Representing and Querying Virtual Worlds. A Fuzzy Approach

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Abstract. In this paper we describe a proposal for a new virtual worlds representation model that requires just a few additional efforts from the world creators, and adds a basic semantic level to the worlds which is useful to improve the interaction of the users with these worlds. We also describe a querying model that allows to found worlds and objects in these worlds, using as a base the proposed representation, and a fuzzy approach to solve the queries.

1 Introduction

The development of the Internet and the World Wide Web has brought many new applications. Some of them represent new ways to approach the relation between users and information. The development of the networks and the possibilities of the information transferences whithin them, permit that today the view of a multimedia society is less utopic and more real. From the two-dimensional digital world we are going at a high speed towards the three-dimensional digital world. As HTML specifies how the 2D documents are represented, VRML [17] is the format to describe how the 3D environments can be created and explored. Amongst other things, VRML offers the possibility of interacting with a digital world, navigating within virtual worlds, visualizing information, inspecting 3D models.

Now then, although the three-dimensional digital world offers enormous posibilities in the interaction between the user and the world of virtual objects, it has the same or more problems than the two-dimensional one. We show an example of this. If a friend tells us that she saw a web page with information about a new book authored by Bernie Roehl whose subject is the integration of VRML and Java, but she forgot the web page URL, we could connect to a web search engine, Altavista for example, and search for *Bernie Roehl and vrml and java and book*. In a few minutes, we would be reading the table of contents of the new book. However, if she tells us that she visited a virtual world where there is a red convertible beetle parked in front of the door of a library, we will have to trust our friend's memory if we want to drive the virtual car.

On the other hand, the incorporation of Artificial Intelligence techniques in the Internet within several fields like e-mail filters, Web search engines, user profile generators, etc, has been promoted by the great development in the last years of the Intelligent Agents. The Intelligent Agents consist of software programs which serve as mediators between the queries and the more or less specialized information existing in the net. The agent allows the user to reach the required information, being the agent the responsible to decide on where to find the information and how to retrieve it [14, 15, 23]. In this sense, we can find proposals for the incorporation of fuzzy techniques in the agents [22, 19, 31], in particular for the use of fuzzy techniques in the Internet search mechanisms, or for the creation of flexible query mechanisms.

In this sense, we describe a proposal for a new virtual worlds representation model that requires just a few additional efforts from the world creators, and adds a basic semantic level to the worlds which is useful to improve the interaction of the users with these worlds. We also describe a querying model that allows to found worlds and objects in these worlds, using as a base the proposed representation and a fuzzy approach to solve the queries. Both proposed models taken together improve the current interaction with virtual worlds.

The structure of this paper is as follows. Section 2 describes related work. Section 3 proposes the virtual worlds representation. Section 4 proposes the querying model. Section 5 provides the conclusions.

2 Related Work

There are various works [24, 27, 28, 16] which present virtual environments with a semantic information layer. Some of them add the semantic level to the virtual environments, others add the virtual environments to preexisting semantic information (GIS, digital cities, etc). In addition, in last years several approaches for the introduction of artificial intelligence in virtual environments have been proposed. For a state-of-the-art see [1].

On the other hand, several researchers have been working in what has been called *flexible querying*, whose objective is to provide users with new interrogation capabilities based on fuzzy criteria. Flexible querying has been applied to both the database querying and the information retrieval problems. The first fuzzy approach to database querying is probably due to Tahani [26], who defined the concept of a fuzzy relation in a database by associating a grade of membership with each tuple. He introduced the usual set operations (union, disjunction, negation and difference) and the AND and OR operators. His works were followed by numerous contributions which introduced the definitions of new operations [3, 8], and the introduction of new concepts, such as the so-called quantified queries [18, 10]. Furthermore, some works have been oriented towards the implantation of such systems in the Internet [19–21]. In the area of information retrieval several models have been proposed [4–6, 2]. Finally, a preliminary investigation of the potencial applications of fuzzy logic in multimedia database is presented in [13].

3 Representing Virtual Worlds

The current virtual worlds description formats describe exclusively geometric information (points, lines, surfaces, etc). This information is the one required by the browsers to visualize the worlds. We propose to add a new semantic information level to the worlds representation, getting more suitable worlds for the interaction with the users, and particularly more suitable to be queried in relation to their contents. We propose to add meta-contents to the information usually describing the worlds. Ideally the worlds should be annotated during the graphical scene edition process. In this case, as we show below, the scene editor could annotate automatically most of the meta-contents. However, it is possible to annotate the worlds once they have been graphically edited with relatively little effort with respect to the one required when graphically editing the world. This process can be at least partially automatized, too.

The meta-contents model every world object as uniquely identified in the Internet, corresponding to a particular object type according to a concrete ontology and geometrically viewed as the minimum box able to contain it. They also establish spatial containment relations among objects. The annotated meta-contents are saved later in knowledge bases that are used as a base to solve the user's queries. In addition, from these data we obtain the information needed to contextualize the queries later. We distinguish two kinds of annotated meta-contents: the ones which can be automatically extracted (usually quantitaive and objective) and the ones which should be manually annotated (usually qualitative and subjective). In the following, we describe the considered meta-contents. First we show the meta-contents which can be automatically extracted, then, the ones which should be manually annotated. Finally we describe the generated information needed to contextualize the queries.

3.1 Meta-Contents which Can Be Automatically Extracted

The automatically extracted meta-contents which we propose to be annotated are: *location*, *orientation*, *width*, *height*, *depth*, *size*, and *spatial containment relations*. The first six of these indicate characteristics of every object in the world that is being considered. The last one indicates relations between pairs of objects in the considered world.

Object Location. X, Y, Z coordinates correspond to the object location with respect to a global reference system which is unique for this world. These coordinates can be either directly extracted from the geometric model or obtained by transforming data directly extracted from the geometric model (for example, if the object is referenced with respect to a relative reference system).

Object Orientation. It is the angle correspondig to the object rotation with respect to an axis determined by two points. These data can be either directly extracted from the geometric model or obtained by transforming data directly extracted from the geometric model.

Object Width, Height and Depth. It specifies the extents of the object along the X, Y, and Z axis respectively. These lengths can be calculated from the object maximum and minimum values in each axis. However, in many cases this calculation is not needed, because the extents are explicitly specified in the geometric models, in order to optimize the visualization. For example, in VRML several of the nodes include a bounding box specification [11] comprised of two fields, *bboxSize* and *bboxCenter*. A bounding box is a rectangular parallelepiped of dimension *bboxSize* centred on the location *bboxCenter* in the local coordinate system. This is typically used by grouping nodes to provide a hint to the browser on the group's approximate size for culling optimizations.

Why does VRML use axis-aligned bounding boxes instead of some other bounding volume representation such as bounding spheres? The choice was fairly arbitrary, but tight bounding boxes are very easy to calculate, easy to transform, and they have a better worst-case behavior than bounding spheres (the bounding box of a spherical object encloses less empty area than the bounding sphere of a long, skinny object).

Object Size. It is the object volume, calculated as the product of the object width, height and depth. Note that it is not necessary to add these volumes to the knowledge base, and they can be seen as redundant, however, we add them for efficiency reasons.

Spatial Containment Relations. These are relations of the type *X s-contains Y* expressing that the object *Y* is spatially contained by the object *X*. These relations can be often calculated from the worlds geometric models, due to the fact that the worlds description formats are based on hierarchical models.

For example, a VRML file is hierarchical [12]; node statements can contain $SFNode$ or $MFNode$ field statements that, in turn, contain node (or USE) statements. This hierarchy of nodes is called the scene graph. Each arc in the graph from A to B means that node A has an $SFNode$ or $MFNode$ field whose value directly contains node B.

Then, due to efficiency reasons, it is interesting that this hierarchical model correspond to the spatial containment relations, in order to get visualization optimizations thanks to the *boundings boxes* described above. In this case, the containment relations can be automatically extracted from the hierarchical model.

3.2 Meta-Contents which Should Be Manually Annotated

The meta-contents we propose to be manually annotated are: *object identifier*, *object type*, and *navigability information*. The first two of these are related to every object in the world being considered. The last one provide information in order to make the virtual worlds more navigable.

Object Unique Identifier. Every virtual world is uniquely identified on the Internet by its related URL. In our model every object is uniquely identified in the world where it is contained. Then every annotated object O in a world W can be uniquely referenced on the Internet and in the knowledge base by the sequence URL_W+OID_O, where + is the string concatenation operator, URL_W is the URL that uniquely identifies W and OID_O is the unique identifier of O in W.

Object Type. Every object is annotated with its object type according with a particular ontology. Definitions of ontologies that define types of objects and relations among them in a particular area are assumed (this subject is not discussed in this paper).

Navigability Information. Every world is annotated with additional meta-contents in order to make it more navigable. As this subject is out of the scope of this paper, we summarize it by saying that these meta-contents represent a graph of navigability composed of nodes and arcs, which is used for example by intelligent virtual assistants in order to program virtual tours.

3.3 Information Needed to Contextualize

Information needed to contextualize the queries later is automatically obtained from the meta-contents data. In particular maximum and minimum values of width, height, depth and size attributes are obtained for every type of object in every context considered. The contexts we consider are the set of all the worlds, every particular world, and some objects (spaces) of particular worlds.

4 Querying Virtual Worlds

Uncertainty refers to the truth of the information stated in a proposition. Note that when we simplify the geometrical models of the objects viewing them as its bounding boxes, we are adding uncertainty to the size of the objects, and therefore to the relations depending of them.

On the other hand, *vagueness* occurs when the value of a variable in a proposition has a higher granularity than the reference domain. For example, the statement *the tree is tall* contains vagueness when the reference domain is the set {0,...,10}, while it is precise when the reference domain is the set of labels {*very short, short, of middle height, tall, very tall*}. The user queries in virtual worlds contain vagueness because the users expresses their requirements with propositions whose variables (linguistic terms) have a higher granularity than the reference domain of their knowledge base counterpart (numerical values).

Therefore, we requere a modelling of a query system able to solve vague user queries working with more precise knowledge bases with some uncertainty. To model this query system we use an approach based on fuzzy set theory [32] and fuzzy logic. In fact, the main contribution of fuzzy logic is a methodology for computing with words [35]. In this sense, several researchers have been working in what has been called *flexible querying* (see Related Work), whose objective is to provide users with new interrogation capabilities based on fuzzy criteria.

The central key of the fuzzy approach is the *fuzzy set* concept, which extends the notion of a regular set in order to express classes with ill-defined boundaries (corresponding to linguistic values. e.g. tall, big, etc). Within this framework, there is a gradual transition between non-membership and full membership. A degree of membership is associated to every element x of a referential X. It takes values in the interval [0,1] instead of the pair {0,1}.

Fuzzy modelling techniques make use of *linguistic hedges* as fuzzy sets tranformers, which modify (often through the use of the basic *concentrator*, *dilator* and *intensifier* modifiers) the shape of a fuzzy set surface to cause a change in the related truth membership function. Linguistic hedges play the same role in fuzzy modelling as adverbs and adjectives do in language: they both modify qualitative statements. For example, *very* is usually interpreted as a concentrator using the function $f(x) = x^2$.

A *linguistic variable* is a variable whose values are words or sentences in a natural or synthetic language. For example, *Height* is a linguistic variable if its values are *short*, *not short*, *very short*, *tall*, *not tall*, *very tall*, and so on. In general, the values of a linguistic variable can be generated from a primary term (for example, *short*), its antonym (*tall*), a collection of modifiers (*not*, *very*, *more or less*, *quite*, *not very*, etc.), and the connectives *and* and *or*. For example, one value of *Height* may be *not very short and not very tall*.

4.1 Dictionaries

The query system includes various dictionaries which define basic operations (conjunctions, disjunctions, negations), basic modifiers (dilation, concentration, intensification), hedges (very, more or less, etc), linguistic values (tall, big, near, etc), linguistic variables (width, height, depth, size, distance, etc) and quantifiers (most, many, etc). The users can personalize the system by redefining the membership functions associated with the linguistic values, which are defined as trapezoidal ones.

4.2 Canonical Form

As pointed out by Zadeh [34], a proposition p in a natural language may be viewed as a collection of elastic constraints, $C_1, ..., C_k$, which restricts the values of a collection of variables $X = (X_1, ..., X_n)$. In general the constraints as well as the variables they constraint are implicit rather than explicit in p. Viewed in this perspective, representation of the meaning of p is, in essence, a process by which the implicit constraints and variables in p are made explicit. In fuzzy logic, this is accomplished by representing p in the so-called *canonical form* $P \rightarrow X$ is A in which A is a fuzzy predicate or, equivalently, an n-ary fuzzy relation in U, where $U = U_1 \times U_2 \times ... \times U_n$, and $U_i, i = 1, ..., n$, is the domain of X_i.

We show the process of making the implicit variables and restrictions explicit through an example. Let the flexible query be *I am searching for a park which has a tall tree.* As the dictionaries relate both linguistic variables with its possible linguistic values and object attributes with linguistic variables, the system relates the linguistic value *tall* with the linguistic variable *heigth* and this in turn, with the world objects attribute *height.* Then the systems makes X = Height(tree) and A = TALL explicit. Therefore the explicit restriction is Height(tree) is TALL. Note that if the query is one that presents ambiguity (the linguistic value is related with various linguistic variables), it should to be solved by interacting with the user.

We have defined a format to describe the queries, which is a kind of canonical form in the sense that it makes the implicit variables and restrictions explicit. The queries are translated to this format independently of the interface modality (natural language interface, graphical form interface, etc). We show the format through an example. Let the flexible query be *I am searching for a world which has a park which has a tall tree which has many nests*; its representation is *[action: searching for, [object: world, quantity: 1, restrictions: [has: [object: park, quantity: 1, restrictions: [has: [object: tree, quantity: 1, restrictions: [height: tall, has: [object: nest, quantity: many]]]]]]]].*

4.3 Query Semantics

Atomic Subqueries Let the flexible query be *I am searching for a world which has a tall tree.* To calculate the degree to which a particular world fulfills the query, we have to evaluate first the satisfaction of *X is tall*, where X = Height(tree), i.e. the height attribute of a tree object of the world being considered. This satisfaction degree is calculated in a two-step process. First the numeric height X of the tree object is contextualized (scaled in this case) obtaining $X_{context}$. Then $\mu_{tall}(X_{context})$ is calculated where μ_{tall} is the membership function corresponding to the fuzzy set associated with the fuzzy term *tall.*

Aggregation Let the flexible query be *I am searching for a world which has a tall tree and a big garden.* To calculate the degree to which a particular world fulfills the query, first we calculate the degrees to which X and Y fulfills the atomic subqueries *X is tall* and *Y is big* respectively, where X = Heigh(tree) and Y = Size(garden), and tree and garden are objects of the world being considered. Then we can use the conjunction (AND) to calculate the aggregation of both degrees.

Note that the AND and OR connectives allow only crisp aggregations which do not capture any vagueness. For example, the AND used for aggregating n selection criteria does not allow to tolerate the unsatisfaction of a single condition; this may cause the rejection of useful items. For example, let the query be *I am searching for a room which has a bed and a wardrobe and a bedside table.* It seems obvious that the user is searching for a bedroom, however a bedroom with no bedside table will be rejected if we use the conjunction to aggregate the degrees of the atomic fulfillments.

We supplement the conjunction and disjunction connectives by a family of aggregation criteria with a intermediate behaviour between the two extreme cases corresponding to the AND and to the OR. These aggregations are modeled by *means* operators and the *fuzzy linguistic quantifiers* (see below).

Context Dependency The meaning of a fuzzy term, such as *tall*, may have several meanings among which one must be chosen dynamically according to a given context [36]. As showed above, maximum and minimum values of width, height, depth and size attributes are obtained for every type of object in every context considered. Then, these values are used to get the contextualized meaning of fuzzy terms. For example, if I search for a tall tree, being myself in a virtual park in a particular world, then the meaning of tall is obtained contextualizing its generic definition, in this particular case scaling whith respect to the maximum and minimum values of the tree heights in this park.

We consider three main factors to contextualize the fuzzy terms in queries: *world immersion* (is the user in a world ?), *location in a world*, (which is the location of the user in the world she is inhabiting ? which is the minimum object (space) that contains the user ?) and *query context* (which is the context of the fuzzy term being considered in the query where it appears ?). Then, a simple algorithm decides the context of every fuzzy term in a query taking into account these factors. In addition, we consider further factors to contextualize the fuzzy terms that express spatial relations (for example far, near, etc).

Linguistic Quantifiers Let the flexible query be *I am searching for a world which has many tall trees*. To calculate the degree to which a particular world fulfills the whole query, first we have to calculate the contextualized quantification of the degrees to which every tree object X in this world fulfills the atomic subqueries X *is tall*, then the degree to which this quantification Q fulfills Q *is many* is calculated. Various interpretations for quantified statements have been proposed in the literature. The classical approach is due to Zadeh. The most currently accepted is due to Yager. In [9] Bosc and Pivert compare these methods to evaluate quantified statements.

Zadeh [33] proposed viewing a fuzzy quantifier as a fuzzy characterization of an absolute or relative cardinality. The advantage of Zadeh's approach is its simplicity. However, it does not permit differentiating the case where many elements have a small membership degree and the case where few elements have a high membership degree. In [29] Yager introduced the concept of a weighted ordered averaging (OWA) operator. This operator provides a family of aggregation operators which have the conjunction at one extreme and the disjunction at the other extreme. Yager showed the close relationship between the OWA operators and the linguistic quantifiers. In particular, he suggested a methodology for associating each regular monotonic increasing quantifier with an OWA operator. Later it has been shown [7][30] that it is possible to extend this method in order to represent monotonous decreasing and increasing-decreasing quantifiers.

5 Conclusions

In this paper we have described a proposal for a new virtual worlds representation model that requires just a few additional efforts from the worlds creators, and adds a basic semantic level to the worlds which is useful to improve the interaction of the users with these worlds. We also have described a querying model that allows to found worlds and objects in these worlds, using as a base the proposed representation, and a fuzzy approach to solve the queries. Both proposed models taken together improve the current interaction with virtual worlds. We have developed a SWI-Prolog [25] prototype of the described models, which is being used in a more general system for the interaction with virtual worlds.

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