A Survey of Fuzzy Techniques in Object Oriented Databases

Praveen Kumar Shukla, Manuj Darbari, Vivek Kumar Singh, Surya Prakash Tripathi

Abstract—Exact information has become crucial part of the modern database applications and next generation information systems to make them more human friendly. In order to deal with information inexactness, fuzzy techniques have been extensively integrated with different database models and theories. But, object oriented database systems are extremely capable to represent and manipulate the complex objects as well as complicated and uncertain relationship existing among them. They are also much suitable for engineering and scientific applications, dealing with large data intensive applications. In this paper, a survey of different approaches regarding integration of fuzzy techniques in object oriented databases has been sketched, under numerous categories of conceptual data modeling, querying, indexing etc.

Index Terms— Fuzzy Techniques, Inexact Information, ODMG (Object Data Management Group), FODMG (Fuzzy Object Data Management Group), FSM (Fuzzy Semantic Model), FOOD (Fuzzy Object Oriented Databases).

1 Introduction

Object oriented databases are considered better than the relational and other databases, due to increasing demand of new approaches to deal with complex data , complex relationship existing among such data and large data intensive applications. These databases are much suitable for modern database applications, like CAD/CAM (Computer Aided Design/Computer Aided Manufacturing), CASE (Computer Aided Software Engineering), GIS (Geographical Information Systems), Spatial Databases, Office Automation; Knowledge based Systems, Hardware and Software Design, Network Management, Multimedia databases, VLSI (Very Large Scale Integrated) Design. In these applications, several types of information inexactness exist. Such incomplete and ill-defined information has been accepted, represented and manipulated with a certainty measure of acceptance using fuzzy techniques.

The integration of fuzzy techniques in databases makes these systems to be closer with human activities. These may include, dealing with different fuzzy concepts, like 'almost all', 'majority', 'approximately', which include a certain vagueness or uncertainty.

As far as the usability point of object oriented database systems is concerned, these are much suitable for scientific and engineering applications, but not very much suitable for industrial and commercial applications. The complex imperfect information has been represented, stored and retrieved in object oriented databases using fuzzy techniques. Complex object structures can be represented well in object oriented databases without fragmentation of aggregate data and also model complex relationship among attributes. As far as the shortcomings are concerned in fuzzy object oriented database, it shows lack of formal semantics and algebra for manipulation and representation of knowledge as well as the inexact information data/information.

This paper has been organized into seven sections. In section 2, different types of information inexactness has been introduced. Section 3 briefly introduces the concept of fuzzy logic. Different conceptual data modeling techniques has been discussed in section 4. Several types of proposals, including ODMG based framework, Graph based, Rough set based, Fuzzy type based data models and mathematical fuzzy object algebra, for fuzzy object oriented databases have been reviewed in section 5. Section 6 contains multiple issues regarding querying in fuzzy object oriented databases. Indexing in fuzzy object oriented databases has been discussed in section 7.

- *Praveen Kumar Shukla is pursuing Ph.D. in Compter Science from Gautam Buddh Technical University,Lucknow, India and he is also working as a faculty in the department of Information Technology in Northern India Engineering College,Lucknow,India.E-mail:praveenshuklak@rediffmail.com*
- *Manuj Darbari is working as Associate Professor with the Department of InfomationTechnology in Babu Banarsi Das National Institute of Technology and Management,Lucknow, India E-mail: manujuma@gmail.com*
- *Vivek Kumar Singh is currently working as Associate Professor in the Department of InfomationTechnology in Babu Banarsi Das National Institute of Technology and Management, Lucknow, India.*
- *Surya Prakash Tripathi is working as Professor in Department of Compter Science at Institute of Engineering & Technology, Lucknow, India,E-mail: triapthee_sp@rediffmail.com*

2 Inexactness In Information

Several kinds of inexactness have been identified in real world engineering and scientific data. These may be considered as:-1. Imprecision 2. Vagueness 3. Uncertainty 4. Ambiguity 5. Inconsistency.

2.1 Imprecision

It is related to the content of values. A choice may be made from set of values. For example, like the size of disk is in the set {40 GB, 120GB, 180 GB}.

2.2 Uncertainty

In this case, we are not sure about the value of any attribute. We can express our some belief to value to be true. For example, I am 95 % sure that a particular student has passed the examination.

2.3 Ambiguity

Few elements of the models lack the complete semantics leading to several possible interpretations. For example, in a company salary of any employee may be monthly, daily or weekly.

2.4 Inconsistency

Values of any attribute which are different at different places either in same or in different databases, leads to inconsistency in data. For example, the salary of any employee is Rs. 10000 at one place and Rs. 12,000 at another place.

2.5 Fuzziness

We can say a value to be fuzzy, if its precise measurement is obtained in principle. For example, somebody is tall, which is not well defined. Other examples include: cold, warm, hot etc.

2.6 Vagueness

It is also related to the content of values, but the value of any attribute is represented by linguistic variables. It is the subcategory of fuzziness. Those terms which have no measurement process are called vague quantities. For example, he is uncomfortable with his tall height. Here, tall is a fuzzy term, but uncomfortable is a vague term.

2.7 NULL Values

When a value is missing, how should this be indicated? A missing value may exist, but be unknown, not exist at all or be inapplicable. Several NULL markers have been used to represent such type of situations.

2.8 Context dependence

Context is very important concept to make the data values precise. For example, the value of term 'high' is different for 'high speed car' and a 'high building'.

Such type of information imprecision discussed above, may be identified at different places in many information and database system applications. Decision making process in knowledge-intensive applications has various forms of inexactness as well as different possible semantic implementations of data are also integrated. Information in many non-traditional applications may be complex as well as uncertain, for example, opinions and decisions in medical diagnosis, economic forecasting, whether forecasting. As far as natural language is concerned several modifiers ('very', 'more' or 'less'), and quantifiers ("many", "few", "most") are considered as the vague information.

3 Introduction to Fuzzy Logic

Fuzzy logic [1, 2] is considered as a mathematical soft computing tool to deal with inexact and subjective information. It was first introduced by L. A. Zadeh in 1965.

Fuzzy set A can be defined over a universe of discourse U can be defined as:

$$A=\{\mu_A(u)/u : u \in U, \mu_A(u) \in [0,1] \in \Re\}$$

Here $\mu_A(u)$ is called the membership degree of element u to the fuzzy set A and $0 \leq \mu A(u) \leq 1$.

If $\mu_A(u)=0$, means the element does not belong to the set A and $\mu_A(u)=1$ means the element completely belongs to the fuzzy set A and $\mu_A(u)=0.5$ is the greatest uncertainty point. In some cases a definition of $\mu_A(u)$ is given instead of discrete values is called characteristics functions or membership functions.

4 Conceptual data modeling in Fuzzy Object Oriented Databases

Conceptual data modeling is the basic step in the design of any database. It is a modeling technique to get the conceptual scheme for the data required by a user. This conceptual scheme includes the representation of interrelationship existing among data, kinds of entities involved and aggregation, associations and other related issues. A high level data model is required to express information without including implementation details. Using such type of schemes leads to enhancement the communication to the non-technical users. There may be several kinds of uncertainty happening in such modeling like imprecise attribute, relationships and in the type of uncertainty. These uncertainties can be handled by using fuzzy techniques. Different approaches developed for the purpose of conceptual modeling are discussed in this section.

A methodology has been proposed to transform an EER model to an OMT model for the purpose of OODB design in [3]. A schema translation procedure and mapping rules are well proposed.

Attribute imprecision values as well as fuzzy set of objects and different uncertainty issues are modeled in a unified manner using a semantic data model in [4].

Several major ER/EER concepts are fuzzified to conceptually model the imprecise and uncertain data in [5]. Fuzzy extensions to subclass/ super class, generalization/specialization and shared sub class / category has been discussed. Attribute inheritance, multiple inheritance and selective inheritances and inheritance for derived attributes are discussed and introduced in fuzzy context.

The object oriented representation of uncertain and complex information has been proposed using $ExIFO_2$, an extension of IFO data model [6]. Also, different graphical notions for fuzzy, incomplete and atomic types, complex types, function types and ISA links has been introduced.

A constructive approach using ExIFO to model complex and uncertain information conceptually and then transformation of the ExIFO into NF_2 Logical Data Model has been proposed with the help of algorithms in [7].

An existing IFO data model [8, 9] has been extended to model fuzziness at different levels in [10]. The new model is titled as IF_2O. Fuzzy printable types, fuzzy abstract and free types, fuzzy constructs, fuzzy fragments and fuzzy ISA relationships are discussed here in this study.

A system for expressing flexible constraints, which can be used in the conceptual modeling using enhanced entity relationship, has been introduced in [11,12]. The restrictions have been proposed using fuzzy quantifiers. In this study, fuzzy

participation constraint, fuzzy cardinality constraints, and fuzzy completeness constraint in the representation of specializations and fuzzy cardinality constraints in overlapping specializations are proposed. Also, it has studied the fuzzy (min, max) notation.

A fuzzy extended entity relationship model has been proposed in [13] to deal with inexact information. Also, a formal framework for mapping a fuzzy extended entity relationship model to fuzzy object oriented database schema has been provided.

Several points of fuzziness have been identified in UML class diagram to model and represent inexact information in [14]. Fuzzy class generalization, aggregation and dependency have been discussed here.

Classical database models at conceptual and logical level lacks the rules and semantics to represent such information. To model such type of information, different classical database models, like ER/EER, IDEF1X, UML, EXPRESS-G are extended using fuzzy logic, a theory of uncertainty handling. The fuzzy extensions of these models are proposed in [15]. Also, a SDAI implementation of the object oriented database and Fuzzy EXPRESS implementation of Fuzzy Object Oriented Database has been proposed in [15].

The fuzzy extension of XML to model information imprecision has been proposed in [16].

A fuzzy EER model has been discussed in [17]. Several issues like, imprecise attributes, fuzzy entity, fuzzy relationship and specialization with fuzzy degree have been discussed also.

formal approach for mapping a Fuzzy IFO (IF_2O) model to a fuzzy object oriented database schema has been proposed in [18]. Also, a generic fuzzy object oriented database system has been developed by extending the objects, classes, their relationships, subtype/super type and multiple inheritances in fuzzy environment.

A pragmatic model has been transformed to the Fuzzy Petri Net formal models in [19]. Different aspects of behavioral and structural modeling are also presented in this study.

5 Proposed Fuzzy Object Oriented Database models

Different object oriented database models have been extended with fuzzy techniques to handle information inexactness. These database models include ODMG based object model, semantic database model, graph based data model, intelligent database models, rough set and UFO based data models. Also, object based algebra and many prototypes have been proposed and implemented.

5.1 ODMG based framework

The syntactic and semantic extensions to the ODMG object model are proposed in [20] in order to deal with fuzzy objects and related issues. As far as, FODMG is concerned, it has been formed as a joint international collaborative research effort among fuzzy database researchers in order to establish common terminology and concepts, to formalize and integrate the current research in the field of Fuzzy Object Oriented Database.

To incorporate uncertainty with object oriented databases, a formal framework has been proposed by Tre, Caluwe and Cruyssen in [21]. This framework was basically developed by integrating different aspects from Object Oriented Databases under ODMG de facto standard and a constraint based algebraic theory.

5.2 Fuzzy semantic database models

An expression of the semantic proximity and evaluated method of the fuzzy association degree has been proposed in [22]. The reasonability and effectiveness has been also derived.

A new database model, FSM (Fuzzy Semantic Model) has been proposed in [23]. This model presents the techniques to formalize and conceptualize the fuzziness and semantics of real world within a manner accepted to human reasoning and perception.

Different uncertainty issues have been handled regarding Fuzzy Semantic Model in [24]. Also, first results of an implementation at automotive company PSA Peugeot Citron are also discussed in this paper.

Conceptual design and different implementation issues has been discussed and proposed in [25] for fuzzy semantic model. A formal approach is also described to map FSM-based model to a fuzzy relational object database model.

A fuzzy semantic model has been proposed in [26] to represent and model fuzziness and uncertainty at different levels of object oriented modeling. Also, a FSM schema and a query language adapted to FSM based database have been introduced.

5.3 Fuzzy graph based models

A Fuzzy Object Oriented Data model (FOOD) is proposed in [27] by generalizing the graph based data model, so that information inexactness can be handled at different levels. This proposed model visually represents fuzzy objects and relations. Fuzzy domain of attributes, fuzzy reference relation, fuzzy instance of relation and fuzzy ISA relations are well explained and represented to produce this model.

The definition of graph based operations to select and browse a fuzzy object oriented database has been proposed in [28]. Also, the evaluation mechanism of graph based operations is formalized in terms of graph transformations and fuzzy pattern matching.

5.4 Intelligent Fuzzy Object Oriented Database models

A fuzzy object oriented approach regarding knowledge representation is discussed in [29]. It is based on the approach of computing with words. Also, a study on the multimedia system KOOFI (Knowledge based Object Oriented Fuzzy Interface) has been given.

A modeling framework has been introduced in [30], for the design of complex and knowledge intensive applications. This approach includes handling the fuzziness at attribute, object/class and class/super class levels, class/class relationship and other various associations among classes. Logical rules are designed to define some of the crisp/fuzzy relationships and associations.

A combination of deductive and object oriented data modeling techniques result in a powerful data modeling tool for new age knowledge based systems. Complex objects and the uncertain relationship among then can be well represented by

this new modeling technique. A formal model in this regard has been implemented and derived in [31]. The prototype for this model is implemented in Prolog environment. Fuzziness is considered at attribute, object/class and subclass/class levels.

In [32], a deductive fuzzy object oriented and probabilistic framework has been developed that provides a formal basis for the design and implementation of FRIL++, which is an object oriented extension of FRIL and is a logic programming language dealing with both fuzziness and probability concepts. Default probabilistic logic rule and probabilistic default reasoning on fuzzy events are also proposed.

Next generation information systems are considered as the integration of database and knowledge base technologies. A fuzzy intelligent Object Oriented Database Architecture has been proposed in [33]. This model supports flexible modeling and querying of complex data and knowledge. This IFOOD architecture is based on the integration of Fuzzy Object Oriented Database system with a Fuzzy Knowledge Base (FKB). IFOOD Language, Fuzzy Inference method, Fuzzy Inference Engine Model are discussed. This model is implemented using C Language Integrated Production System (CLIPS) for the implementation of object oriented database component.

A new approach in [34] has been developed for modeling applications, by integrating the approaches of fuzzy, active and deductive rules. This approach enables objects to perceive dynamic occurrences and answer user queries, resulting the production of new knowledge and maintain themselves in a consistent, stable and up-to-date state. The development of such an approach is the advancement in the field of knowledge intensive applications requiring intelligent environment.

5.5 Application specific data models

Fuzzy object oriented databases are tested as much suitable to represent and manipulate the spatial data. The work done in [35] is the expansion of work proposed in [36]. It is well discussed in the paper that we can incorporate all collection types described in ODMG de facto standard in this framework.

In [37], the advantages of using fuzzy object data model for geographic information systems has been discussed. Overview of the model and current implementations of prototype are also discussed in this study.

An approach for imprecision and uncertainty handling in images has been introduced in [38]. An object oriented graph theoretic approach for representing image in the context of spatial and topological relations existing among object has been proposed. The assessment of similarity between images has been performed using fuzzy graph matching.

A fuzzy object oriented framework has been described in [39] to efficiently model the spatial data. Also, a prototype system FOOSBALL has been derived to implement this framework. This prototype system supports both Boolean and fuzzy queries, represents uncertain query results and also stores the objects with the uncertain boundaries.

A fuzzy object oriented database model has been proposed in [40] for the imperfect spatial information based on the fuzzy set theory and possibility theory.

A fuzzy entity relationship diagram (ERD) data model has been proposed in [41]. New methods including, object model flattening, entity payload data containerization, and a non-integrated object model design has been proposed for ERD.

A model have been developed to handle different types of data formats as a single logical entity , based on the concept of aggregating data into sets in [42]. It also manages the descriptive information. Initially, it was annotated as entity relation diagram.

The imprecision and uncertainty has been modeled with spatial data in GIS Applications in [43].

Recently, a fuzzy conceptual data model has been proposed to represent semantic content of video data in [44]. An intelligent fuzzy object oriented data model for video applications has been proposed, which supports various flexible queries including fuzzy semantic, temporal and fuzzy spatial queries.

5.6 Implemented prototypes

A FOODB prototype have been implemented with a data manipulation language based on Encore Query Algebra written in AKCL (Austin Kyoto Common Lisp), running on Unix operating system in [45].

A FOOD (Fuzzy Object Oriented Database) version of SQL (Structured Query Language) and a supporting Data Manipulation Language has been designed and implemented by Umano et. al. in [46].

In [47], a prototype is implemented in the Visual C++ Programming Language and interfacing with the commercial ODBMS by VERSANT. It has the capability to visually create fuzzy linguistic terms and use them for object attribute values. The capability to reason with fuzzy-attribute-valued-objects is provided through integration with the fuzzy CLIPS Expert Systems.

To represent imperfections and uncertainty in knowledge bases, a fuzzy object oriented model has been proposed using extended Java in [48]. This extended Java permits to model the fuzzy inheritance. The NCR Fuzzy JLibrary has been used to deal with information inexactness in class attributes. Also, a semantic & fuzzy object-oriented data model in Java has been proposed and implemented called Fuzzy Java, supporting mono-valued and multi-valued attributes.

Object Relational Database Management Systems (ORDBMS) is the integrated approach of object oriented methods over relational databases. A new object relational framework pg4DB has been presented in [49] that enables the storage and manipulation of fuzzy objects in an object relational system, such as PostgreSQL. Also, it is shown in this framework that management of fuzzy object oriented data in object relational systems can be done in transparent way. This framework allows the user to define a hierarchy of classes to manage fuzzily described objects and manipulate them using object relational SQL compliant sentences. This pg4DB is built over PostgreSQL.

A general framework for managing fuzziness in the conventional object oriented systems has been proposed in [50]. FOODBI, which is a fuzzy object oriented database interface, is presented as a prototype that generates fuzzy object oriented schemata. It can be translated into sets of standard java classes.

In this [51], an extension of proposed FOOD model by George [73] has been developed. Also, software architecture as well as a prototype implementation by EXODUS Storage Manager (ESM) has been discussed for the above model.

5.7 Rough set based models

A formal introduction and definition of a fuzzy rough object oriented data base model is presented in [52]. This model is based on an algebraic type system and a formally defined constraints. Such data model is very useful in representing spatial data entities and in their relationship existing among them.

An approach for integrating the uncertainty in database has been processed in [53] using indiscernibility relation and approximation region of rough set theory.

5.8 UFO based models

Generalized fuzzy sets are used to introduce the uncertainty in fuzzy object oriented data model in [54].

UFO database model has been proposed in [55] that provide semantic capability to enhance object oriented model to support information imprecision. Such information imprecision is handled by possibility distributions and modeled by using the concept of role objects. These role objects model imprecise information as well as imprecise roles played by different roles.

A meaning full way of fuzzyfying the inheritance relationship in UFO data model has been discussed in [56].

5.9 General survey discussions

Different approaches, based on querying and modeling the fuzzy databases have been reviewed in [57], under category of crisp database with fuzzy data querying and representation, and fuzzy database with fuzzy data. Also a comparative study between fuzzy relational database and fuzzy object oriented database has been derived in this study.

A good comparison between relational model and object oriented fuzzy database model has been derived in [58], based on different modeling and querying issues.

A survey of current approaches on the integration of object oriented theory and fuzzy techniques have been studied in [59]. These approaches are categorized under three sub areas, databases, software engineering and knowledge representation in AI systems.

Different fuzzy database models including object oriented data models have been reviewed and discussed in [60]. Different concepts of modeling, querying, and data processing are presented in this study.

5.10 Proposals based on fuzzy type

A framework for the behavioral analysis of the model is presented in [61]. The analysis of the dynamic behavior of the model through the use of Type I and Type II models is discussed in this framework.

The representation of fuzzy types in a traditional ODBMS has been discussed in [62]. Also, the implementation of instantiation and inheritance mechanism has been introduced. Fuzzy types are considered as an important approach for managing the fuzzy structures.

A proposal of describing different types of fuzziness at different levels in traditional ODBMS has been introduced in [63]. Imprecise attribute domains, uncertainty in attribute values, uncertain object relationship, fuzzy sub-classes, fuzzy categories, uncertain object definition, uncertain class definition and fuzzy types are discussed in this proposal.

In [64], an approach of fuzzy object oriented database modeling has been sketched based on level-2 fuzzy sets. In this, main considerations are at structural and behavioral aspects of the data and level-2 fuzzy sets are used to generalize the concept 'type'.

The model proposed in [65], introduces the concept of fuzzy type, where properties are ranked in different levels of precision according to their relationship with type.

The architecture of the prototype implementation of the model was presented in [66] using Java.

5.11 Fuzzy object centered models

A mathematical model has been introduced in [67], derived by the extension principle and fuzzy virtual object concepts. The fuzzy virtual objects can be considered as the universal objects in space, time and function to deal with crisp and linguistic information, simultaneously and consistently. Also, a hypothetical device has been introduced to convert the exact information into linguistic format. These fuzzy objects are much suitable in multimedia databases to easily understand the linguistic information, like, "red', "large", "right bottom" etc.

In [68], a new object oriented modeling technique has been developed based on fuzzy theory. Some of the advancements included in this approach are: extension of class by grouping objects with similar properties into a fuzzy class, encapsulation of fuzzy rules in classes, evaluating the membership function of a fuzzy class and modeling of uncertain fuzzy associations among classes.

A set of operators has been introduced in [69] to find the similarity between two objects in a fuzzy environment. A generalized resemblance degree has been proposed between fuzzy sets of the imprecise objects.

The fuzzification of objects with knowledge base and inference engine has been proposed in [70]. Such objects are considered as intelligent objects. Fuzzy object attributes, relationships, fuzzy generalization and aggregation are formulated in this framework.

Rossazza et. al. have been proposed a model in [71], in which all the information is contained in objects. Concepts of class, class hierarchies and attributes are explained and fuzzy ranges of allowed values and typical values are specified for attributes. Graded inclusion relations between classes are also defined.

An object oriented model has been proposed in [72], and fuzziness is defined in both structural and behavioral aspects, at the levels of instantiation, inheritance, relationship among classes.

5.12 Proposals based on mathematical fuzzy object algebra

Fuzzy association algebra (FA algebra) has been discussed in [73] as a fuzzy algebra for fuzzy object oriented data model (F-model) in the context of new intelligent information systems. Fuzzy objects and the fuzzy associations are uniformly represented by fuzzy association patterns.

Another framework has been proposed in [74] for modeling uncertainty in the OODM (Object Oriented Data Model). Calculating membership values or similarity based relations are the two different approaches to deal with uncertainty. The

framework combines the two approaches and demonstrated how these two can be used in conjunction in the OODB. Fuzzy object algebra is developed in [74]. Two operators have been defined as an extension to relational algebra, Conjunctive Nest (CNest) and its collary UnNest. A new operation is also introduced that merges objects at the schema level, called disjunctive nest (DNest.).

Object algebra for manipulating complex objects in fuzzy object oriented database systems has been proposed in [75]. A framework has been presented by executing set theoretic operations, like union, intersection, difference on the class construct. Also, inheritance property characteristics for the derived class with fuzzy objects have been discussed.

A mathematical framework for Fuzzy object oriented database, including definition of different constraints, constraint systems, database schemes, database model, operators, has been developed in [76]. Different types of generalization constraints, equality constraints, possibilistic constraints, veristic constraints are included in this algebraic type framework.

An extension of EQUAL-algebra for handling imprecision is proposed in [77]. EQUAL algebra is the part of object oriented database model, Extensible and Natural Common Object Resource (ENCORE) [78].

5.13 Proposals based on hierarchical relationship

An approach for uncertainty modeling in class hierarchies has been proposed in [79]. Multiple inheritances in class hierarchies has been defined and explained in this approach. Membership degree calculation shows the degree of fuzziness existing in the data values and the semantics of the situation to be modeled.

In [80], nearest rule has been incorporated with fuzzy object oriented databases, fuzzy information in the multiple inheritances is retrieved using closeness function and nearest rule. The use of these techniques also beneficial in the development of a query language supporting fuzziness to get the answer by measuring the distance between the query and answer. Also, two algorithms are provided to implement the nearest rule of a closeness functions.

In some cases, it may be possible that a subclass may contradict in some way one of its superclass definitions and resulting in an imprecision with super class and subclass relationship. A language feature is presented in [81] to allow class definitions, which contradicts aspects of other classes.

In [82], a method of computing the default value for unknown objects' attribute is proposed. It is based on both association of typical values with the attributes in the intentional definition of a class and the application of a prioritized aggregation operator to combine typical values appearing in an inheritance structure. This method is also applicable to refine vague attribute values expressed by means of the fuzzy sets interpreted as possibility distributions. A new interpretation of partial inheritance is also proposed, developing the concept of partial overriding of typical values.

A logic based fuzzy object oriented database model has been introduced in [83] and a probabilistic default reasoning approach is given to deal with uncertain inheritance and recognition problems. This proposed approach is also implemented with FRIL++, which is an uncertain and fuzzy object oriented logic programming language to be used for developing intelligent systems.

An object oriented framework has been proposed in [84]. This framework supports a range of allowed values and typical values for the attributes describing a fuzzy class. Different inclusion relations between classes are also defined. Inheritance mechanisms with different reasoning tasks are also discussed.

A frame-based data structure has been introduced to represent knowledge in [85]. Inheritance of information from different frames and inference in inheritance network is also introduced. A Prioritized Conjunction (PC) operator has been investigated to combine information contained in frames connected by means of inheritance structure.

5.14 Similarity based approach

Concept of similarity based relation has been used for the derivation to generalize the equality to similarity in [86]. This permits the representation of imprecision in data and inheritance. An object algebra based on the extension of union, difference, product and selection is also introduced.

5.15 Other proposals

In [87, 88] Bordogna et. al. presented prototypical implementation of fuzziness in object oriented databases models. Vague attributes and uncertain relations are well represented in these implementations.

An extended fuzzy object oriented data model [89] has been proposed to model complex objects, based on possibility distribution and semantic measure. Objects, classes and their relationships and multiple inheritances are extended in this proposed data model.

A flexible generalized fuzzy object model has been introduced in [90].

Abstraction principle based suggestions with a review of proposals for fuzzy object models for incorporating fuzzy techniques in object modeling has been introduced in [91].

The introduction of the generic classes in incremental design has been proposed in [92]. Incomplete information has been expressed in object instances with the use of explicit null values, presenting the incomplete information both at schema and object instance level in object oriented database.

Different research issues and principles have been discussed in [93], including fuzzy inheritance, fuzzy objects, fuzzy subtype/super type hierarchy.

In [94], a fuzzy object oriented data model has been extended to cope with modeling and manipulation of uncertain information in an object oriented environment.

A good work regarding fuzzy object oriented databases has been discussed in [95]. Different proposals and discussions related to conceptual data modeling, querying and fuzzy path dictionary index: a new access technique as well as algebra for fuzzy object oriented database has been given.

A good collection of discussions on fuzzy object oriented databases, UFO data model and uncertainty, Fuzzy Association Algebra has been given in [96].

Fuzzy data mining, fuzzy functional dependency, theoretical framework addresses the definition of fuzzy extensions of relational database modeling; implementation in specific context of Geographical Information Systems has been discussed in [97].

An approach of utilizing a design pattern for fuzzy approach in object oriented database systems has been proposed in [98]. An original pattern has been introduced to give an easy understandable and general solution, which is not tightly coupled with any specific database system or programming.

In [99], the admitted values of attributes are linguistic, the proposed method hinges on the concept of linguistic approximation and computational enhancements stemming from the theory of fuzzy neural network.

A new object oriented framework has been proposed for the modeling of time and to extend the traditional temporal database concepts in [100].

The concept of nuanced value, nuanced domain and fuzzy thesaurus has been introduced in [101]. A Chomsky grammar is used to generate the characteristics membership functions of the thesaurus terms.

6 Querying in Fuzzy Object Oriented Databases

Querying in databases can be performed by using many languages, like SQL (Structured Query Language) in Relational Databases, OQL (Object Query Language) in object oriented databases. But, these traditional database querying techniques does not support information inexactness. These techniques are extended by including fuzzy preferences and/or fuzzy conditions in querying to retrieve the inexact information.

A high level domain independent query language for pictorial and alphanumeric database management, called PICQUERY+ has been introduced in [102]. Certain advancements, like convenient specification of the data domain space among a multimedia database federation, visualization of underlying data models, knowledge based hierarchies and domain rules are sketched in this paper. Also, the proposed language is illustrated using examples drawn from the medical imaging domain.

The fuzzy query approach has been discussed in [103] for GIS user interface to deal with natural language. A fuzzy formulae and a prototype for implementing this approach with sample queries has been discussed.

An extended fuzzy association algebra has been introduced in [104] based on fuzzy association patterns. It has processed the fuzzy queries with fuzzy values and linguistic hedges.

An approach has been proposed to obtain approximate answers for NULL queries on similarity relation based fuzzy object oriented data model in [105]. It is an approach by the generalization of the former models of analogy.

Different issues regarding the uncertainty modeling and querying of imperfect spatial information have been discussed in [106] with reference to object oriented database systems.

A fuzzy Object Query Language has been presented in [107]. This language supports fuzzy values and fuzzy collections required for image database. Also, it can be used for defining schemas and high level concepts and querying image databases. This is an extension of the ODMG-OQL language.

Querying issues in multimedia databases as well as comparison of semi structured documents are well introduced in [108]. A preliminary investigation of fuzzy logic in multimedia databases is also discussed.

A formal framework of the generalized object oriented model has been presented in [109]. This model is based on the generalized algebraic type system and constraint system. Also, object algebra is defined with data manipulation and data definition language.

A new environment for flexible modeling and querying of complex data and knowledge with uncertainty has been discussed in [110]. An intelligent retrieval of information from knowledge intensive applications have been proposed based on a fuzzy knowledge base coupled with fuzzy object oriented databases.

7 Indexing in Fuzzy Object Oriented Databases

Index structures are responsible for efficient and fast access to data by content. Several indexing techniques have been developed for object oriented databases, like nested inherited index and enhanced nested inherited structure [111], [112], path index [113]. These index structures are not capable to deal with imprecise and uncertain data in proposed FOOD model.

Numerous methods have been introduced in [114], for the indexing of fuzzy sets in databases to improve the performance of querying. These methods are based on rely or inverted files or super-imposed coding.

An overview of different indexing techniques for Fuzzy Object Oriented Database has been discussed in [115].

A new index structure for supporting different kinds of fuzziness in FOOD databases and multidimensional indexing, have been proposed in [116].

Yazici et. al. in [117] has been proposed a new index structure called Food Index (FI) as an extension of the work in [116]. This supports and deals with different kind of fuzziness as well as multidimensional indexing. It is also shown that how FI supports flexible querying and evaluate the performance for exact, range and fuzzy queries. Also, the insertion, deletion and retrieval algorithms are investigated in this paper.

8 Conclusion

Reasoning inexact information extensively exists in data and knowledge intensive applications and fuzzy techniques plays vital role to handle such type of information in modeling at conceptual and logical level, query and data processing, indexing and implementations of the next generation database systems. Fuzzy object oriented data bases are the natural fit for many engineering and scientific applications suffering from the representation and manipulation of inexact information precisely. A brief overview of different advancements in fuzzy object oriented databases has been discussed in this paper. Different conceptual models based on object oriented, EER, IFO models have been introduced. Numerous approaches for querying and indexing are also surveyed in this study. These various issues related to Fuzzy Object Oriented Databases are listed in the following table I.

Table I Different Issues in Fuzzy Object Oriented Databases

S. No.	Category	Focus	References
1	Conceptual Database Models	Object Oriented and EER based models	[3]-[19]

		ExIFO and NF² based models	[7]
		IFO and IF2O Based Models	[8]-[18]
		XML based models	[16]
2	Proposed Fuzzy Object Oriented Database Models	ODMG based models	[20, 21]
		Semantic Database Models	[22]-[26]
		Graph based models	[27,28]
		Intelligent Fuzzy Object Oriented Database Models	[29]-[34]
		Application Specific	[35]-[44]
		Implemented Prototypes	[45]-[51]
		Rough set based	[52, 53]
		UFO based	[54]-[56]
		General survey discussions	[57]-[60]
		Fuzzy type based	[61]-[66]
		Fuzzy Object Centred Models	[67]-[72]
		Mathematical Fuzzy Object Algebra based	[73]-[78]
		Proposal based hierarchical relationship	[79]-[85]
		Similarity based models	[86]
3	Querying in Fuzzy Object Oriented Databases	Fuzzy Object Query Langugae (FOQL), PICQuery	[102]-[110]
4	Indexing in Fuzzy Object Oriented Databases	FOOD Index	[111]-[117]

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