A New Approach to Object Based Fuzzy Database Modeling

Debasis Dwibedy, Laxman Sahoo, Sujoy Dutta

Abstract— ***The requirements in diversified application domains like Engineering, Scientific technology, Multimedia, Knowledge management in expert systems etc shift the momentum of current trends in designing database models to an innovative concept of Object Based fuzzy Database Model. The ongoing research concentrates on representing the imprecise information by taking object modelling methodology and fuzzy techniques through different levels of class hierarchy and abstractions. Still, a formal definition of fuzzy class is not yet given by which we can represent all standards of fuzzy objects and attributes. In this paper, we redefine the fuzzy class in an efficient manner and propose the structure of the fuzzy class using more effective generalized techniques to develop a new object based fuzzy data model in order to manipulate imprecise information and exposed to wider range of applicability. Also, we define a formal framework for generalized fuzzy constraints which can be applied effectively to fuzzy specialized classes in fuzzy class hierarchy.***

Index Terms— ***Fuzzy, Class, Constraints, Generalization, Object Model, Specialization, Fuzzy object Model.***

I. INTRODUCTION

The modelling and manipulation of complex object and imprecise information together are emerging as leading problems to the database research. The involvement of complex object & uncertainty measures in the data or attribute values make the existing relational data models unanswered. Object oriented data models are capable enough to handle complex objects but are restricted towards the representation of imprecise or uncertain data. These problems in the database world bring the innovative concept of object based fuzzy data model by extending the object oriented data model and applying fuzzy techniques to it. The fuzzy object data model is being continuously prototyped with the objective that it evolves into a powerful knowledge representation methodology with inherent fuzzy reasoning techniques for problem solving in complex and uncertain environment [11]. Research has started from defining fuzzy attribute, fuzzy object, fuzzy class and is continuing to define relationship among fuzzy objects, attributes, classes and to represent fuzziness at various level of class hierarchies [4], [6], [13], [19]. What is still lacking, a formal definition of a fuzzy type or fuzzy class, the existing definitions of fuzzy class are specified to a particular model and applicable to only limited application domain which also creates problems in determining fuzziness at different level of class hierarchy or establishing fuzziness at inheritance and multiple inheritance structure.

Constraints serve as integrity rules in database systems [5]. The fuzzy object modelling is lacking a systematic framework for defining constraints to fuzzy class hierarchy.

Thus, by concentrating on these important factors, we first introduce a formal definition of fuzzy class along with an efficient and generalized fuzzy class structure. Secondly, we develop an effective framework to represent constraints to the fuzzy super class-subclass hierarchies. The various sections of the paper are organized as follows. In first section we discuss the existing definitions of fuzzy class. In second section, we define the fuzzy class in a more generalized manner and propose an efficient structure for representing fuzzy class. In third section, we discuss the concept of fuzzy super class-subclass. In fourth section we introduce a generalized formulation to impose constraints into fuzzy super class-subclass hierarchy in an efficient and easily implementable manner. In last section we provide the conclusion of this study and discuss some future research directions.

II. PREVIOUS STUDIES

The existing definitions of fuzzy class are based on certain specifications which can be applied to limited application domains. The primary examples of fuzzy class in the literature are taking a crisp type and establish some fuzzy property for it [3].

In [8], the author defined fuzzy class as a class with fuzzy boundary. He defined such a fuzzy class as: $FC_i = \{(O_{ij}.....a_{ij}, \mu(O_{ij}..))/O_{ij}...$is object, a_{ij} is attribute, $0 \le \mu(O_{ij}....a_{ij}) \le 1\}$. The idea is to represent a fuzzy class in terms of fuzzy object in which the attributes of the object belongs to the object with certain membership degree.

In [7], the author defined fuzzy class as fuzzy type whose structural part is a fuzzy structure. That means all the attributes defined for a class should belongs to the class with certain membership degree. A two layer graphical structure is also purposed by the author to represent a fuzzy type. First layer shows classes with fuzzy structure that make up the conceptual hierarchy of the problem that is being modelled. Second layer is a crisp layer, made up of classes with crisp structure containing different hierarchy used to represent fuzzy classes of other type. In [15], the author defined the fuzzy class with respect to weights of the attributes to the class, in addition to these common attributes a special attribute has to be added which indicates the membership degree to which an object of the class belongs to the class. If the class is fuzzy sub class then the degree that the sub class belongs to super class is illustrated in the specifications.

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In [5], the author defined a fuzzy class in terms of attributes belongs to fuzzy class or objects belongs to the fuzzy class. If attributes belongs to the class takes values from fuzzy domain or contains fuzzy value then the class is fuzzy. Similarly when the objects form the class contains uncertain value then class is fuzzy.

In [10], the author extended the work of [15] and represented three level of fuzziness. First, fuzziness of the class belongs to the database model. Second fuzziness of objects belongs to the class. Third, fuzziness in terms of attributes belongs to the object or class. Fuzziness of the class belongs to the model is represented as: CLASS NAME WITH m DEGREE. Fuzziness in terms of instance belongs to the class can be represented by λ. Fuzziness of attributes belongs to the class is represented in two ways: 1) FUZZY attribute name: when attribute take value from fuzzy domain.
2) ATTRIBUTE NAME WITH m DEGREE: when attribute value domain is fuzzy.
All the above representations of fuzzy class reflect to more or less a same concept or single point of view specified to only some specific application area. A fuzzy class needs to be defined with respect to specific relationship between two objects, an object and its type, super type-subtype and purpose of relationship [23]. The existing fuzzy class structure is lacking of flexibility to cater the representations of all type of fuzzy value as it is concentrated on a single point of specification, due to lack of a formal or general specifications it needs to be redefined to represent more complex or advanced requirements. A formal definition of fuzzy class is needed which incorporates a wider range of possibilities within it. The fuzzy class structure should be designed in such a way that it can accommodate all possible type of attributes of a class and have the portability to add more features when the requirements gets changed.

III. A NEW DEFINITION TO FUZZY CLASS

We define the fuzzy class as a specialized crisp class with an added linguistic label which comprises of general attributes, fuzzy attributes, and iterative attribute or special object.
A fuzzy class must contain either all of the above mentioned attributes or some of the attributes.
We introduce the concept of "Iterative fuzzy attribute or Special object". An iterative fuzzy attribute is an attribute or special object which is having its own properties or attributes. It is quite often seen in many applications like knowledge management and expert systems, where we have classes consist of attribute which can be decomposed into further more simplified attributes. The existing fuzzy object models do not provide any interface to represent or manipulate such an attribute, which shows their lacking in uniform formalization towards the global representations of fuzzy class at any circumstances.
The representation of a new fuzzy class structure along with fuzzy iterative attribute is given as follows:

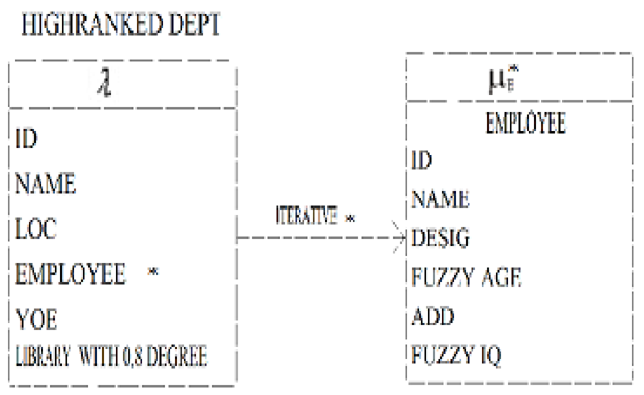


Fig I: REPRESENTION OF FUZZY CLASS

We represent such a fuzzy class by two dashed line class diagrams with little modifications of general object oriented class diagram. For example, an application demands to represent all the departments of our country into three distinct categories:
HIGHRANKEDDEPT, MEDIUMRANKEDDEPT, and LOWRANKEDDEPT. All these classes are specialized classes of the class DEPT and are associated with a linguistic label which clearly indicates their fuzziness.

Fig I shows the representation of a fuzzy class HIGHRANKEDDEPT. The proposed model of fuzzy class consists of two dashed rectangles each divided into two parts. The first rectangle represents the fuzzy class whose name placed at top of it, the first part of the rectangle shows the membership degree of the fuzzy class belongs to the data model or its membership degree to the super class if it is the sub class and is represented by the symbol" λ" .The second part of the rectangle represents all type of attributes possible for the fuzzy class. A general attribute is represented as: ATTRIBUTE NAME.
An attribute which takes value from a fuzzy domain like AGE which might take fuzzy values as young, middle aged, old etc is represented as:
FUZZY ATTRIBUTE NAME.
An attribute whose value is uncertain or imprecise is represented as:
ATTRIBUTE NAME WITH m DEGREE.
For example, all the departments may or may not have their own library so we can write LIBRAY WITH 0.8 DEGREE.
A fuzzy iterative attribute is represented as:
ATTRIBUTE NAME *.
For example, EMPLOYEE *.
The second dashed rectangle represents a fuzzy iterative attribute along with its associated properties. The first part of the rectangle shows the membership degree of the fuzzy iterative attribute to the fuzzy class and is represented as:
$\mu_{\text{attribute name}}$*.
The second part of the rectangle represents the properties of the fuzzy iterative attribute headed by the name of fuzzy iterative attribute. The fuzzy class and its fuzzy iterative attribute are associated with a dashed arrow labelled with ITERATIVE *.

If the fuzzy iterative attribute contains another iterative attribute then it can also be represented through another dashed rectangle of same type and the association between these two attributes can be represented as a dashed arrow labelled with ITERATIVE **.
The proposed model is flexible enough to represent and manipulate a fuzzy class in a more efficient way considering a wider range of possibilities of fuzziness in the classes to cater services to diversified application domains. The model strictly follows the ODMG guidelines and is easy to implement. The portability inside the model will also encourage adding more features as per requirements. Above all, the model is very simple and easy to understand and can surely serve as a conceptual modelling for object based fuzzy database.

IV. FUZZY SUPER CLASS- SUBCLASS

The definitions of fuzzy super class-sub class relationship is provided by many researchers in various way by using fuzzy techniques, probability theory, possibility theory and inclusion degree [7], [10], [14], [15]. The concept of property inheritance is extensively used to define the fuzzy super class-sub class relationship [17]. All these researches roam around a central concept that states, a class is a sub class of a super class if and only if for any fuzzy object belongs to the class, if the membership degree that it belongs to the super class is greater than the membership degree that it belongs to the corresponding class and the membership degree that it belongs to the corresponding class is greater than a given threshold value [10]. Another important aspect that is being frequently reflected in the literature is that the inclusion degree of attribute value domain of one class with respect to another class attribute value domain establishes the relationship between fuzzy super class-subclass. A subclass formed from a fuzzy super class is also fuzzy or vice versa. The instances of all fuzzy subclasses belong to the fuzzy super class but it may happen, some of the instances of the super class may not belong to any of the fuzzy subclasses. In fuzzy subclass-super class hierarchy, each subclass belongs to its super class with certain membership degree and is formed from super class on the basis of a special attribute type of the super class. Most of the fuzzy application environment requires the organization of the data in fuzzy subclass-super class hierarchy in order to manipulate the imprecise or uncertain data values in an efficient manner. Since the hierarchy provides an inevitable part of conceptual fuzzy object modeling, we should be in a state to represent all shots of operations that can be performed with subclass-super class hierarchy. In the next section we provide a simplified framework for representing constraints to the fuzzy super class-subclass relationship.

V. CONSTRAINTS TO FUZZY SUPER CLASS-SUBCLASS

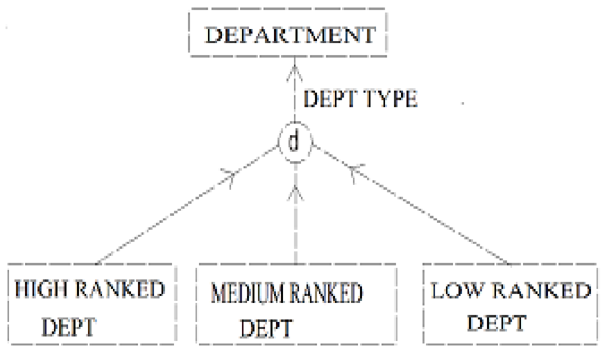
Constraints are used to enforce integrity rules on databases and to specify formal semantics of a database schema [12]. Constraints also play vital role in a database design because these are the rules or sometimes called business logic which restricts the participation of an object or entity in a relationship when it is not required. Defining constraints in a fuzzy object model is a challenge because there is partial belonging of attributes to the object and partial membership of an object to a class occurs. The partial applicability of class properties and uncertainty in attribute values in the fuzzy object data models restrict the researchers to define constraints to fuzzy object data model. However, very few are able to represent constraints to a fuzzy object data model but are theoretically more complex, so difficult to implement.
Here we introduce a formal definition of constraints to fuzzy super class-subclass hierarchy. We focus on defining generalized constraints that can be imposed to a fuzzy class hierarchy to maintain integrity among the fuzzy objects or classes and to restrict the fuzzy sub classes to overlap with in each other domains. We propose following type of fuzzy constraints to fuzzy super class-subclass hierarchy those are:

A. Fuzzy Condition Defined Constraint

This is a constraint to fuzzy specialized classes which states that if at all, an instance can belong to any of the subclasses in a super class-subclass hierarchy with certain membership degree but it will only belongs to a particular fuzzy sub class among the subclasses of the super class to which it satisfy a “Fuzzy condition” which make the sub classes to be the value of one of the subclasses.
We can fuzzily define this concept as: Let’s assume X be the fuzzy super class. Y_1, Y_2, ……………Y_n be the fuzzy subclasses of X. e_1 is an instance of X.
$\mu_X(e_1)$ is the membership degree to which $e_1 \in X$.
$\mu_{Y1}(e_1)$, $\mu_{Y2}(e_1)$,……………$\mu_{Yn}(e_1)$ are the membership degree of the instance e_1 belongs to the sub classes Y_1, Y_2, ……………Y_n respectively.
Now, we can put the constraint on e_1 to belong to a particular class suppose Y_1. So $e_1 \in Y_1$ if and only if it satisfies the following fuzzy condition:
$\text{Max}((\mu_X(e_1) \wedge \mu_{Y1}(e_1)), \mu_{Y2}(e_1),……………\mu_{Yn}(e_1)) = \mu_{Y1}(e_1)$.
The statement $\mu_X(e_1) \wedge \mu_{Y1}(e_1)$ in the formulation ensures that X is the super class of the given sub classes and the instance should have greater membership degree to it than other subclasses keeping the integrity within the subclass-super class relationships and providing a generalized constraint.

B. Fuzzy Disjoint Constraint

Fuzzy disjoint constraints specify that the fuzzy subclasses of specialization must be disjoint. That means an instance of the super class belongs to at most one subclass.



FigII: DISJOINT FUZZY SUBCLASSES

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The subclasses are constraint to be disjoint to restrict their set of entities to be overlapped. Fig II shows the representation of disjoint fuzzy subclasses.

The fuzzy disjoint constraint that we propose says that an instance belongs to the subclass to which it has higher membership grade or it will not belongs to any of the subclasses if its membership grade to all the fuzzy subclasses is zero.

Assume, X is the super class & $Y_1, Y_2, \ldots\ldots\ldots Y_n$ be the fuzzy subclasses of X. e_1 is an instance of X.

$\mu_X(e_1)$ is the membership degree to which $e_1 \in X$.

$\mu_{Y1}(e_1)$, $\mu_{Y2}(e_1), \ldots\ldots\ldots \mu_{Yn}(e_1)$ are the membership degree of the instance e_1 belongs to the sub classes $Y_1, Y_2, \ldots\ldots\ldots Y_n$ respectively.

Now, to make the subclasses disjoint we need to formulate that each instance either belong to one of the fuzzy subclass to which its membership grade is highest or does not belong to any of the fuzzy subclasses if its membership grade to all the fuzzy subclasses is zero.

We can represent the concept with the fuzzy formulation:

$$(\forall e) \; \{ 1 \geq \max (\mu_{Y1}(e), \mu_{Y2}(e), \ldots\ldots\ldots \mu_{Yn}(e)) \geq 0 \}$$

All the constraints that we have discussed are more generic type and can be imposed to fuzzy super class-subclass hierarchy of any kind fuzzy object database model. The transparency in the constraint definition makes it more flexible for implementation. We have taken some general concepts of object modeling to define the constraints, so they are easy to understand as compare to the existing complex definitions which also generates a path for further research in imposing constraints to fuzzy conceptual modeling.

VI. FUTURE RESEARCH DIRECTION AND CONCLUSION

In this study, we investigate by defining a new fuzzy class structure in an efficient and more effective generalized technique to develop the new fuzzy object database model in order to manipulate uncertain or imprecise data. The main advantages of the proposed model are its ability to represent all levels of fuzzy classes, fuzzy objects and fuzzy attributes. The model is strictly following the guidelines of ODMG de facto standard and also easy to understand and implement. The proposed fuzzy constraints are also general in nature which supports the modeling of integrity rules and provides extra facilities for modeling of semantics of a database. We will extend the study further to define and manipulate the fuzzy inheritance structure, fuzzy casual relations, fuzzy exception handling which emerge as the biggest challenging aspects in the fuzzy object database research. The future study will also emphasize on mapping the fuzzy class model into fuzzy object oriented databases, design a systematic algebra for fuzzy object query processing and query optimization. The research will remain in progress to establish a complete formalization of object based fuzzy database.

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