

II. Algebraic Properties of STRT

STRT satisfies few interesting properties like Cyclic Shift Invariance, Graphical Inverse Invariance, Dyadic Shift invariance. All these properties are discussed below.

a) Cyclic Shift Invariance

Let us consider the same set of sequences X(n)={1,2}, {3,4,6},{4,5}{1,5},{1,4,5},{3,4,5},{2,6},{1,4,6}. Using this set of sequences, one can generate seven more cyclic shifted versions such as Xc1={1,4,6}, {1,2},{3,4,6},{4,5}{1,5},{1,4,5}, {3,4,5},{2,6}; Xc2={2,6},{1,4,6}, {1,2},{3,4,6},{4,5}{1,5},{1,4,5}, {3,4,5}; Xc3={3,4,5}, {2,6},{1,4,6},{1,2},

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{3,4,6},{4,5}{1,5},{1,4,5}; Xc4={1,4,5},{3,4,5},{2,6},{1,4,6},{1,2},{3,4,6},{4,5}{1,5}; Xc5={1,5},{1,4,5},{3,4,5},{2,6},{1,4,6},{1,2},{3,4,6},{4,5}; Xc6={4,5},{1,5},{1,4,5},{3,4,5},{2,6},{1,4,6},{1,2},{3,4,6}; Xc7={3,4,6},{4,5},{1,5},{1,4,5},{3,4,5},{2,6}, {1,4,6},{1,2}. It is obvious that the cyclic shifted version of Xc7(n) is X(n) itself. One can easily verify that all these eight sequences have the same Y(k), that is {1,2,3,4,5,6},{2,3},{1,3,6},{3,6},{2,4,5,6},{2},{4,6},{4,6}.

b) Graphical Inverse Invariance Property

Consider a sample sequence X(n) = {1,2},{3,4,6},{4,5}{1,5},{1,4,5},{3,4,5},{2,6},{1,4,6} and its has Graphical Inverse X-1(n)={1,4,6},{2,6},{3,4,5},{1,4,5},{1,5},{4,5},{3,4,6},{1,2}. Using this sequence one can generate seven more cyclic shifted versions such as Xc1-1(n)={1,2},{1,4,6},{2,6},{3,4,5},{1,4,5},{1,5},{4,5},{3,4,6}; Xc2-1(n)={3,4,6},{1,2},{1,4,6},{2,6},{3,4,5},{1,4,5},{1,5},{4,5}; Xc3-1(n)={4,5},{3,4,6},{1,2},{1,4,6},{2,6},{3,4,5},{1,4,5},{1,5}; Xc4-1(n)= {1,5},{4,5},{3,4,6},{1,2},{1,4,6},{2,6},{3,4,5},{1,4,5}; Xc5-1(n)={1,4,5},{1,5},{4,5}, {3,4,6},{1,2},{1,4,6},{2,6},{3,4,,5}; Xc6-1(n)={3,4,5},{1,4,5},{1,5},{4,5},{3,4,6},{1,2},{1,4,6},{2,6}; Xc7-1(n)={2,6}{3,4,5},{1,4,5},{1,5},{4,5}, {3,4,6},{1,2},{1,4,6}.It is obvious that the cyclic shifted version of Xc8-1(n) is X-1(n) itself. One can easily verify that all these eight sequences have the same Y(k), that is, {1,2,3,4,5,6},{2,3},{1,3,6},{3,6},{2,4,5,6},{2},{4,6}, {4,6}.

c) Dyadic Shift Invariance property

The term 'dyad' refers to a group of two, and the term 'dyadic shift' to the operation of transposition of two blocks of elements in a sequence. For instance, let us take X(n)={1,2},{3,4,6},{4,5}{1,5},{1,4,5}, {3,4,5},{2,6},{1,4,6} and transpose its first half with the second half. The resulting sequence Td(2)[Xn)]={1,4,5},{3,4,5},{2,6}. {1,4,6},{1,2},{3,4,6},{4,5},{1,5} is the 2-block dyadic shifted version of X (n). The symbol Td(2) denotes the 2- block dyadic shift operator. In the same manner, we obtain Td(4)[Td(2)[X(n)]]={2,6},{1,4,6}{1,4,5},{3,4,5},{4,5},{1,5},{1,2},{3,4,6} and Td(8)[Td(4)[Td(2)[X(n)]]]={1,4,6},{2,6},{3,4,5}, {1,4,5},{1,5},{4,5},{3,4,6},{1,2}. One can easily verify that all these dyadic shifted sequences have the same Y(k), that is, {1,2,3,4,5,6},{2,3},{1,3,6},{3,6}, {2,4,5,6},{2},{4,6},{4,6}. There is yet another way of dyadic shifting input sequence X(n) to Td(2)[Td(4)[Td(8)[X(n)]]]. Let us take X(n) =,{1,2}, {3,4,6},{4,5}{1,5},{1,4,5},{3,4,5},{2,6},{1,4,6} and obtain following dyadic shifts: Td(8)[X(n)]={3,4,6},{1,2},{1,5},{4,5},{3,4,5},{1,4,5}, {1,4,6},{2,6} Td(4)[Td(8)[X(n)]]={1,5},{4,5},{3,4,6}, {1,2},{1,4,6},{2,6},{3,4,5},{1,4,5} and Td(2)[Td(4) [Td(8)[X(n)]]]={1,4,6},{2,6},{3,4,5},{1,4,5},{1,5}, {4,5},{3,4,6},{1,2}. Note thatTd(2)[Td(4)[Td(8) [X(n)]]]= Td(8)[Td(4)[Td(2)[X(n)]]]. One can easily verify from the above that other than Td(4)[Td(2)[X(n)]] and Td(8)[X(n)], all other dyadically permuted sequences fall under the category of the cyclic permutation class of X(n) and X-1(n). This amounts to saying that the cyclic permutation class of X(n) has eight non-repeating independent sequences, that of X-1(n) has eight non-repeating independent sequences and the dyadic permutation classes of X(n) has two non-repeating independent sequences. To conclude, all these 18 sequences could be seen to have the same Y(k).Set Theoretic Rajan Transform has many emerging applications. It can be used as a powerful tool in encrypting digital (color) images. It has many other applications in domains like Signal Processing and Higher Order Mathematics.

III. Application of STRT in the Study of Extended Topological Filters Defined Over a Finite Set

Consider a finite set X={a,b,c}. Then its power set is {{Φ},{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}. One can construct a filter set F whose elements satisfy the following property: 'Any element of F ensures the presence of all its super sets present in the power set of X. For example consider a set X = {a,b,c}. The power set is {ϕ, {a}, {b}, {c}, {a,b}, {a,c}, {b,c}, {a,b,c}}. The set F = {{a}, {a,b}, {a,c}, {a,b,c}} is a valid topological filter set since every element in F ensures the presence of all its super sets. One can construct 18 such topological filters from the ground set X as shown in table 1.

Table 1: List of topological filters from X = {a,b,c}

Filters	Filter Contents	Cardinality
F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c} }	7
F2	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	6
F3	{{a},{c},{a,b},{a,c},{b,c},{a,b,c}}	6
F4	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	6
F5	{{a},{a,b},{a,c},{b,c},{a,b,c})	5
F6	{{b},{a,b},{a,c},{b,c},{a,b,c})	5
F7	{{c},{a,b},{a,c},{b,c},{a,b,c})	5
F8	{{a},{a,b},{a,c},{a,b,c}}	4
F9	{{b},{a,b},{b,c},{a,b,c}}	4
F10	{{c},{a,c},{b,c},{a,b,c}}	4
F11	{{a,b},{a,c},{b,c},{a,b,c}}	4
F12	{{a,b},{a,c},{a,b,c}}	3
F13	{{a,b},{b,c},{a,b,c}}	3
F14	{{a,c},{b,c},{a,b,c}}	3
F15	{{a,b},{a,b,c}}	2
F16	{{a,c},{a,b,c}}	2
F17	{{b,c},{a,b,c}}	2
F18	{{a,b,c}}	1

Lattice of topological filters

The lattice <Φ, ⊆> is constructed as given in Fig. 2 whose elements are 18 topological filters defined over the ground set X = {a,b,c}. Note that the symbol ⊆ denotes the partial order relation of 'subset of'.

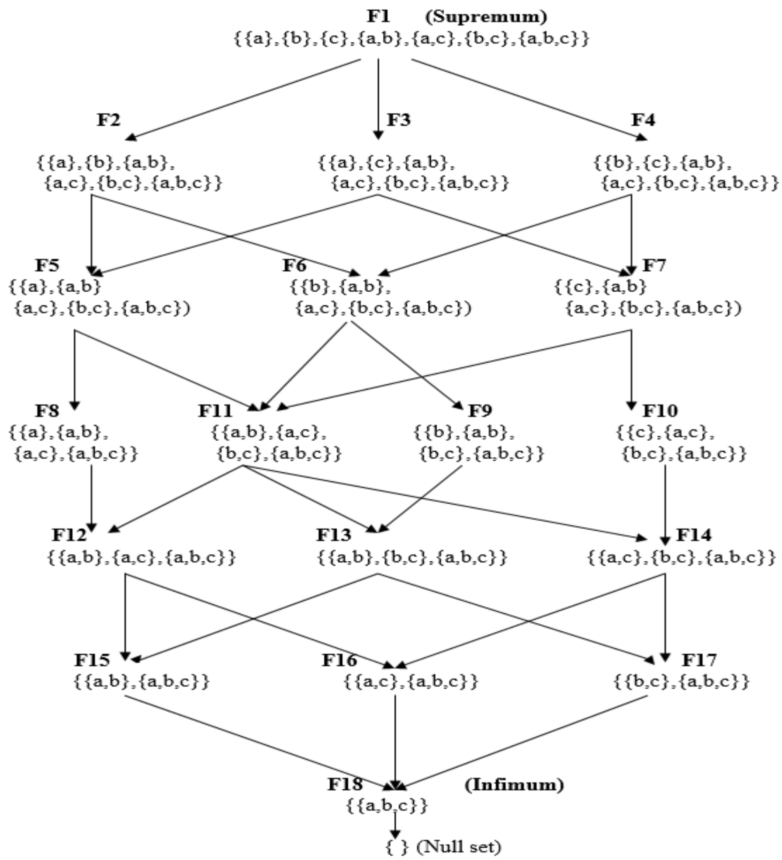

Fig. 2: Lattice diagram showing the linear filter chains over a set X = {a, b, c}

To apply STRT to a filter chain, the length of the chain should be a power of 2. The length of the chain in this case is 7. So the null set { } is considered as the eighth filter as it is a subset of any set. By applying STRT to these 48 filter chains, we get their corresponding spectra. Table 2 gives the STRT spectra of all 48 linear filter chains.

Table 2: STRT spectra of all 48 linear filter chains

Filter chain # 1 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,} , {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,} , {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F2	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{c}}
F5	{{a},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{c}}	{{b},{c},{b,c}}
F8	{{a},{a,b},{a,c},{a,b,c }}	{{a},{a,b},{a,c},{a,b,c }}	{{b},{b,c}}	{{c},{b,c}}
F12	{{a,b},{a,c},{a,b,c}}	{{a},{b},{c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{ b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F15	{{a,b},{a,b,c}}	{{a},{b},{a,c},{b,c}}	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{c},{a,b,c}}
F18	{{a,b,c}}	{{a},{a,b},{a,c},{b,c}}	{{b},{c},{a,b},{a,c}}	{{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
-	{Φ}	{{a},{a,b},{a,c},{a,b,c }}	{{b},{a,b},{b,c},{a,b,c}}	{{c},{a,c},{b,c},{a,b,c}}

Filter chain # 2 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F2	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{c}}
F5	{{a},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c}}	{{b},{c},{b,c}}
F8	{{a},{a,b},{a,c},{a,b,c}}	{{a},{a,b},{a,c},{a,b,c}}	{{b},{b,c}}	{{c},{b,c}}
F12	{{a,b},{a,c},{a,b,c}}	{{a},{b},{c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F16	{{a,c},{a,b,c}}	{{a},{b},{a,b},{b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{c},{a,b,c}}
F18	{{a,b,c}}	{{a},{a,b},{a,c},{b,c}}	{{b},{c},{a,b},{a,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
-	{Φ}	{{a},{a,b},{a,c},{a,b,c}}	{{b},{a,c},{b,c},{a,b,c}}	{{c},{a,b},{b,c},{a,b,c}}

Filter chain # 3 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F2	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{c}}
F5	{{a},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b}}	{{a},{c}}
F12	{{a,b},{a,c},{a,b,c}}	{{a},{b},{c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F15	{{a,b},{a,b,c}}	{{a},{b},{a,c},{b,c}}	{{a},{b},{a,c},{a,b},{b,c},{a,b,c}}	{{c},{a,b,c}}
F18	{{a,b,c}}	{{a},{a,b},{a,c},{b,c}}	{{b},{c},{a,b},{a,c}}	{{a},{b},{c},{a,b},{a,c},{a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,b,c}}	{{a},{c},{a,c},{a,b,c}}

Filter chain # 4 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F2	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{c}}
F5	{{a},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b}}	{{a},{c}}
F12	{{a,b},{a,c},{a,b,c}}	{{a},{b},{c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F16	{{a,c},{a,b,c}}	{{a},{b},{a,b},{b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{c},{a,b,c}}
F18	{{a,b,c}}	{{a},{a,b},{a,c},{b,c}}	{{b},{c},{a,b},{a,c}}	{{a},{b},{c},{a,b},{a,c},{a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,c},{a,b,c}}	{{a},{c},{a,b},{a,b,c}}

Filter chain # 5 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F2	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{c}}
F5	{{a},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c}, {a,b,c}}	{{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{b}}	{{a},{c}}
F13	{{a,b},{b,c},{a,b,c}}	{{a},{b},{c},{a,c}}	{{a},{b},{c},{a,b}, {a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F15	{{a,b},{a,b,c}}	{{a},{b},{a,c},{b,c}}	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{c},{a,b,c}}
F18	{{a,b,c}}	{{a},{a,b},{a,c},{b,c}}	{{b},{c},{a,b},{b,c}}	{{a},{b},{c},{a,b},{b,c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,b,c}}	{{a},{c},{b,c},{a,b,c}}

Filter chain # 6 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{ a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c }, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F2	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{c}}
F5	{{a},{a,b},{a,c},{b,c }, {a,b,c}}	{{a},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a ,b,c}}	{{a,b},{a,c},{b,c},{a,b,c }}	{{a},{b}}	{{a},{c}}
F13	{{a,b},{b,c},{a,b,c}}	{{a},{b},{c},{a,c}}	{{a},{b},{c},{a,b},{a,c }, {b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F17	{{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c}}	{{a},{b},{a,b},{a,c},{b ,c}, {a,b,c}}	{{c},{a,b,c}}
F18	{{a,b,c}}	{{a},{a,b},{a,c},{b,c}}	{{b},{c},{a,b},{b,c}}	{{a},{b},{c},{a,b},{b,c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c }}	{{a},{b},{b,c},{a,b,c}}	{{a},{c},{a,b},{a,b,c}}

Filter chain # 7 and its STRT spectrum

F1	{{a},{b},{c},{a,b },{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c }, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F2	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{c}}
F5	{{a},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c }}	{{a,b},{a,c},{b,c},{a,b,c }}	{{a},{b}}	{{a},{c}}
F14	{{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b}}	{{a},{b},{c},{a,b},{a,c },{b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F16	{{a,c},{a,b,c}}	{{a},{b},{a,b},{b,c}}	{{a},{b},{a,b},{a,c},{b, c}, {a,b,c}}	{{c},{a,b,c}}
F18	{{a,b,c}}	{{a},{a,b},{a,c},{b,c}}	{{b},{c},{a,c},{b,c}}	{{a},{b},{c},{a,c},{b,c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c }}	{{a},{b},{a,c},{a,b,c}}	{{a},{c},{b,c},{a,b,c}}

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Filter chain # 8 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F2	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{c}}
F5	{{a},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b}}	{{a},{c}}
F14	{{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F17	{{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{c},{a,b,c}}
F18	{{a,b,c}}	{{a},{a,b},{a,c},{b,c}}	{{b},{c},{a,c},{b,c}}	{{a},{b},{c},{a,c},{b,c},{a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{b,c},{a,b,c}}	{{a},{c},{a,c},{a,b,c}}

Filter chain # 9 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F2	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{c}}
F6	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b}}	{{b},{c}}
F12	{{a,b},{a,c},{a,b,c}}	{{a},{b},{c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F15	{{a,b},{a,b,c}}	{{a},{b},{a,c},{b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{c},{a,b,c}}
F18	{{a,b,c}}	{{b},{a,b},{a,c},{b,c}}	{{a},{c},{a,b},{a,c}}	{{a},{b},{c},{a,b},{a,c},{a,b,c}}
	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,b,c}}	{{b},{c},{a,c},{a,b,c}}

Filter chain # 10 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F2	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{c}}
F6	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b}}	{{b},{c}}
F12	{{a,b},{a,c},{a,b,c}}	{{a},{b},{c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F16	{{a,c},{a,b,c}}	{{a},{b},{a,b},{b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{c},{a,b,c}}
F18	{{a,b,c}}	{{b},{a,b},{a,c},{b,c}}	{{a},{c},{a,b},{a,c}}	{{a},{b},{c},{a,b},{a,c},{a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,c},{a,b,c}}	{{b},{c},{a,b},{a,b,c}}

Filter chain #11 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c }, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a, c}, {b,c},{a,b,c}}
F2	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c}, {a,b,c}}	{{c}}
F6	{{b},{a,b},{a,c},{b,c},{a ,b,c}}	{{b},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c }}	{{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{b}}	{{b},{c}}
F13	{{a,b},{b,c},{a,b,c}}	{{a},{b},{c},{a,c}}	{{a},{b},{c},{a,b},{a,c},{b, c}}	{{a},{b},{c},{a,b},{a, c}, {b,c},{a,b,c}}
F15	{{a,b},{a,b,c}}	{{a},{b},{a,c},{b,c}}	{{a},{b},{a,b},{a,c},{b,c}, {a,b,c}}	{{c},{a,b,c}}
F18	{{a,b,c}}	{{b},{a,b},{a,c},{b,c}}	{{a},{c},{a,b},{b,c}}	{{a},{b},{c},{a,b},{b, c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b, c}}	{{a},{b},{a,b},{a,b,c}}	{{b},{c},{b,c},{a,b,c} }

Filter chain # 12 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c }, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a, c}, {b,c},{a,b,c}}
F2	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c}, {a,b,c}}	{{c}}
F6	{{b},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c} }	{{a,b},{a,c},{b,c},{a,b, c}}	{{a},{b}}	{{b},{c}}
F13	{{a,b},{b,c},{a,b,c}}	{{a},{b},{c},{a,c}}	{{a},{b},{c},{a,b},{a,c},{b,c }}	{{a},{b},{c},{a,b},{a, c}, {b,c},{a,b,c}}
F17	{{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c}}	{{a},{b},{a,b},{a,c},{b,c}, {a,b,c}}	{{c},{a,b,c}}
F18	{{a,b,c}}	{{b},{a,b},{a,c},{b,c}}	{{a},{c},{a,b},{b,c}}	{{a},{b},{c},{a,b},{b, c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b, c}}	{{a},{b},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,b,c} }

Filter chain # 13 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c }, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c }, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F2	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{a,b},{a,c}, {b,c},{a,b,c}}	{{c}}
F6	{{b},{a,b},{a,c},{b,c},{a, b,c}}	{{b},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b ,c}}	{{a},{b}}	{{b},{c}}
F14	{{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b}}	{{a},{b},{c},{a,b},{a,c },{b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F16	{{a,c},{a,b,c}}	{{a},{b},{a,b},{b,c}}	{{a},{b},{a,b},{a,c},{b ,c},{a,b,c}}	{{c},{a,b,c}}
F18	{{a,b,c}}	{{b},{a,b},{a,c},{b,c}}	{{a},{c},{a,c},{b,c}}	{{a},{b},{c},{a,c},{b,c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b ,c}}	{{a},{b},{a,c},{a,b,c}}	{{b},{c},{b,c},{a,b,c}}

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Filter chain # 14 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F2	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{c}}
F6	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b}}	{{b},{c}}
F14	{{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F17	{{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{c},{a,b,c}}
F18	{{a,b,c}}	{{b},{a,b},{a,c},{b,c}}	{{a},{c},{a,c},{b,c}}	{{a},{b},{c},{a,c},{b,c},{a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{b,c},{a,b,c}}	{{b},{c},{a,c},{a,b,c}}

Filter chain # 15 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F2	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{c}}
F6	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c}}	{{a},{c},{a,c}}
F9	{{b},{a,b},{b,c},{a,b,c}}	{{b},{a,b},{b,c},{a,b,c}}	{{a},{a,c}}	{{c},{a,c}}
F13	{{a,b},{b,c},{a,b,c}}	{{a},{b},{c},{a,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F15	{{a,b},{a,b,c}}	{{a},{b},{a,c},{b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{c},{a,b,c}}
F18	{{a,b,c}}	{{b},{a,b},{a,c},{b,c}}	{{a},{c},{a,b},{b,c}}	{{a},{c},{a,b},{a,c},{b,c},{a,b,c}}
-	{Φ}	{{b},{a,b},{b,c},{a,b,c}}	{{a},{a,b},{a,c},{a,b,c}}	{{c},{a,c},{b,c},{a,b,c}}

Filter chain # 16 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F2	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{c}}
F6	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c}}	{{a},{c},{a,c}}
F9	{{b},{a,b},{b,c},{a,b,c}}	{{b},{a,b},{b,c},{a,b,c}}	{{a},{a,c}}	{{c},{a,c}}
F13	{{a,b},{b,c},{a,b,c}}	{{a},{b},{c},{a,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F17	{{b,c},{a,b,c}}	{{a},{b},{a,b},{a,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}	{{c},{a,b,c}}
F18	{{a,b,c}}	{{b},{a,b},{a,c},{b,c}}	{{a},{c},{a,b},{b,c}}	{{a},{c},{a,b},{a,c},{b,c},{a,b,c}}
-	{Φ}	{{b},{a,b},{b,c},{a,b,c}}	{{a},{a,c},{b,c},{a,b,c}}	{{c},{a,b},{a,c},{a,b,c}}

Filter chain # 17 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F3	{{a},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b}}
F5	{{a},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c}}	{{b},{c},{b,c}}
F8	{{a},{a,b},{a,c},{a,b,c}}	{{a},{a,b},{a,c},{a,b,c}}	{{c},{b,c}}	{{b},{b,c}}
F12	{{a,b},{a,c},{a,b,c}}	{{a},{b},{c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F15	{{a,b},{a,b,c}}	{{a},{c},{a,c},{b,c}}	{{a},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{a,b,c}}
F18	{{a,b,c}}	{{a},{a,b},{a,c},{b,c}}	{{b},{c},{a,b},{a,c}}	{{b},{c},{a,b},{b,c},{a,c},{a,b,c}}
-	{Φ}	{{a},{a,b},{a,c},{a,b,c}}	{{c},{a,b},{b,c},{a,b,c}}	{{b},{a,c},{b,c},{a,b,c}}

Filter chain # 18 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F3	{{a},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b}}
F5	{{a},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c}}	{{b},{c},{b,c}}
F8	{{a},{a,b},{a,c},{a,b,c}}	{{a},{a,b},{a,c},{a,b,c}}	{{c},{b,c}}	{{b},{b,c}}
F12	{{a,b},{a,c},{a,b,c}}	{{a},{b},{c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F16	{{a,c},{a,b,c}}	{{a},{c},{a,b},{b,c}}	{{a},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{a,b,c}}
F18	{{a,b,c}}	{{a},{a,b},{a,c},{b,c}}	{{b},{c},{a,b},{a,c}}	{{b},{c},{a.b},{a,c},{b,c},{a,b,c}}
-	{Φ}	{{a},{a,b},{a,c},{a,b,c}}	{{c},{a,c},{b,c},{a,b,c}}	{{b},{a,b},{b,c},{a,b,c}}

Filter chain # 19 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F3	{{a},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b}}
F5	{{a},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c}}	{{a},{b}}
F12	{{a,b},{a,c},{a,b,c}}	{{a},{b},{c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F15	{{a,b},{a,b,c}}	{{a},{c},{a,c},{b,c}}	{{a},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{a,b,c}}
F18	{{a,b,c}}	{{a},{a,b},{a,c},{b,c}}	{{b},{c},{a,b},{a,c}}	{{a},{b},{c},{a,b},{a,c},{a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c},{a,b},{a,b,c}}	{{a},{b},{a,c},{a,b,c}}

Filter chain # 20 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}

F3	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c},{b,c }, {a,b,c}}	{{a},{c},{a,b},{a,c},{b,c }, {a,b,c}}	{{b}}
F5	{{a},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b, c}}	{{a,b},{a,c},{b,c},{a,b,c }}	{{a},{c}}	{{a},{b}}
F12	{{a,b},{a,c},{a,b,c}}	{{a},{b},{c},{b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F16	{{a,c},{a,b,c}}	{{a},{c},{a,b},{b,c}}	{{a},{c},{a,b},{a,c},{b,c }, {a,b,c}}	{{b},{a,b,c}}
F18	{{a,b,c}}	{{a},{a,b},{a,c},{b,c}}	{{b},{c},{a,b},{a,c}}	{{a},{b},{c},{a,b},{a,c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c }}	{{a},{c},{a,c},{a,b,c}}	{{a},{b},{a,b},{a,b,c}}

Filter chain # 21 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F3	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{b}}
F5	{{a},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c} }	{{a,b},{a,c},{b,c},{a,b,c} }	{{a},{c}}	{{a},{b}}
F13	{{a,b},{b,c},{a,b,c}}	{{a},{b},{c},{a,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F15	{{a,b},{a,b,c}}	{{a},{c},{a,c},{b,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{a,b,c}}
F18	{{a,b,c}}	{{a},{a,b},{a,c},{b,c}}	{{b},{c},{a,b},{b,c}}	{{a},{b},{c},{a,b},{b,c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c} }	{{a},{c},{a,b},{a,b,c}}	{{a},{b},{b,c},{a,b,c}}

Filter chain # 22 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c }, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c }, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F3	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{b}}
F5	{{a},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b, c}}	{{a,b},{a,c},{b,c},{a,b, c}}	{{a},{c}}	{{a},{b}}
F13	{{a,b},{b,c},{a,b,c}}	{{a},{b},{c},{a,c}}	{{a},{b},{c},{a,b},{a,c},{b,c }}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F17	{{b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}}	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{b},{a,b,c}}
F18	{{a,b,c}}	{{a},{a,b},{a,c},{b,c}}	{{b},{c},{a,b},{b,c}}	{{a},{b},{c},{a.b},{b,c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b, c}}	{{a},{c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,b,c}}

Filter chain # 23 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c }, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c} , {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F3	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{b}}

F5	{{a},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b, c}}	{{a,b},{a,c},{b,c},{a,b, c}}	{{a},{c}}	{{a},{b}}
F14	{{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b}}	{{a},{b},{c},{a,b},{a,c},{b,c }}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F16	{{a,c},{a,b,c}}	{{a},{c},{a,b},{b,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{a,b,c}}
F18	{{a,b,c}}	{{a},{a,b},{a,c},{b,c}}	{{b},{c},{a,c},{b,c}}	{{a},{b},{c},{a,c},{b,c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b, c}}	{{a},{c},{a,c},{a,b,c}}	{{a},{b},{b,c},{a,b,c}}

Filter chain # 24 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c }, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c} , {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F3	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b}}
F5	{{a},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{a,b},{a,c},{b,c},{ a,b,c}}	{{b},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b, c}}	{{a,b},{a,c},{b,c},{a,b, c}}	{{a},{c}}	{{a},{b}}
F14	{{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b}}	{{a},{b},{c},{a,b},{a,c},{b,c }}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F17	{{b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{a,b,c}}
F18	{{a,b,c}}	{{a},{a,b},{a,c},{b,c}}	{{b},{c},{a,c},{b,c}}	{{a},{b},{c},{a,c},{b,c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b, c}}	{{a},{c},{b,c},{a,b,c}}	{{a},{b},{a,c},{a,b,c}}

Filter chain # 25 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F3	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b}}
F7	{{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{b}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c}}	{{b},{c}}
F12	{{a,b},{a,c},{a,b,c}}	{{a},{b},{c},{b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F15	{{a,b},{a,b,c}}	{{a},{c},{a,c},{b,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{a,b,c}}
F18	{{a,b,c}}	{{c},{a,b},{a,c},{b,c}}	{{a},{b},{a,b},{a,c}}	{{a},{b},{c},{a,b}, {a,c},{a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c},{a,b},{a,b,c}}	{{b},{c},{a,c},{a,b,c}}

Filter chain # 26 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F3	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b}}

F7	{{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{b}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c}}	{{b},{c}}
F12	{{a,b},{a,c},{a,b,c}}	{{a},{b},{c},{b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F16	{{a,c},{a,b,c}}	{{a},{c},{a,b},{b,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{a,b,c}}
F18	{{a,b,c}}	{{c},{a,b},{a,c},{b,c}}	{{a},{b},{a,b},{a,c}}	{{a},{b},{c},{a,b},{a,c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c},{a,c},{a,b,c}}	{{b},{c},{a,b},{a,b,c}}

Filter chain # 27 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c}, {a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F3	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b}}
F7	{{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{b}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c} }	{{a,b},{a,c},{b,c},{a,b,c} }	{{a},{c}}	{{b},{c}}
F13	{{a,b},{b,c},{a,b,c}}	{{a},{b},{c},{a,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F15	{{a,b},{a,b,c}}	{{a},{c},{a,c},{b,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{a,b,c}}
F18	{{a,b,c}}	{{c},{a,b},{a,c},{b,c}}	{{a},{b},{a,b},{b,c}}	{{a},{b},{c},{a,b},{b,c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c},{a,b},{a,b,c}}	{{b},{c},{b,c},{a,b,c}}

Filter chain # 28 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F3	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{b}}
F7	{{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{b}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c}}	{{b},{c}}
F13	{{a,b},{b,c},{a,b,c}}	{{a},{b},{c},{a,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F17	{{b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{a,b,c}}
F18	{{a,b,c}}	{{c},{a,b},{a,c},{b,c}}	{{a},{b},{a,b},{b,c}}	{{a},{b},{c},{a,b},{b,c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,b,c}}

Filter chain # 29 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F3	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b}}
F7	{{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{b}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c}, {a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c}}	{{b},{c}}
F14	{{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b}}	{{a},{b},{c},{a,b},{a,c}, {b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}

F16	{{a,c},{a,b,c}}	{{a},{c},{a,b},{b,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{a,b,c}}
F18	{{a,b,c}}	{{c},{a,b},{a,c},{b,c}}	{{a},{b},{a,c},{b,c}}	{{a},{b},{c},{a,c},{b,c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c},{a,c},{a,b,c}}	{{b},{c},{b,c},{a,b,c}}

Filter chain # 30 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F3	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b}}
F7	{{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{b}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c}}	{{b},{c}}
F14	{{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b}}	{{a},{b},{c},{a,b},{a,c}, {b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F17	{{b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{a,b,c}}
F18	{{a,b,c}}	{{c},{a,b},{a,c},{b,c}}	{{a},{b},{a,c},{b,c}}	{{a},{b},{c},{a,c},{b,c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c},{b,c},{a,b,c}}	{{b},{c},{a,c},{a,b,c}}

Filter chain # 31 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F3	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{b}}
F7	{{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{b}}	{{a},{b},{a,b}}
F10	{{c},{a,c},{b,c},{a,b,c}}	{{c},{a,c},{b,c},{a,b,c}}	{{a},{a,b}}	{{b},{a,b}}
F14	{{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b}}	{{a},{b},{c},{a,b},{a,c}, {b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c}, {a,b,c}}
F16	{{a,c},{a,b,c}}	{{a},{c},{a,b},{b,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{a,b,c}}
F18	{{a,b,c}}	{{c},{a,b},{a,c},{b,c}}	{{a},{b},{a,c},{b,c}}	{{a},{b},{a,b},{a,c},{b,c}, {a,b,c}}
-	{Φ}	{{c},{a,c},{b,c},{a,b,c}}	{{a},{a,b},{a,c},{a,b,c}}	{{b},{a,b},{b,c},{a,b,c}}

Filter chain # 32 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a, c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c }, {b,c},{a,b,c}}
F3	{{a},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{c},{a,b},{a,c},{b,c} , {a,b,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b}}
F7	{{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{b}}	{{a},{b},{a,b}}
F10	{{c},{a,c},{b,c},{a,b,c }}	{{c},{a,c},{b,c},{a,b,c}}	{{a},{a,b}}	{{b},{a,b}}
F14	{{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b}}	{{a},{b},{c},{a,b},{a,c},{b,c} }	{{a},{b},{c},{a,b},{a,c }, {b,c},{a,b,c}}
F17	{{b,c},{a,b,c}}	{{a},{c},{a,b},{a,c}}	{{a},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{a,b,c}}
F18	{{a,b,c}}	{{c},{a,b},{a,c},{b,c}}	{{a},{b},{a,c},{b,c}}	{{a},{b},{a,b},{a,c},{b ,c},

				{a,b,c}}
-	{Φ}	{{c},{a,c},{b,c},{a,b,c}}	{{a},{a,b},{b,c},{a,b,c}}	{{b},{a,b},{a,c},{a,b,c }}

Filter chain # 33 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c }, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{ a,c}, {b,c},{a,b,c}}
F4	{{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b ,c}}	{{a}}
F6	{{b},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b, c}}	{{a,b},{a,c},{b,c},{a,b,c }}	{{b},{c}}	{{a},{b}}
F12	{{a,b},{a,c},{a,b,c}}	{{a},{b},{c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b}, {a,c}, {b,c},{a,b,c}}
F15	{{a,b},{a,b,c}}	{{b},{c},{a,c},{b,c}}	{{b},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{a,b,c}}
F18	{{a,b,c}}	{{b},{a,b},{a,c},{b,c}}	{{a},{c},{a,b},{a,c}}	{{a},{b},{c},{a,b}, {a,c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c }}	{{b},{c},{a,b},{a,b,c}}	{{a},{b},{a,c},{a,b,c }}

Filter chain # 34 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b}, {a,c}, {b,c},{a,b,c}}
F4	{{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c} , {a,b,c}}	{{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a}}
F6	{{b},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{c}}	{{a},{b},{c}}
F1 1	{{a,b},{a,c},{b,c},{a,b,c} }	{{a,b},{a,c},{b,c},{a,b,c} }	{{b},{c}}	{{a},{b}}
F1 2	{{a,b},{a,c},{a,b,c}}	{{a},{b},{c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c} }	{{a},{b},{c},{a,b}, {a,c}, {b,c},{a,b,c}}
F1 6	{{a,c},{a,b,c}}	{{b},{c},{a,b},{b,c}}	{{b},{c},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{a,b,c}}
F1 8	{{a,b,c}}	{{b},{a,b},{a,c},{b,c}}	{{a},{c},{a,b},{a,c}}	{{a},{b},{c},{a,b}, {a,c}, {a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c} }	{{b},{c},{a,c},{a,b,c}}	{{a},{b},{a,b},{a,b ,c}}

Filter chain # 35 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c} ,{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F4	{{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a}}
F6	{{b},{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{a,b},{a,c},{b,c}, {a,b,c}}	{{a},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c}, {a,b,c}}	{{a,b},{a,c},{b,c}, {a,b,c}}	{{b},{c}}	{{a},{b}}
F13	{{a,b},{b,c},{a,b,c}}	{{a},{b},{c},{a,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F15	{{a,b},{a,b,c}}	{{b},{c},{a,c},{b,c}}	{{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}	{{a},{a,b,c}}
F18	{{a,b,c}}	{{b},{a,b},{a,c},{b,c}}	{{a},{c},{a,b},{b,c}}	{{a},{b},{c},{a,b},{b,c},

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				{a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,b,c}}	{{a},{b},{b,c},{a,b,c}}

Filter chain # 36 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F4	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a}}
F6	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c}}	{{a},{b}}
F13	{{a,b},{b,c},{a,b,c}}	{{a},{b},{c},{a,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F17	{{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b,c}}
F18	{{a,b,c}}	{{b},{a,b},{a,c},{b,c}}	{{a},{c},{a,b},{b,c}}	{{a},{b},{c},{a,b},{b,c},{a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{b,c},{a,b,c}}	{{a},{b},{a,b},{a,b,c}}

Filter chain # 37 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F4	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a}}
F6	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c}}	{{a},{b}}
F14	{{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c}, {b,c},{a,b,c}}
F16	{{a,c},{a,b,c}}	{{b},{c},{a,b},{b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b,c}}
F18	{{a,b,c}}	{{b},{a,b},{a,c},{b,c}}	{{a},{c},{a,c},{b,c}}	{{a},{b},{c},{a,c},{b,c},{a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,c},{a,b,c}}	{{a},{b},{b,c},{a,b,c}}

Filter chain # 38 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F4	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a}}
F6	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c}}	{{a},{b}}
F14	{{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F17	{{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b,c}}
F18	{{a,b,c}}	{{b},{a,b},{a,c},{b,c}}	{{a},{c},{a,c},{b,c}}	{{a},{b},{c},{a,c},{b,c},{a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{b,c},{a,b,c}}	{{a},{b},{a,c},{a,b,c}}

Filter chain # 39 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F4	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a}}
F6	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c}}	{{a},{c},{a,c}}
F9	{{b},{a,b},{b,c},{a,b,c}}	{{b},{a,b},{b,c},{a,b,c}}	{{c},{a,c}}	{{a},{a,c}}
F13	{{a,b},{b,c},{a,b,c}}	{{a},{b},{c},{a,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F15	{{a,b},{a,b,c}}	{{b},{c},{a,c},{b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b,c}}
F18	{{a,b,c}}	{{b},{a,b},{a,c},{b,c}}	{{a},{c},{a,b},{b,c}}	{{a},{c},{a,b},{a,c},{b,c},{a,b,c}}
-	{Φ}	{{b},{a,b},{b,c},{a,b,c}}	{{c},{a,b},{a,c},{a,b,c}}	{{a},{a,c},{b,c},{a,b,c}}

Filter chain #40 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F4	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a}}
F6	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{c}}	{{a},{c},{a,c}}
F9	{{b},{a,b},{b,c},{a,b,c}}	{{b},{a,b},{b,c},{a,b,c}}	{{c},{a,c}}	{{a},{a,c}}
F13	{{a,b},{b,c},{a,b,c}}	{{a},{b},{c},{a,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F17	{{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b,c}}
F18	{{a,b,c}}	{{b},{a,b},{a,c},{b,c}}	{{a},{c},{a,b},{b,c}}	{{a},{c},{a,b},{a,c},{b,c},{a,b,c}}
-	{Φ}	{{b},{a,b},{b,c},{a,b,c}}	{{c},{a,c},{b,c},{a,b,c}}	{{a},{a,b},{a,c},{a,b,c}}

Filter chain # 41 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F4	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a}}
F7	{{c},{a,b},{a,c},{b,c},{a,b,c}}	{{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c}}	{{a},{c}}
F12	{{a,b},{a,c},{a,b,c}}	{{a},{b},{c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F15	{{a,b},{a,b,c}}	{{b},{c},{a,c},{b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b,c}}
F18	{{a,b,c}}	{{c},{a,b},{a,c},{b,c}}	{{a},{b},{a,b},{a,c}}	{{a},{b},{c},{a,b},{a,c},{a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,b,c}}	{{a},{c},{a,c},{a,b,c}}

Filter chain # 42 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F4	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a}}
F7	{{c},{a,b},{a,c},{b,c},{a,b,c}}	{{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c}}	{{a},{c}}

F12	{{a,b},{a,c},{a,b,c}}	{{a},{b},{c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F16	{{a,c},{a,b,c}}	{{b},{c},{a,b},{b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b,c}}
F18	{{a,b,c}}	{{c},{a,b},{a,c},{b,c}}	{{a},{b},{a,b},{a,c}}	{{a},{b},{c},{a,b},{a,c},{a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,c},{a,b,c}}	{{a},{c},{a,b},{a,b,c}}

Filter chain # 43 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F4	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a}}
F7	{{c},{a,b},{a,c},{b,c},{a,b,c}}	{{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c}}	{{a},{c}}
F13	{{a,b},{b,c},{a,b,c}}	{{a},{b},{c},{a,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F15	{{a,b},{a,b,c}}	{{b},{c},{a,c},{b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b,c}}
F18	{{a,b,c}}	{{c},{a,b},{a,c},{b,c}}	{{a},{b},{a,b},{b,c}}	{{a},{b},{c},{a,b},{b,c},{a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,b,c}}	{{a},{c},{b,c},{a,b,c}}

Filter chain # 44 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F4	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a}}
F7	{{c},{a,b},{a,c},{b,c},{a,b,c}}	{{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c}}	{{a},{c}}
F13	{{a,b},{b,c},{a,b,c}}	{{a},{b},{c},{a,c}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F17	{{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b,c}}
F18	{{a,b,c}}	{{c},{a,b},{a,c},{b,c}}	{{a},{b},{a,b},{b,c}}	{{a},{b},{c},{a,b},{b,c},{a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{b,c},{a,b,c}}	{{a},{c},{a,b},{a,b,c}}

Filter chain # 45 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F4	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a}}
F7	{{c},{a,b},{a,c},{b,c},{a,b,c}}	{{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c}}	{{a},{c}}
F14	{{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F16	{{a,c},{a,b,c}}	{{b},{c},{a,b},{b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b,c}}
F18	{{a,b,c}}	{{c},{a,b},{a,c},{b,c}}	{{a},{b},{a,c},{b,c}}	{{a},{b},{c},{a,c},{b,c},{a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,c},{a,b,c}}	{{a},{c},{b,c},{a,b,c}}

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Filter chain # 46 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F4	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a}}
F7	{{c},{a,b},{a,c},{b,c},{a,b,c}}	{{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b}}	{{a},{b},{c}}
F11	{{a,b},{a,c},{b,c},{a,b,c}}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c}}	{{a},{c}}
F14	{{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F17	{{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b,c}}
F18	{{a,b,c}}	{{c},{a,b},{a,c},{b,c}}	{{a},{b},{a,c},{b,c}}	{{a},{b},{c},{a,c},{b,c},{a,b,c}}
-	{Φ}	{{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{b,c},{a,b,c}}	{{a},{c},{a,c},{a,b,c}}

Filter chain # 47 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F4	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a}}
F7	{{c},{a,b},{a,c},{b,c},{a,b,c}}	{{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b}}	{{a},{b},{a,b}}
F10	{{c},{a,c},{b,c},{a,b,c}}	{{c},{a,c},{b,c},{a,b,c}}	{{b},{a,b}}	{{a},{a,b}}
F14	{{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F16	{{a,c},{a,b,c}}	{{b},{c},{a,b},{b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b,c}}
F18	{{a,b,c}}	{{c},{a,b},{a,c},{b,c}}	{{a},{b},{a,c},{b,c}}	{{a},{b},{a,b},{a,c},{b,c}, {a,b,c}}
-	{Φ}	{{c},{a,c},{b,c},{a,b,c}}	{{b},{a,b},{a,c},{a,b,c}}	{{a},{a,b},{b,c},{a,b,c}}

Filter chain # 48 and its STRT spectrum

F1	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F4	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a}}
F7	{{c},{a,b},{a,c},{b,c},{a,b,c}}	{{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{b}}	{{a},{b},{a,b}}
F10	{{c},{a,c},{b,c},{a,b,c}}	{{c},{a,c},{b,c},{a,b,c}}	{{b},{a,b}}	{{a},{a,b}}
F14	{{a,c},{b,c},{a,b,c}}	{{a},{b},{c},{a,b}}	{{a},{b},{c},{a,b},{a,c},{b,c}}	{{a},{b},{c},{a,b},{a,c},{b,c},{a,b,c}}
F17	{{b,c},{a,b,c}}	{{b},{c},{a,b},{a,c}}	{{b},{c},{a,b},{a,c},{b,c},{a,b,c}}	{{a},{a,b,c}}
F18	{{a,b,c}}	{{c},{a,b},{a,c},{b,c}}	{{a},{b},{a,c},{b,c}}	{{a},{b},{a,b},{a,c},{b,c},{a,b,c}}
-	{Φ}	{{c},{a,c},{b,c},{a,b,c}}	{{b},{a,b},{b,c},{a,b,c}}	{{a},{a,b},{a,c},{a,b,c}}

Consider a finite set X={a,b,c,d}. Then its power set is {{},{a},{b},{c},{d},{a,b},{a,c}, {a,d},{b,c},{b,d},{c,d}, {a,b,c},{a,b,d},{a,c,d},{b,c,d}, {a,b,c,d}}. One can construct a filter set F whose elements satisfy the following property: 'Any element of F ensures the presence of all its super sets present in the power set of X. One can construct 166 topological filters from the ground set X = {a,b,c,d}. This list is given in table 2.

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Table 2: List of topological filters defined over X = {a,b,c,d}

Filter No.	Filter Elements	Cardinality
F1	{{a},{b},{c},{d},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d}, {a,b,c,d}}	15
F2	{{a},{b},{c},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	14
F3	{{a},{b},{d},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	14
F4	{{a},{c},{d},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	14
F5	{{b},{c},{d},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	14
F6	{{a},{b},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	13
F7	{{a},{c},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	13
F8	{{b},{c},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	13
F9	{{a},{d},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	13
F10	{{b},{d},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	13
F11	{{c},{d},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	13
F12	{{a},{b},{a,b},{a,c},{a,d},{b,c},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	12
F13	{{a},{a,b},{a,c},{a,d},{b,c},{b,d}{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	12
F14	{{a},{c},{a,b},{a,c},{a,d},{b,c},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	12
F15	{{b},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	12
F16	{{b},{c},{a,b},{a,c},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	12
F17	{{c},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	12
F18	{{a},{d},{a,b},{a,c},{a,d},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	12
F19	{{d},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	12
F20	{{b},{d},{a,b},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	12
F21	{{c},{d},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	12
F22	{{a},{a,b},{a,c},{a,d},{b,c},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	11
F23	{{a},{a,b},{a,c},{a,d},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	11
F24	{{a},{a,b},{a,c},{a,d},{b,c},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	11
F25	{{b},{a,b},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	11
F26	{{b},{a,b},{a,c},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	11
F27	{{a,b},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	11
F28	{{b},{a,b},{a,c},{a,d},{b,c},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	11
F29	{{c},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	11
F30	{{c},{a,b},{a,c},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	11
F31	{{c},{a,b},{a,c},{a,d},{b,c},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	11
F32	{{d},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	11
F33	{{d},{a,b},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	11
F34	{{d},{a,b},{a,c},{a,d},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	11
F35	{{a},{a,b},{a,c},{a,d},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F36	{{a},{a,b},{a,c},{a,d},{b,c},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F37	{{a},{a,b},{a,c},{a,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F38	{{b},{a,b},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F39	{{b},{a,b},{a,d},{b,c},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F40	{{b},{a,b},{a,c},{b,c},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F41	{{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F42	{{a,b},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F43	{{a,b},{a,c},{b,c},b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F44	{{a,b},{a,c},{a,d},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F45	{{a,b},{a,c},{a,d},{b,c},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F46	{{a,b},{a,c},{a,d},{b,c},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F47	{{c,},{a,c},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F48	{{c},{a,c},{a,d},{b,c},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F49	{{c},{a,b},{a,c},{b,c},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F50	{{d},{a,c},{a,d},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F51	{{d},{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F52	{{d},{a,b},{a,d},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	10
F53	{{a},{a,b},{a,c},{a,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F54	{{b},{a,b},{b,c},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F55	{{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F56	{{a,d},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9

F57	{{a,c},{a,d},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F58	{{a,c},{a,d},{b,c},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F59	{{a,c},{a,d},{b,c},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F60	{{a,b},{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F61	{{a,b},{a,d},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F62	{{a,b},{a,d},{b,c},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F63	{{a,b},{a,d},{b,c},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F64	{{a,b},{a,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F65	{{a,b},{a,c},{b,c},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F66	{{a,b},{a,c},{b,c},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F67	{{a,b},{a,c},{a,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F68	{{a,b},{a,c},{a,d},{b,c},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F69	{{a,b},{a,c},{a,d},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F70	{{c},{a,c},{b,c},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F71	{{d},{a,d},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	9
F72	{{a},{a,b},{a,c},{a,d},{a,b,c},{a,b,d},{a,c,d},{a,b,c,d}}	8
F73	{{b},{a,b},{b,c},{b,d},{a,b,c},{a,b,d},{b,c,d},{a,b,c,d}}	8
F74	{{b,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F75	{{a,d},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F76	{{a,d},{b,c},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F77	{{a,d},{b,c},{b,d} ,{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F78	{{a,c},{b,c},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F79	{{a,c},{b,c},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F80	{{a,c},{a,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F81	{{a,c},{a,d},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F82	{{a,c},{a,d},{b,c},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F83	{{a,b},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F84	{{a,b},{b,c},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F85	{{a,b},{b,c},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F86	{{a,b},{a,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F87	{{a,b},{a,d},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F88	{{a,b},{a,d},{b,c},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F89	{{a,c},{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F90	{{a,b},{a,c},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F91	{{a,b},{a,c},{b,d} ,{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F92	{{a,b},{a,c},{b,c},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F93	{{a,b},{a,c},{a,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F94	{{c},{a,c},{b,c},{c,d},{a,b,c},{a,c,d},{b,c,d},{a,b,c,d}}	8
F95	{{d},{a,d},{b,d},{c,d},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	8
F96	{{a,d},{b,d},{c,d},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	7
F97	{{a,c},{b,c},{c,d},{a,b,c},{a,c,d},{b,c,d},{a,b,c,d}}	7
F98	{{b,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	7
F99	{{b,c},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	7
F100	{{b,c},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	7
F101	{{a,d},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	7
F102	{{a,d},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	7
F103	{{a,d},{b,c},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	7
F104	{{a,c},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	7
F105	{{a,c},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	7
F106	{{a,c},{b,c},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	7
F107	{{a,c},{a,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	7
F108	{{a,b},{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	7
F109	{{a,b},{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	7
F110	{{a,b},{b,c},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	7
F111	{{a,b},{a,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	7
F112	{{a,b},{a,c},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	7
F113	{{a,b},{b,c},{b,d},{a,b,c},{a,b,d},{b,c,d},{a,b,c,d}}	7
F114	{{a,b},{a,c},{a,d},{a,b,c},{a,b,d},{a,c,d},{a,b,c,d}}	7
F115	{{b,d},{c,d},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	6
F116	{{b,c},{c,d},{a,b,c},{a,c,d},{b,c,d},{a,b,c,d}}	6

F117	{{b,c},{b,d},{a,b,c},{a,b,d},{b,c,d},{a,b,c,d}}	6
F118	{{a,d},{c,d},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	6
F119	{{a,d},{b,d},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	6
F120	{{a,c},{c,d},{a,b,c},{a,c,d},{b,c,d},{a,b,c,d}}	6
F121	{{c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	6
F122	{{b,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	6
F123	{{b,c},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	6
F124	{{a,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	6
F125	{{a,c},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	6
F126	{{a,b},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	6
F127	{{a,c},{b,c},{a,b,c},{a,c,d},{b,c,d},{a,b,c,d}}	6
F128	{{a,c},{a,d},{a,b,c},{a,b,d},{a,c,d},{a,b,c,d}}	6
F129	{{a,b},{b,d},{a,b,c},{a,b,d},{b,c,d},{a,b,c,d}}	6
F130	{{a,b},{b,c},{a,b,c},{a,b,d},{b,c,d},{a,b,c,d}}	6
F131	{{a,b},{a,d},{a,b,c},{a,b,d},{a,c,d},{a,b,c,d}}	6
F132	{{a,b},{a,c},{a,b,c},{a,b,d},{a,c,d},{a,b,c,d}}	6
F133	{{b,d},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	5
F134	{{c,d},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	5
F135	{{c,d},{a,b,c},{a,c,d},{b,c,d},{a,b,c,d}}	5
F136	{{b,d},{a,b,c},{a,b,d},{b,c,d},{a,b,c,d}}	5
F137	{{b,c},{a,b,c},{a,c,d},{b,c,d},{a,b,c,d}}	5
F138	{{b,c},{a,b,c},{a,b,d},{b,c,d},{a,b,c,d}}	5
F139	{{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	5
F140	{{a,d},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	5
F141	{{a,d},{a,b,c},{a,b,d},{a,c,d},{a,b,c,d}}	5
F142	{{a,c},{a,b,c},{a,c,d},{b,c,d},{a,b,c,d}}	5
F143	{{a,c},{a,b,c},{a,b,d},{a,c,d},{a,b,c,d}}	5
F144	{{a,b},{a,b,c},{a,b,d},{b,c,d},{a,b,c,d}}	5
F145	{{a,b},{a,b,c},{a,b,d},{a,c,d},{a,b,c,d}}	5
F146	{{b,d},{a,b,d},{b,c,d},{a,b,c,d}}	4
F147	{{c,d},{a,c,d},{b,c,d},{a,b,c,d}}	4
F148	{{b,c},{a,b,c},{b,c,d},{a,b,c,d}}	4
F149	{{a,b,c},{a,b,d},{a,c,d},{a,b,c,d}}	4
F150	{{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	4
F151	{{a,b,c},{a,c,d},{b,c,d},{a,b,c,d}}	4
F152	{{a,b,c},{a,b,d},{b,c,d},{a,b,c,d}}	4
F153	{{a,d},{a,b,d},{a,c,d},{a,b,c,d}}	4
F154	{{a,c},{a,b,c},{a,c,d},{a,b,c,d}}	4
F155	{{a,b},{a,b,c},{a,b,d},{a,b,c,d}}	4
F156	{{a,c,d},{b,c,d},{a,b,c,d}}	3
F157	{{a,b,d},{a,c,d},{a,b,c,d}}	3
F158	{{a,b,d},{b,c,d},{a,b,c,d}}	3
F159	{{a,b,c},{a,c,d},{a,b,c,d}}	3
F160	{{a,b,c},{b,c,d},{a,b,c,d}}	3
F161	{{a,b,c},{a,b,d},{a,b,c,d}}	3
F162	{{a,c,d},{a,b,c,d}}	2
F163	{{b,c,d},{a,b,c,d}}	2
F164	{{a,b,d},{a,b,c,d}}	2
F165	{{a,b,c},{a,b,c,d}}	2
F166	({a,b,c,d}}	1

The lattice $<\Phi, \subseteq>$ is constructed as given in Fig. 3 whose elements are 166 topological filters defined over the ground set X = {a,b,c,d}. Note that the symbol $\subseteq$ denotes the partial order relation of 'subset of'. One can enumerate 13,767 linear maximal filter chains from this lattice. One can compute STRT spectra for all the 13,767 linear maximal filter chains. For example, one linear maximal filter chain is considered here and its STRT shown in table 3.

Table 3: Filter chain and its STRT spectrum

Sl.No.	Filter Chain		Spectrum
1.	F1	{{a},{b},{c},{d},{a,b},{a,c},{a,d},{b,c},{b,d}, {c,d},{a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	{{a},{b},{c},{d},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d}, {a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}
	F2	{{a},{b},{c},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d}, {a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	{{d}}
	F7	{{a},{c},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d}, {a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	{{b},{c},{d}}
	F13	{{a},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d},{a,b,c}, {a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}	{{c},{d}}
	F22	{{a},{a,b},{a,c},{a,d},{b,c},{b,d},{a,b,c}, {a,b,d}, {a,c,d},{b,c,d},{a,b,c,d}}	{{b},{c},{d},{b,c},{b,d},{c,d},{b,c,d}}
	F36	{{a},{a,b},{a,c},{a,d},{b,c},{a,b,c},{a,b,d}, {a,c,d}, {b,c,d},{a,b,c,d}}	{{b},{b,c,d}}
	F53	{{a},{a,b},{a,c},{a,d},{a,b,c},{a,b,d},{a,c,d}, {b,c,d},{a,b,c,d}}	{{b},{c},{d},{b,c},{b,d},{b,c,d}}
	F72	{{a},{a,b},{a,c},{a,d},{a,b,c},{a,b,d},{a,c,d}, {a,b,c,d}}	{{c},{d},{b,d},{b,c,d}}
	F114	{{a,b},{a,c},{a,d},{a,b,c},{a,b,d},{a,c,d}, {a,b,c,d}}	{{a},{b},{c},{d},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d}, {a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}
	F132	{{a,b},{a,c},{a,b,c},{a,b,d},{a,c,d},{a,b,c,d}}	{{d},{a,b,c,d}}
	F145	{{a,b},{a,b,c},{a,b,d},{a,c,d},{a,b,c,d}}	{{b},{c},{d},{a,b,c},{a,b,d},{a,b,c,d}}
	F155	{{a,b},{a,b,c},{a,b,d},{a,b,c,d}}	{{c},{d},{a,b,c,d}}
	F161	{{a,b,c},{a,b,d},{a,b,c,d}}	{{b},{c},{d},{a,b},{a,c},{a,d},{b,c},{b,d},{c,d}, {a,b,c},{a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}
	F265	{{a,b,c},{a,b,c,d}}	{{d},{a,d},{b,c,d},{a,b,c,d}}
	F166	{{a,b,c,d}}	{{b},{c},{d},{a,c},{a,d},{b,c},{b,d},{a,b,c}, {a,b,d},{a,c,d},{b,c,d},{a,b,c,d}}
		{Φ}	{{c},{d},{a,d},{b,d},{a,b,d},{a,c,d},{b,c,d}, {a,b,c,d}}

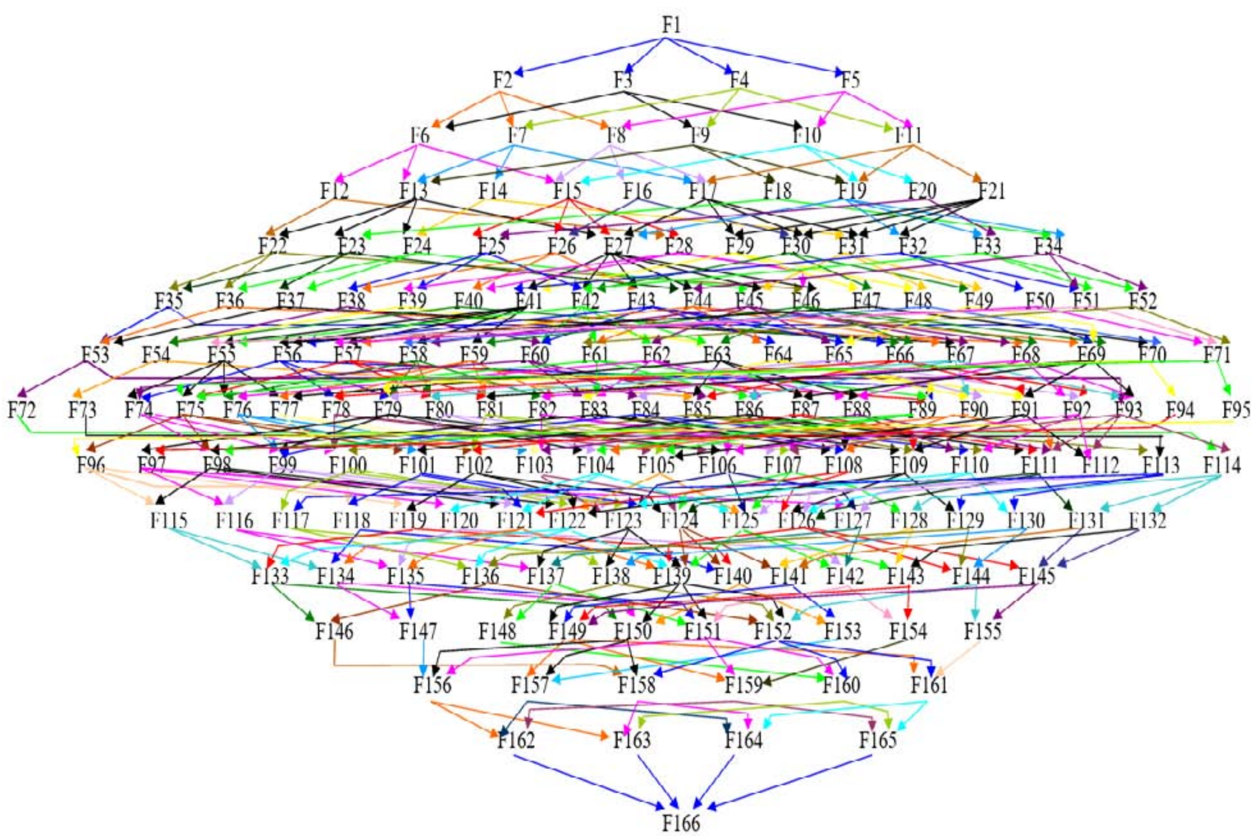

Fig. 3: Lattice diagram showing the linear filter chains over a set X = {a, b, c,d}

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IV. Observations

By applying STRT to the above maximal filter chains, we examined few pair-wise intersection properties. The level with filter of maximum cardinality is considered as Level1.By taking two random filter chains, which deviate at certain levels the following properties were observed:

Deviation in any combination of even levels results in following properties:

Union of spectra of two filter chains is same as Spectrum of Intersection of those two filter chains.

Intersection of spectra of two filter chains is same as Spectrum of Union of those two filter chains.

One can easily verify these properties by applying STRT to the below pair of filter chains:
For example, let us consider n=3,

Deviation in Level 2-

F1-F2-F5-F8-F12-F15-F18
F1-F3-F5-F8-F12-F15-F18

Deviation in Level 4-

F1-F3-F5-F8-F12-F15-F18
F1-F3-F5-F11-F12-F15-F18

Deviation in Level 6-

F1-F4-F7-F10-F14-F16-F18
F1-F4-F7-F10-F14-F17-F18

Deviation in Level 4 and 6-

F1-F2-F5-F8-F12-F15-F18
F1-F2-F5-F11-F12-F16-F18

Deviation in any combination of odd levels results in following properties:

Union of spectra of two filter chains is same as Spectrum of Union of those two filter chains.

Intersection of spectra of two filter chains is same as Spectrum of Intersection of those two filter chains.

One can easily verify these properties by applying STRT to the below pair of filter chains:

Deviation in Level 3-

F1-F3-F5-F11-F12-F15-F18
F1-F3-F7-F11-F12-F15-F18

Deviation in Level 5-

F1-F2-F5-F11-F12-F16-F18
F1-F2-F5-F11-F14-F16-F18

Deviation in Level 3 and 5-

F1-F3-F5-F11-F12-F15-F18
F1-F3-F7-F11-F13-F15-F18

V. Concluding Remarks

All orthogonal transforms, be it continuous or discrete, are models of first order logic, that is, they have been developed in the framework of first order logic that deal with elements of sets. Alternatively, STRT is a novel concept developed in the framework of second order logic that deals with set of sets, and so it has potential applications to solve problems related to functions of sets.

Acknowledgement

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5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10.Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.
- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- o Single section and succinct.
- o An outline of the job done is always written in past tense.
- o Concentrate on shortening results—limit background information to a verdict or two.
- o Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- o You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- o Give details of all of your remarks as much as possible, focusing on mechanisms.
- o Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- o One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- o Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

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Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

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Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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