An Overview of Fuzzy Object Oriented Database Systems (FOODBs)

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Abstract— Continuous advancement of information technology is looking for more generalized and specific database definition that could make possible the storage, retrieval and manipulation of multiple, different variety of imprecise, ambiguous, and incomplete complex information in the form of data. To explore such databases, researchers' blends the concept of database with object oriented modeling and fuzzy theory, and evolved the concept of fuzzy object oriented databases. Several concepts, definitions, models, operations, and query languages have been proposed by researchers, but it is still lacking a formal definition and recognition. Conceptually, Fuzzy Object Oriented Database is, a type of database, that could store, retrieve and manipulate the imprecise and uncertain complex data, where complex data is stored in the form of objects with fuzzy techniques applied on it to encapsulate the impreciseness and uncertainty. This paper presents an overview of research work done on fuzzy object database design, processing and manipulation.

Index Terms— database design, fuzzy objects oriented databases, database design, conceptual modeling, logical modeling, physical modeling, query techniques

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1 INTRODUCTION

The rapid application of Computer Engineering and Information Technology in various fields are encouraging the researchers to enhance the remodeling approach of data in order to manipulate the database in a very efficient and convenient way with the inclusion of more complexity and uncertainty in data. Classical data was well thought-out, as the collections of facts and statistics in concert, for the purpose of referencing and analyzing, and was being described by simple attributes. To enhance the classical data models and include the uncertainty and impreciseness in data, modern data types such as text files, documents, audio, video, spatial, temporal, astronomical data, medical and scientific research data, etc. have evolved the concept of Fuzzy Object Oriented Databases for the designing, storage and manipulation of such brand of data.

Fuzzy object Oriented databases are encompassment of concepts of (1) Database techniques (2) Object Oriented Modeling (3) Fuzzy Set Theory, where database techniques include defining, manipulating and controlling of data in the database, modeling of the real world entities with characteristics and their behavior in the form of objects and methods is object oriented modeling, and the application of fuzzy set theory incorporates the modeling of impreciseness and uncertainty with the objects, to represent and manipulate the complex imprecise data. Expert system knowledge base, Geographical Information System, Video storage and retrieval, Temporal and Spatial databases, Office Automation, Network Management, Multimedia database, CASE (Computer Aided Software Engineering), etc. are some applications which use fuzzy and complex information and require implementation of Fuzzy Object Databases. Still the Fuzzy Object Oriented Database is lacking a formal definition an architecture design, definition of operational algebra and query language.

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Remainder of this paper is organized as the 2nd section presents overview of fuzzy object oriented database design that contains three sections conceptual modeling, logical modeling and physical modeling, 3rd section contains summary of algebraic operations that could be performed on fuzzy object databases, 4th section concludes the paper.

2 FUZZY OBJECT DATABASE DESIGN

Database design is the process of producing a detail data model of a database. The non-traditional applications focus on database models for modeling complex information and uncertainty at the conceptual, logical, physical design levels of the database design. Conceptual data models, including the ExIFO and ExIFO2 data models, the logical database models, including the extended NF2 database model, and the fuzzy deductive object-oriented database model and physical models are the three levels of fuzzy object oriented database design. There have been few efforts at defining physical structures that accommodate fuzzy information. A new access structure and data organization for fuzzy information is overviewed.

2.1 Fuzzy Conceptual Modeling

Conceptual data modeling is the first step of the top-down database development process and is performed during the analysis stage of the system development lifecycle [1]. It provides conceptual scheme of the data of the domain for which the database is going to be designed. The interrelationship existing among data, kinds of entities involved, aggregation, associations and other related issues are represented in conceptual modeling [2]. A very comprehensive review on conceptual modeling of fuzzy object oriented database is presented in [3], with a effective summarization and study in a classified manner, where classes are Fuzzy ER models, Fuzzy EER models, Fuzzy IFO model and Fuzzy UML data model. Extension of conventional conceptual models to fuzzy techniques permits the representation and manipulation of imprecise and

uncertain information at conceptual level, and can be characterized with five characteristics such as (i) Fuzziness in level, (ii) Fuzzy constraints, (iii) Representation of Fuzziness, (iv) Graphical representation, and (v) Algebra/operations [3] Fuzzy ER Model is fuzzy extension of classical Entity-Relationship model and it includes fuzziness in attributes, entity and relationship all the three major components of ER model. These components may have a membership degree to the ER model. Fuzzy occurrences of entities and relationships and fuzzy values of attributes are also included in fuzzy entity relationship models. Fuzziness is represented through the probabilistic theory and operations are performed through the entity-relational algebra [4].

ER model extended with the inclusion of fuzzy values in the attributes and a truth value associated with each relationship instance in [5] and special fuzzy-relationships such as same-object, subset-of and member-of are also proposed. Advanced ER concepts such as subclass/super class, specialization/ generalization are proposed for fuzzy ER in [6] and a possibility distribution is defined for the each proposition truth value. For the geo spatial data (GIS) a model is proposed in [7] that treats the data sets as a collection of fuzzy objects.

Fuzzy EER Model: Enhance entity-relationship model or extended entity-relationship model is a conceptual data model that includes all the concepts of Entity-Relationship (ER) model and additionally includes the concepts of subclass, super class, specialization and generalization. Advanced applications such as CAD/CAM, CASE, and GIS etc. do not found the ER model sufficient for the representation of data of their domain, so that new concepts are included into the ER model and the picture of EER model came into existence with the idea of specialization/generalization, category and aggregation. Fuzzy extensions of EER concepts are proposed by Chen [8]. Some fuzzy constraints are studied in [9] and could be used in the FEER models, such fuzzy constraints are named as fuzzy participation constraint, fuzzy cardinality constraint, the fuzzy completeness constraint. A Fuzzy extended entity-relational model introduced with three types of constraints for fuzzy relationships, where the constraints are inheritance constraint, the total participation constraint, and the cardinality constraint to model the imperfect, complex object conceptually [10].

Fuzzy UML Data Model: Unified modeling language (UML) is a standardized, general-purpose modeling language, used to express information or knowledge of system in a structure that is defined by a consistent set of rules. The rules are used for interpretation of the meaning of components in the structure. It includes a set of graphic notation techniques to make visual models of object-oriented software intensive systems and adopted by object management group (OMG). Fuzzy extension of map or UML concepts such as association and dependency with the graphical representation is studied in [11]. The implementation and real world approach towards fuzzy-UML storage is studied and described in [12].

Fuzzy IFO Data Model: IFO data model is a mathematically defined conceptual data model that incorporates the fundamental principles of semantic database modeling within a graph based framework [13]. IFO models extended to model object-oriented database modeling and design into a formal object model IFO$_2$ in [14]. IFO and IFO$_2$ models extended for the representation of imprecise and uncertain information such as the values without semantic representation, the values with semantic representation, and disjunctive meaning, values with semantic representation and conjunctive meaning, and the representation of uncertain information is incorporated into the attribute domain of the objet-based data model [15]. Different level of fuzziness is introduced into IFO model with the corresponding graphical representations in [16] and IFO data model is extended to fuzzy IFO data model and denoted IF$_2$O with the attention on the fuzzification of objects and relationships, especially ISA relationships. A formal approach to map a fuzzy IFO (IF$_2$O) model to a fuzzy object-oriented database schema is proposed in [17]. Conceptual and logical data models IxIFO and NF^2 database model is presented in [18] and also described a mapping process to transform the conceptual schemas of the ExIFO model into the extended NF^2 relations including uncertain properties that are presented in both models.

Fuzzy semantic model (FSM) to handle fuzziness, uncertainty and imprecision of real-world at the attribute, entity and class levels is proposed in [19] with the principles and constructs and the ways to define the membership functions within all the constructs of FSM. Specification of FSM schema and a language to FSM is also proposed. An extended graph-based fuzzy object-oriented data model is defined in [20] where the strength is expressed by linguistic qualifiers, associated with the instance relationship and an object of a class. Modeling of fuzzy classes and fuzzy class hierarchies are also described.

2.2 Fuzzy Logical Data Modeling

A database model is a type of data model to determine the logical structure of a database and the manner in which the data can be stored, organized and manipulated. The most popular database model is the relational model. To model fuzzy, uncertain and complex data several database models have been proposed by researchers. An impressive review on proposed fuzzy logical data models is presented in [21]. This review presents the focus of proposed models such as imprecise data management, uncertainty in hierarchy, fuzzy classification, fuzzy intelligent architecture, and modeling fuzziness uncertainty with the fuzziness in objects, class, object-class, class-subclass and the possible operations that could be performed. A fuzzy object-oriented database model is proposed in [22], which incorporates logic for representation of knowledge. It introduces a similarity relations based model to handle fuzziness at three levels: attribute level, object/class level, class/super class level.

A coupling of fuzzy logic with object oriented databases model to define various complex and uncertain relationship

associations and associated constraints are also proposed in [22]. Syntactic and semantic extensions of ODMG (Object Data Modeling Group) are proposed to deal with fuzzy objects and FODMG (Fuzzy Object Data Modeling Group) evolved. FODMG is a joint international collaborative research effort to standardize common terminology and concepts [23]. ODMG and constraint based framework to include uncertainty with object oriented database is proposed in [24]. A prototypical implementation of fuzziness with vagueness in attributes and uncertainty in relations is presented in [25]. An extended fuzzy object oriented data model based on possibility distribution and semantic measure has been proposed to model complex objects [26]. A multidimensional indexing technique to efficiently handle both fuzzy and crisp queries is proposed in [27]. It can also be used for both aggregation and inheritance hierarchies and can deal with the fuzzy relations of fuzzy object model. The retrieval, insertion and deletion algorithms are also investigated.

A complete definition of fuzzy object oriented databases is offered in [28] by analyzing different kinds of uncertainty and imprecision. A definition of fuzzy query language and design of a query evaluation mechanism to answer visual queries defined as patterns is also proposed in [28]. A management system for fuzzy and probabilistic object model FPOB has been proposed with the syntax and semantics of FPOB schemas, instances and selection operations, where uncertain and imprecise object attribute values are represented by probability distributions on fuzzy set values [29]. A general object-oriented framework for the modeling of the time with fuzzy and uncertain data, to support and extend the traditional database concepts has been proposed in [30]. Another fuzzy object-oriented database system prototype is presented with the representation of hierarchical data whose attribute value can be a possibility distribution with a certainty factor and deal with a degree of inheritance of possibility distributions in [31]. A fuzzy deductive object-oriented database model for representation and deduction of complex and fuzzy objects is introduced in [32]. Various types of uncertainty, such as null incomplete and fuzzy types are also considered. Deduction is used to cope with complex relationships and to derive new information [32].

A generalized object model that incorporates fuzzy set theory as a tool to use in the task of object modeling is presented in [33]. ODMG based object model is proposed to systematically identify where, how and what kind of uncertainty can be introduced in [34]. A UFO database model is an extension of object oriented database model (OODBM) and it allows the manipulation and recording of fuzzy and uncertain (imprecise) information. A UFO based model is proposed to enhance the modeling capabilities of database applications by making it possible to model approximations of reality in a flexible way within the database scheme. A fuzzy inheritance relationship between classes in UFO DBM allows for a flexible modeling of fuzzy extensions of both crisp and fuzzy notations. Its influence to the inheritance of both structure and behavior is also discussed in [35].

A framework for fuzzy object-oriented database is proposed on the idea of computing with words (CW), where fuzzy objects as objects that take linguistic variables and their operations (number functions) take linguistic values as argument variables. Fuzzy rules, described in this framework include two parts - condition and action, predicate part contains the firing condition for the action, which are visualized as the fuzzy event schema and fuzzy state transition diagrams and fuzzy event types play key roll [36]. A fuzzy object-oriented database model based on a formal framework using an algebraic type system and formally defined constraints are introduced in [37].

2.3 Fuzzy Physical Data Modeling

Physical design of the database specifies the physical configuration of the database on the storage media. It includes detailed specification of data elements, data types indexing options and other parameter residing in the DBMS data dictionary. It is the detailed design of a system that includes modules and databases hardware and software specifications of the system. Fuzzy object-oriented database physical design is in immature state. The current crisp index structures are inappropriate for representing and efficiently accessing fuzzy data.

To allow both the non-fuzzy and fuzzy attributes to be indexed together; a multidimensional access structure is proposed in [38] and named as Multi Level Grid File (MLGF), which can efficiently access both crisp and fuzzy data from fuzzy databases. For efficient retrieval of data a suitable access structure, an effective partitioning, representation, and storage of fuzzy data are necessary. An implementation of the access structure is described and compared with extant fuzzy access methods [38].

A superimposed coding together with detailed cost model based indexing of fuzzy object-oriented database is discussed in [39]. The correctness of the cost models as well as the efficiency of the index structures proposed is validated by a number of measurements on experimental fuzzy databases [39]. An inverted file based indexing of fuzzy data based to speedup retrieval considerably by stopping the traversal of posting lists early is studied in [40]. The augmented ordered fuzzy subset is introduced in [41] that make the nearest rule a more powerful derivation and retrieval mechanism in fuzzy object oriented database environment.

3 ALGEBRAIC OPERATIONS ON FUZZY OBJECT SDATABASE

Extraction of data from conventional database is being performed with the algebraic operations such as projection, Join, Union, Difference etc. To retrieve and manipulate data/information from fuzzy object oriented database, advancement of existing algebras and new algebras are proposed. Algebras such as Object algebra, Query algebra and Association algebra are evolved for retrieval and manipulation of complex objects with the imprecise and uncertain values, stored in fuzzy object oriented databases.

3.1 Object Algebra

Object algebra is a formal foundation for a query language that can handle both the state and the behavior of objects. Creation of new objects and introduction of new relationships among objects/classes are also facilitated by the object algebra. It is as powerful as relational and nested relational algebra and provides greater computational power [42]. Data definition and data manipulation operators based on types, constructs and object schemes are introduced in [43], a set of data definition operators and data manipulation operators are introduced to act on the set of all database schemes for the data definition purposes and to define query database objects. Defined operators satisfy the principle of "Compositionality", which guarantees the closure property of the algebra [43].

A full –fledged algebra is defined as the syntax and semantics of the selection and other main data operations on the proposed object base model in [44]. Computation of resemblance between fuzzy sets of fuzzy objects is proposed by a set of operators and a policy to handle resemblance in basic objects and an aggregation policy to compare complex objects is also studied in [45]. Algebraic operations and fuzzy query processing based on the fuzzy class model are introduced in [46]. First a fuzzy class model is defined and then fuzzy combination operations such as (1) Fuzzy Product, (2) Fuzzy Join, (3) Fuzzy Union, (4) Fuzzy Difference, and (5) Fuzzy Projection are defined here. A SQL (Structured Query Language) like query syntax with a strategy to rank the objects in query answers according to their satisfaction degree of satisfying the given query requirement is also described in [46]. Depending on the relationships between the attribute sets of the combining classes, three kinds of combination operations such as Fuzzy Product, Fuzzy Join, and Fuzzy Union and a flexible query through SQL like query syntax is described in [47].

3.2 Query Algebra

An algebra which synthesizes the relational query concepts with fuzzy object oriented databases and fully supports abstract data types and object identity while providing associative access to objects, including a unique join capability is defined in [48]. The operation takes an abstract view of objects and accesses typed collections of objects through the public interface defined for the type. The algebra supports access to relationships implied by the structure of the objects, as well as the definition and creation of new relationships between objects. The structure of the algebra and the abstract access to objects offer opportunities for query optimization [48].

A hedge algebra based approach, for handling the attribute values of object classes with fuzzy and uncertain information is studied in [49]. Through this approach the evaluating semantics, searching uncertain and fuzzy information and classical data entirely comes to a consistence based on ensuring data homogeneity. An algorithm is also constructed to carry a data matching in service of data query [49]. An approach to solve division-like queries in fuzzy object databases in studied in [50] based on the use of fuzzy inclusion operators. Two ways of incorporating resemblance measure in the computation of inclusion, named as a constraint of the implication and as a constraint of the membership to the dividend, are proposed based on the fact that the attribute values fuzzily described objects makes the division operator to mean of resemblance measures. Two approximate inclusion operators based on the use of a quantifier for relaxing the division condition are also studied [50].

An approach to obtain approximate answers for null queries on similarity relation-based fuzzy object-oriented data model is presented in [51] based on the concept of contexts on domain attributes and analogical reasoning. A performance comparison is done in [52] between fuzzy queries on fuzzy databases and classical databases on the basis of time cost. An SQL-type data manipulation language for fuzzy object-oriented databases has been proposed in [53] and demonstrated with several examples for the select operation. A multidimensional indexing technique (Fuzzy Index structure) is proposed to efficiently handle both fuzzy and crisp queries and can be used for aggregation and inheritance hierarchies and to deal with the fuzzy relations of the fuzzy object oriented database model. It is also concluded that fuzzy index has better performance in insertion, deletion operations [54]. A fuzzy object query language (FOQL) for Image Databases is introduced in [55]. It is a content based retrieval system for querying image data where users can pose queries based on visual properties such as color and texture. It is an extension of ODMG- OQL and can be easily mapped to ODMG-Complex Visual Query Language [55]. A measure of fuzzy equality comparison based on the similarity of possibility distributions is proposed in [56] and a sort-merge join algorithm based on a partial order of intervals is used to evaluate the fuzzy equi-join. Fuzzy technique for querying in

Multimedia database is emphasized in [56] and classified in to two types of requests (1) those which can be handled within some extended version of and SQL-like language (2) and those for which one has to elicit user's preference.

3.3 Association Algebra

Association algebra is analogous to relational algebra of relational databases. In this algebra, objects and their associations in object-oriented database are uniformly represented by association patterns and are manipulated by a number of operators. These operators are defined to operate on association patterns of both heterogeneous and homogeneous such as network structures of object associations across several classes, can be directly manipulate by these operators. Association algebra has greater expressive power than the relational algebra and it is the basis for the design and implementation of an object-oriented query language called OQL and knowledge rule specification language [57].

Fuzzy association algebra for fuzzy object oriented data model is proposed in [58] and denoted as FA-algebra. FA-algebra as query algebra for a new fuzzy object oriented data model (F-Model) is used to uniformly represent fuzzy objects and fuzzy associations by fuzzy association patterns. Operators defined in FA-algebra perform operations and in the result return fuzzy association patterns that contain the truth values, where truth values means the degree of suitability of patterns as answers for the queries [58]. A fuzzy-association algebra (FA-algebra) based on fuzzy association patterns, fuzzy queries with fuzzy values and linguistic hedges are proposed in [59]. Fuzzy association algebra is studied for querying fuzzy object oriented databases, based on possibility distribution and the semantic measure of fuzzy data and equivalence degree of two objects. A more general way to define truth values of fuzzy association patterns is proposed with illustrative example in [60].

4 CONCLUSION

Requirement of imprecise and uncertain complex information by the new computer technology applications provides a new domain of research for the database researchers. Application of fuzzy techniques on the database systems with object oriented modeling techniques on the database systems with object oriented modeling techniques evolved the concept of fuzzy object-oriented databases. In this paper we have investigated and summarized the advancement and research work on the field of fuzzy object-oriented databases in the form of fuzzy object oriented database design and algebraic operations. The fuzzy object database design is studied in three types of database design (1) Fuzzy conceptual modeling, (2) Fuzzy logical modeling, and (3) Fuzzy physical modeling; algebraic operations of fuzzy object-oriented databases are summarized in object algebra, query algebra and association algebra as proposed by different researchers.

After investigating all such research works, we could see that still lots of work are remaining to be done and the research area is open to work indefinitely.

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