STUDY OF FUZZY LOGIC IN MEDICAL DATA ANALYTICS

Mrs. Susmita Mishra and Dr. M Prakash

1Assistant Professor, Department of Computer Science and Engineering
Rajalakshmi Engineering College, Chennai, India

2Professor, Department of Information and Technology
Karpagam College of Engineering, Coimbatore, India

susmita.mishra@rajalakshmi.edu.in; salemprakash@gmail.com

ABSTRACT

Fuzzy logic provides an intelligent periphery for knowledge representation and reasoning to handle inaccuracy, uncertainty, and vagueness. Fuzzy systems have been successfully applied in healthcare due to their ability to infuse human expert knowledge and granular computing, to describe the behavior of complex systems without requiring a precise mathematical model. This paper provides an outline of basic fuzzy logic and how this logic can be used to perform various decision-making tasks. It also emphasizes FL tasks can be applied to different types of medical data, to classify a certain type of disease or diseased patients, in constructing a decision support system. This paper is a descriptive study of FL and its applications in healthcare related fields. The main motive of this paper is to draw a brief description of fuzzy logic applications on various medical diagnosis system.

Key Terms: Fuzzy Clustering Mean (FCM), Fuzzy Inference System (FIS), Fuzzy Logic (FL), Fuzzy Membership Functions (MFs), Fuzzy Set Theory (FST)
INTRODUCTION
Medical datum is any single observation of a patient, thus medical data is a combination of different observations of a patient. Medical data contains information on a person’s state of health and the medical treatment that they have received. Szolovits (2006) stated that medical data analytics is a term used to describe the medical analysis activities that can be undertaken on medical data. Medical analysis is one of the important aspects of our life. But it is impossible to give exact definitions and symptoms of medical concepts and relationship between the concepts in most of the cases. The boundaries are not clear. The uncertain nature of medical field needs the use of Fuzzy Logic or its combination with other AI techniques.

Güney (2016) emphasized in his paper, Fuzzy Logic (FL) is a method of computing that follows human cognitive ability. FL acts like the way of decision making in humans which based on degrees of truth instead of Boolean logic YES and NO. The idea of fuzzy logic was introduced by Dr. Lotfi Zadeh of the University of California in the 1960s when he was working on the problem of computer understanding of natural language. He highlighted that human decision making includes a lot of possibilities between YES and NO, such as possibly, certainly, almost. The fuzzy logic takes possibilities of input to achieve the distinct output.

Consider the statement, “If the back pains severe and the patient is old, then apply acupuncture to a certain point for a long time.” To process and model this statement in a computer system, we need more than programming skills and true-false statements. All the terms we need to model that is severe, old, certain point and long-time are vague and fuzzy. For example, old as a variable is expressed such as the age group above 50 years, 60 years or 70 years. In the same way here for time variable we may go for different time chunks. For this reason, medical data analysis applications need to employ methodologies with fuzzy logic.

Categories of Medical Data
Medical data can be divided based on its attributes. In Fig-1, shows the different data we have considered for this paper. We may have following types of medical data or it can be combinations of them:

- Textual or narrative medical data such as social or family history, answers or description provided by the patient
- Numerical Measurements such as lab results, and other observations
- Recorded signals such as ECG, graphical tracing
- Pictures of CT scan images, radiologic images
Heterogeneous Medical Data, combinations of different types of data

Types of Medical Records

Based on the source of data and who maintains the data we have different types of medical records.

Electronic medical records (EMRs) are digital versions of the notes and information collected by and for the clinicians in that office, clinic, or hospital. Electronic health records (EHRs) contain information from all the clinicians involved in a patient's care and all authorized clinicians involved in a patient's care can access the information to provide care to that patient. EHRs also share information with other healthcare providers, such as laboratories and specialists. EHRs follow patients — to the specialist, the hospital, the nursing home, or even across the country. Personal health records (PHRs) contain the same types of information as EHRs—diagnoses, medications, immunizations, family medical histories, and provider contact information—but are designed to be set up, accessed, and managed by patients. PHRs can include information from a variety of sources including clinicians, home monitoring devices, and patients themselves.

![Figure 1. Categories of Medical Data](image)

Fuzzy Inference System

There are mainly four functional blocks as shown in Fig-2. It contains a knowledge base which consists of rule base and database. Rule Base contains fuzzy if-then rules and database defines the membership functions of fuzzy sets used in fuzzy rules. Fuzzification interface unit converts the crisp quantities into fuzzy quantities. De-Fuzzification interface unit converts the fuzzy quantities into crisp quantities.

To construct a FIS first, we have to define linguistic variables and terms. Then for each linguistic variables, we have to define membership function. The next task is the construction of membership functions and then by using these membership functions construction of fuzzy rules. Predefined facts about the world and expert's knowledge are saved in the database. Then fuzzification takes place means crisp input will be converted into fuzzy data sets using membership functions. Then fuzzy inference
system which performs decision making task starts. It evaluates the rules in the rule base and combines results from each rule. The last step is de-fuzzification where output data is converted into non-fuzzy values.

There are two common fuzzy inference methods used in medical diagnosis systems. The first one is Mamdani’s fuzzy inference method proposed in 1975 by EbrahimMamdani. The second method is Takagi-Sugeno-Kang, introduced in 1985. Blej and Mostafa (2016) highlighted the differences between these two FISs. Sugeno inference method is modified version of Mamdani but both of them have their own pros and cons. Mamdani fuzzy inference system entails a substantial computational burden whereas Sugeno inference method is computationally efficient. Mamdani is well suited to human input whereas the latter is well suited to mathematically analysis. The main difference lies in the output. Mamdani gives an output that is a fuzzy set whereas Sugeno gives an output that is either constant or a linear mathematical expression. A fuzzy rule in Mamdani can be defined as “If A is X1, and B is X2, then C is X3” where, X1, X2, X3 are fuzzy sets. But in Sugeno, it is defined as” If A is X1 and B is X2 then C = ax1 + bx2 + c “where a, b and c are constants.

Figure 2. Functional Blocks of FIS

Different types of fuzzy membership functions
We know the first stage of an inference system is to select suitable membership functions. There are different MFs such as crisp MFs, type-1 (T1) fuzzy MFs, and type-2 (T2) fuzzy MFs. A T1 fuzzy MF is considered as a continuous function on the constituent features. A fuzzy relation of higher type (e.g., type-2) has been regarded as one way to increase the fuzziness of a relation. Based on data distribution different application we can use different MFs. Raj, Gupta, Garg, Tanna, Rhee, and Frank (2017) explained in their work, when the data follows a uniform random distribution, a crisp MF best represents the data set. For a crisp MF, every element in the fuzzy set has an equal probability of occurrence, hence satisfying the requirement of a uniform random distribution. When the data distribution closely represents a continuous function of the constituent features without many deviations, a T1 fuzzy MF may be best suited for its representation. Further, if flexibility is required with each instance of the generated data, an IT2 fuzzy MF may be used as it incorporates a uniform uncertainty with the primary membership. When the data distribution is such that it vaguely follows a well-defined function on the constituent features and a significant number of data samples deviate from it. Here it may be useful to represent the data using a T2 fuzzy Membership Function.

The next section describes the application of FL on different types of medical data. Here we consider the broad categories based on attributes of input.

**FUZZY LOGIC TASKS IN MEDICAL DATA**

Singh (2013) explained fuzzy logic is excessively helpful for people involved in research and development including engineers, mathematicians, computer software developers and researchers, natural scientists, medical researchers, social scientists, public policy analysts, business analysts, and jurists. Fuzzy logic has been used in numerous applications such as facial pattern recognition, air conditioners, washing machines, vacuum cleaners, antiskid braking systems, transmission systems, control of subway systems and unmanned helicopters, knowledge-based systems for multi-objective optimization of power systems, weather forecasting systems, models for new product pricing or project risk assessment, medical diagnosis and treatment plans, and stock trading. Fuzzy logic has been successfully used in numerous fields such as control systems engineering, image processing, power engineering, industrial automation, robotics, consumer electronics, and optimization. From NCBI (National Center for Biotechnology Information) we identified the number of publications in healthcare using fuzzy logic increases every year. Here Figure3. shows the number of publications from the year 2010 to 2016. Here we have used the keyword “fuzzy logic” to get the count of publications.

Torres and Nieto (2006) explained in their paper diagnosis of the disease involves several levels of uncertainty and inaccuracy. A single disease may appear in many forms based on the patient, and with different intensities. A single symptom may correspond to different diseases. The description of disease...
entities uses linguistic terms that are also not exact and vague. To deal with inaccuracy and uncertainty, fuzzy logic introduces fractional truth values, between YES and NO.

In many real-life applications, it is convenient to consider fractional logical values. Consider the statement "I am healthy". Is it true if I have only one cavity tooth? Is it false if I have a chronic disease? Everybody is healthy to some degree (say h) and unhealthy to some degree (say u). If we are totally healthy, then of the value of \( h = 1, u = 0 \). Usually, everybody has some minor health problems and \( h < 1 \), but \( h + u = 1 \). In the other extreme situation, \( h = 0, u = 1 \) so that we are unhealthy i.e. we are dead. In the case we have only a cavity tooth, we may write \( h = 0.999, u = 0.001 \); if we have a painful gastric ulcer, \( u = 0.6, h = 0.4 \), but in the case we have a cancer, probably \( u = 0.95, h = 0.05 \). FL has a wide area of tasks in health care. In Figure-4, listed out few tasks, which take help of fuzzy logic.

**Ranking Analysis**

In healthcare fuzzy logic is also used for ranking studies. Ranking studies are nothing but ordering alternatives from best to worst. In healthcare, alternatives mean different types of tests, risk factors, the performance of health cares, different attributes related to a particular disease, which are crucial for decision making. T. Kempowsky\(^\text{\textregistered}\)Hamonet al. (2015) applied the fuzzy logic selection on breast cancer databases and obtained four new gene signatures. D Tadic, M Stefanovic and A Aleksic (2014) proposed a fuzzy multi-criteria decision-making approach to evaluate suppliers of one kind of medical device with respect to numerous criteria. Duncan Rangela, Pamplona Salomon (2015) proved that TODIM is better for ranking analysis than Fuzzy Set Theory (FST). M Shrief, W Al\textsuperscript{\textregistered}Atabany and M El\textsuperscript{\textregistered}Wakadi (2015) given a new quantitative ranking model based on multi-criteria decision making using fuzzy logic to rank the computed tomography departments in hospitals. The system is based on factors extracted from both the hospitals and the CT scan devices.
Clustering Analysis

Clustering is a process of partitioning a set of data into a set of meaningful sub-classes known as clusters, in which objects within the same cluster have similar properties and objects of different clusters have different properties. Clustering cancers cells, genes, and images are the main areas of clustering in health care. The studies of DPriya, Krithiga, Pavithra and Rajesh Kumar (2015) states that by using modified fuzzy C-mean clustering algorithm leukaemia in blood microscopic images can be detected. Sharma and Wasson (2015) published a paper which highlighted a method based on fuzzy rules to segment retinal blood vessels. This proposed method makes use of the different set of fuzzy rules to process retinal images taken from publically available DRIVE data set. Tran and Nguyen (2016) proposed a unified framework using Clustering and Fuzzy Rule-based systems for the diagnosis of dental problems, which shows improvements on the side of classification and decision making.

Prediction Analysis

Predictive analytics is the branch of the advanced analytics which is used to make predictions about unknown future events. Predictive analytics uses many techniques from data mining, statistics, modelling, machine learning, and artificial intelligence to analyze current data to make predictions about future.
predicting medical issues before they start to provide better treatment programs for patients, predictive analytics is poised to revolutionize the healthcare industry.

FarzanaIslam et al. (2017) used Adaptive Neuro-fuzzy inference system with a fuzzy C-mean classifier to predict risk for stroke which is helpful for medical experts. Nilashia, Ibrahima, Ahmadic and Shahmoradic (2017) proposed a knowledge-based system using EM, PCA, CART and fuzzy rule-based methods for classifications using fuzzy logic to improve the prediction accuracy of breast cancer. Vanessa, Cátia and Susana (2016) addressed the prediction of short and long-term mortality in patients that presented Acute Kidney Injury (AKI) diagnosis at their hospital admission. Fuzzy models are developed using fuzzy c-means and Gustafson-Kessel algorithms to predict mortality in the ICU within 24 hours. Alhaddad, Mohammed, Kamel and Hagras (2015) presented an interval type-2 fuzzy logic-based model which can deal with uncertainties to produce better prediction accuracies by generating rules with one antecedent to find the effective time instances within the effective sensors in relation to given P300 event.

Classifications

In classification, we try to find group memberships for the known and predefined labels (classes). But in medical field classification, is the process of transforming descriptions of medical diagnoses and procedures into universal medical code numbers. Diagnosis codes track diseases and other health conditions. These codes helps in statistical analysis of diseases and therapeutic actions, reimbursement (insurance claim) and also in knowledge-based and decision support systems.

Sridhar, Reddy and Prasad (2015) proposed methodologies, the binding of fuzzy logic with morphological operator to classify mammograms into more intensity colour parts for the suspicious area. Cátia, Salgado et al. (2016) proposed an ensemble fuzzy modelling approach to a classification problem based on subgroups of patients identified by individual characteristics by using fuzzy c-means clustering algorithm.

Pattern Recognition and Feature Extraction

Pattern recognition focuses on the recognition of patterns and regularities in data. Time series analysis tries to find patterns and rule depending on time, recognition of medical images belong to this type of studies. Whereas feature selection is the methodology that finds and eliminates the irrelevant samples in the given space of the samples to help the decider in the decision-making process. This method is used especially to eliminate the unhealthy cells/images/tissues to spot the illness in the patients.

implemented an efficient algorithm for gait based human identification. They considered the features such as height, hip, neck, the knee of the human silhouette and a model based feature such as area under Hermite curve of hip and knee. The subject recognition has done using Fuzzy Logic. Rubio, Oscar, and Sepulveda (2016) implemented a method for detection of early-stage breast cancer. They have collected mammography images from the mini-MIAS database and passed the gradient operator of images as Fuzzy variables to recognize area with high tone variation. Herman, Prasad and Thomas (2017) has examined the applicability of the T2FL approach to the problem of EEG pattern recognition. Sriparna Saha et al. (2016) demonstrated an interesting approach to gesture recognition for elderly people on the basis of gesture analysis and generate alarms, thereby finding significance in elderly healthcare. They have used the concept of interval type-2 fuzzy logic based classification. Wu CH and Wang (2015) constructed a cloud-based fuzzy expert system for the risk assessment of chronic kidney disease (CKD).

Figure 4. Fuzzy Logic Tasks on Medial Data

Figure 5. shows the flowchart of fuzzy inferences on medical data. The input can be any medical data and output will be ranking, classification, risk analysis or prediction of disease.

**DIAGNOSIS THROUGH MEDICAL IMAGING USING FUZZY LOGIC**

Peter (2006) highlighted the importance of fuzzy in medical imaging. According to him medical imaging is a strong supporting element in medical decision making. Two dimensional or three-dimensional medical images are generated by magnetic resonance imaging, computed tomography, digital mammography, positron emission tomography tests. These images can only be usable in medical decision
support by postprocessing. FL techniques are also well used in this area. The medical domain is full of imprecise conditions and vagueness. There exist noise and inaccuracies in edge detection, so we can use fuzzy logic with traditional methods to detect edges efficiently. Pattern recognition is the way of determining the patterns, cells, images, etc. Classification and clustering are common techniques used for pattern recognition. The major fuzzy methods in medical image pattern recognition are fuzzy clustering, fuzzy rule-based methods, fuzzy pattern matching methods, and methods based on fuzzy relations. In fuzzy clustering, the fuzzy c-mean algorithm is one of the most used techniques. Some examples of FL-supported medical imaging applications are supported in the diagnosis of brain tumor, classification of radiographic images, edges detection, images thresholding, motion detection, ranking segmentation paths.

Figure 6. shows the general framework of fuzzy on images. This describes the input will be features of an image or grayscale image or Histogram of that input image. After inferencing, the output will be any decisive measure either classes or segments.

According to Wang, Li, Qin and Hao (2015) modalities of medical images convey different information about the human body, organs, and cells, and have their own uses. For example, computed tomography (CT) images can depict dense structures like bones and hard tissue with less distortion, while magnetic resonance imaging (MRI) images are better visualized in the case of soft tissues. Whereas T1-MRI images provide anatomical structure details of tissues, while T2-MRI images provide information about normal and pathological tissues.

Mohajerani and Ntziachristos (2016) proposed a method to improve imaging performance of fluorescence molecular tomography (FMT). They proposed a new approach for utilizing prior information, using a weighted least square (WLS) approach, where the weights were optimized using a Mamdani-type fuzzy inference system.
Yong Yang et al. (2016) proposed a novel multimodal medical image fusion method that adopts a multiscale geometric analysis of the non-subsampled contourlet transform (NSCT) with type-2 fuzzy logic techniques. First, the NSCT was performed on preregistered source images to obtain their high- and low-frequency sub-bands. Next, an effective type-2 fuzzy logic-based fused rule is proposed for fusion of the high-frequency sub-bands. In the presented fusion approach, the local type-2 fuzzy entropy is introduced to automatically select high-frequency coefficients. However, for the low-frequency sub-bands, they were fused by a local energy algorithm based on the corresponding image's local features. Finally, the fused image was constructed by the inverse NSCT with all composite sub-bands. Both subjective and objective evaluations showed better contrast, accuracy, and versatility in the proposed approach compared with state-of-the-art methods. Besides, an effective color medical image fusion scheme is also given in this paper that can inhibit color distortion to a large extent and produce an improved visual effect.
FUZZY IN DIAGNOSIS THROUGH SIGNAL PROCESSING

To provide more comfortable and effective healthcare services, a recent trend of healthcare has been directed towards deinstitutionalization, community care, and home care. The quality of community and home health care has been significantly improved and many portable devices have also been developed for a wide variety of applications where signal processing-based software plays a pivotal role in their success.

Zalabarria, Irigoyen, Martíneaquel and Ramirez (2016) proposed a system for stress detection and monetarization. This work uses physiological variables such as the electrocardiogram (ECG), the galvanic skin response (GSR) and the respiration (RSP) in order to estimate the level and classify the type of stress. On that purpose, an algorithm based on fuzzy logic has been implemented. This computer-intelligent technique has been combined with a structured processing shaped in the state machine. This processing classifies stress into 3 different phases or states: alarm, continued stress and relax.

Plerou, Vlamou, and Papadopoulos (2016) concerned with the evaluation of EEG signal analysis using several pattern recognition methods, and compared analysis to linear and nonlinear pattern recognition for enhanced efficiency of fuzzy logic systems has been carried out.

Yang, Deng, Choi, Wang and Takagi-Sugeno-Kang (2016) proposed an important approach to the detection of epilepsy. They proposed to construct a Takagi-Sugeno-Kang (TSK) FLS based on transductive transfer learning for identifying epileptic EEG signals. The main objective is to increase the performance of the epileptic EEG datasets to deal with situations where the training and test datasets differ with regard to data distribution.

FUZZY LOGIC IN DIAGNOSIS THROUGH TEXTUAL MEDICAL DATA

The majority of medical documents and electronic health records (EHRs) are in text format that poses a challenge for data processing and finding relevant documents. Looking for ways to automatically retrieve the enormous amount of health and medical knowledge has always been an intriguing topic. Powerful methods have been developed in recent years to make the text processing automatic.

Karami, Gangopadhyay, Zhou, and Kharrazi (2017) described fuzzy latent semantic analysis (FLSA), a novel approach in topic modelling using fuzzy perspective. FLSA can handle health medical corpora redundancy issue and provides a new method to estimate the number of topics. The quantitative evaluations show that FLSA produces superior performance and features to Latent Dirichlet allocation (LDA), the most popular topic model.
Figure 6. Framework of Fuzzy Image Processing

Wang, Zhang, and Xu (2016) proposed a new sentiment computation approach, which is defined as public sentiments discriminator (PSD), considering both fuzzy logic and sentiment complexity. Unlike traditional machine learning methods, PSD is based on the rational hypothesis that sentiments are correlated with each other. A three-level computing structure, sentiment-term level, microblog level and public sentiment level, is employed. Experiments show that the proposed approach, PSD, can achieve similar accuracy and F1-measure but more cognitive results when compared with traditional well-known machine learning methods. These experimental studies have confirmed that PSD can generate an interpretable result with no restriction among sentiments.

Karamia et al. (2018) analyzed unstructured health-related text data exchanged via Twitter to characterize health opinions regarding four common health issues, including diabetes, diet, exercise, and obesity on a population level. To discover topics from the collected tweets, they used a topic modelling approach that fuzzy clusters the semantically related words such as assigning "diabetes", "cancer", and "influenza" into a topic that has an overall "disease" theme.

Najafi, AmirkhaniPapageorgiou, Mosavi and Mohammad (2017) proposed an innovative medical decision support system by using computing with words in fuzzy cognitive maps. In this paper, all concepts and the weights of connecting links between them are described based on interval type-2 membership functions (IT2 MFs) expressed as a set of words. In this paper, we utilize CWW FCM to classify celiac disease (CD), a chronic disorder.
FUZZY LOGIC IN DIAGNOSIS THROUGH NUMERICAL/ EXPERIMENTAL MEDICAL DATA

Experimental data in science are data produced by a measurement, test method, experimental design or quasi-experimental design. In clinical research, any data produced are the result of a clinical trial. Experimental data may be qualitative or quantitative, each being appropriate for different investigations.

Generally speaking, qualitative data are considered more descriptive and can be subjective in comparison to having a continuous measurement scale that produces numbers. Whereas quantitative data are gathered in a manner that is normally experimentally repeatable, qualitative information is usually more closely related to phenomenal meaning and is, therefore, subject to interpretation by individual observers.

Chavan, Sambare and Joshi. (2016) proposed a method to recommend a diet based on Prakriti of person and current season and data is collected from different websites where different dieticians recommended different diet plans for different Prakriti. They have used Type-2 Fuzzy Logic to handle uncertainty and Ontology is integrated with fuzzy logic to represent food knowledge for the efficient and accurate diet recommendation.

Thakur, Raw, Sharma and Mishra(2016) developed a fuzzy based Inference System in order to analyze the severity of Thalassemia disease using Fuzzy Logic Toolbox in Matlab by developing 26 if-then rules. For this three fuzzy input variables such as Mean corpuscular hemoglobin (MCH), Mean Corpuscular Volume (MCV) and hemoglobin (HGB) were considered. To show the sensitivity of Thalassemia, three output variables such as minor, intermediate and major were analyzed with input and rules.

PERFORMANCE ILLUSTRATION

Fuzzy logic with other algorithms and methods is an efficient tool for disease diagnosis. By considering different works we can list down main application areas in medicine, but not limited to, with their reported performance accuracy in Table 1.
### Table 1

*Accuracy of diagnosis of different disease using Fuzzy Logic Techniques*

<table>
<thead>
<tr>
<th>Disease</th>
<th>Techniques</th>
<th>Reported Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast Cancer Determination</td>
<td>ANFIS for classification</td>
<td>93.7%</td>
</tr>
<tr>
<td></td>
<td>Fuzzy Cognitive Maps</td>
<td>98.3%</td>
</tr>
<tr>
<td></td>
<td>CART and Fuzzy rule based system</td>
<td>93.2%</td>
</tr>
<tr>
<td>Brain Tumor Detection</td>
<td>FCM with CSO and OBD</td>
<td>98.3%</td>
</tr>
<tr>
<td></td>
<td>HSD with Fuzzy-HKSVM</td>
<td>98.6%</td>
</tr>
<tr>
<td>Diabetes</td>
<td>Fuzzy Classifier</td>
<td>93.82%</td>
</tr>
<tr>
<td></td>
<td>Fusion of Fuzzy Logic, ANN and SVM</td>
<td>95.10%</td>
</tr>
<tr>
<td>Heart Disease Prediction</td>
<td>FCM</td>
<td>92%</td>
</tr>
<tr>
<td>Crohn’s disease</td>
<td>Neuro Fuzzy Classifier</td>
<td>97.67%</td>
</tr>
<tr>
<td>Tuberculosis diagnosis</td>
<td>ANFIS</td>
<td>97%</td>
</tr>
<tr>
<td>Lung Cancer Detection</td>
<td>Fuzzy Local Information Cluster Means</td>
<td>85.9%</td>
</tr>
<tr>
<td></td>
<td>Hybrid Neuro Fuzzy System</td>
<td>95.5%</td>
</tr>
</tbody>
</table>

### CONCLUSION

Diagnosis of the disease involves several degrees of uncertainty and vagueness. FL is employed in every critical decision-making process of healthcare from supply chain to diagnosis, from mining health data to retrieve information. Fuzzy nature of the medical decision-making process makes traditional methods suffer from elasticity. By using FL, we can make systems more flexible, robust, and efficient by taking into account all possible values including the blurred ones. Designing an FL system or application requires more effort and time. This makes the computation time for the desired output longer but it provides more accurate results in the medical field as it deals with obscurity.
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