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A Query-by-Example Concept and User Interface for Global and Partial 3D Object Retrieval

Tobias Schreck[1] and Benjamin Bustos[2] and Michael Walter[1]

[1]Interactive Graphics Systems Group, Technische Universitaet Darmstadt, Germany
[2]Department of Computer Science, University of Chile, Santiago de Chile

Abstract

Effective retrieval of 3D objects is an important difficult problem. In addition to considering object-global similarity notions, partial *similarity among 3D objects has been addressed in recent research. In this paper, we introduce a simple, yet effective retrieval system design based on extending standard global 3D descriptors with local descriptions of the objects. The approach is mapped to a novel retrieval interface concept that supports both global and local search for 3D objects. Also, an implementation of the concept is presented. Finally, experimentation performed on two benchmark data sets illustrates improved retrieval results for certain types of queries, as compared to the standard (global) retrieval approach.*

Categories and Subject Descriptors (according to ACM CCS): Information Systems [H.3.3]: INFORMATION STORAGE AND RETRIEVAL—Information Search and RetrievalSearch process Information Systems [H.5.2]: INFORMATION INTERFACES AND PRESENTATION—User InterfacesGraphical user interfaces (GUI) Computing Methodologies [I.3.7]: COMPUTER GRAPHICS—Three-Dimensional Graphics and Realism

1. Introduction

The definition of similarity between 3D objects is an interesting research topic. Indeed, a wealth of methods for 3D similarity search has been proposed in recent years. A common characteristic to many of these proposed approaches is the usage of descriptors that capture properties of the geometry of whole models. While the results obtained by the descriptor-based retrieval systems are so far promising, many applications demand also support for partial similarity search. To fill this gap, first approaches addressing partial 3D similarity search have been recently proposed in the literature. However, the definition of user interface aspects in partial 3D queries has been often neglected.

In this paper, we introduce a simple, yet effective system design supporting both global and partial 3D similarity queries. It is based on the idea to apply an existing global 3D descriptor both on whole models and model segments. The proposed design allows the user to seamlessly operate global and local queries by example. We present an experimental evaluation with two 3D data sets, and show that the approach is able to support effective interactive retrieval. The results indicate that the approach also retrieves more relevant objects than global-only queries, for certain object classes.

2. Related Work

Recent surveys indicate that the descriptor-based approach to 3D retrieval is popular [TV08, IJL*05, BKS*05]. Descriptors capture specific 3D object properties via compact representations (e.g., vectors, or histograms), and based on their definition, support varying similarity concepts. For example, many of these descriptors support global geometric similarity under invariance w.r.t. rigid transformations. In many applications, local similarity concepts are required. In [LZQ06], features of 3D objects are sampled locally, and aggregated by a bag-of-words approach. In [BMSF06], geometric and structural object properties are used for partial matching. Further approaches identify specific local areas of interest together with customized matching strategies to find correspondences between object parts [GCO06, WNK06]. A generic problem to solve in this context is to identify the scale at which interesting areas are detected. To this end, scale space analysis methods have been adapted from 2D (see [Low04]) to the 3D case (see [CCFM08]).

In [BSW*], we present a framework to extend any global 3D object descriptor by local descriptors of the same type, obtained for segments of the respective object. Appropriately combined global and partial descriptors are experimentally shown to improve the retrieval precision as compared to using global descriptors alone. The focus of [BSW*] lies in the derivation and quantitative evaluation of the proposed methodology. In this paper, we design a complementary interactive retrieval system architecture around that basic methodology.

3. Global-Local 3D Object Retrieval

Consideration of both global and partial descriptors to perform similarity queries is interesting for two main reasons. First, partial similarity search can be performed by searching for local-to-local correspondences. Second, partial descriptors may also improve the global retrieval, by including model information which is suppressed by certain descriptor extractors when they process whole models [BSW*].

3.1. Proposed Concept

We propose a novel retrieval system architecture extending the standard query-by-(global)-example approach to support also partial queries. We assume there is a 3D retrieval system available, and that there are one or more 3D descriptor extraction algorithms implemented in the system. A suitable model segmentation algorithm partitions each 3D object into a fixed number n of object segments. 3D descriptors are extracted for each 3D model and for each of the models' segments. Our retrieval system architecture consists of $n+1$ *linked query rows* representing global and partial queries executed in parallel. It can be described as follows:

- The first (top) row is the full model query row. It represents a (standard) query-by-example executed in the space of full models. The first slot shows the query model.
- Rows $2,\ldots,n+1$ are segment query rows. They represent queries executed in the space of model segments. The query segments belong to the query model set in the first row. The first slot in each row shows the query segment.
- A query is specified by selecting a model or model segment. The selection is done by browsing, or by selecting an answer of a preceding query. The specification identifies uniquely an object and all of its segments; they are set as the query in each row.
- After the query specification, the queries for the global model and each of its segments are carried out simultaneously. The system shows a (possibly filtered, cf. below) number of nearest neighbors in the slots to the right of the query objects.

For the segment query rows, either model segments or whole models belonging to the respective segment can be shown. The segment rankings can optionally be filtered for unique global model answers, either for each of the query rows, or for all of them simultaneously. This is useful to avoid duplicate answers for queries consisting of symmetric segments.

3.2. Discussion of the Concept

Compared to standard global-only approaches, this concept adds flexibility to the 3D object retrieval process. In conjunction with a suitable segmentation algorithm, it allows to query for model segments, supporting partial 3D retrieval. While several authors have proposed techniques for partial retrieval, so far little attention has been spent on the interactive system side of partial querying so far. Our work addresses this shortcoming.

Partial querying can be pursued actively in our approach. In this case, the user explicitly provides a model segment to search for. On the other hand, by executing queries for each of the segments of a specified full model, partial querying is also supported indirectly. Showing segments similar to those of the (full) query model may result in identification of additional interesting results not retrieved by the global query. It may also motivate the user to extend the search to model segment space, which can be seen in support of a more *explorative* mode of querying.

Showing global and partial search results simultaneously requires display space that could otherwise be used for the global query. Note that it is always possible for the user to switch to global-only mode, in which case all rows and slots are used for the answers of the global query.

Whether or not the partial retrieval results are beneficial to the user search will depend on many aspects, including the type of query model, the used descriptor type, the segmentation algorithm, and the user information need. In the next section, we show examples of queries where the proposed approach is regarded beneficial.

4. Application of the Concept

We present a prototypical implementation of our concept, and discuss application results indicating the usefulness of the approach.

4.1. Prototype Implementation

We consider a simple object partitioning scheme based on an Octree segmentation of 3D objects normalized for scale and orientation (see Figure 1 for an illustration). While this is a very simple, non-adaptive segmentation scheme, it has been shown to produce on average useful segmentations [BSW*]. In addition, it also serves as a pragmatic starting point for our architecture. However, more intelligent segmentation schemes can easily be incorporated.

We consider two data sets for our application: The *Konstanz 3D Benchmark* [BKS*06] (KNDB; structurally similar to the Princeton Shape Benchmark [SMKF04, BKS*06]),

and the *Purdue Engineering Shape Benchmark* (ESB) as introduced in [JKIR06]. Also, our retrieval system supports a number of 3D descriptors. For the remainder of this discussion, we consider the DSR descriptor, as it has been shown to provide state-of-the-art retrieval performance [Vra05].

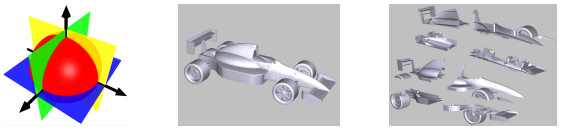

Figure 1: *Octant-based partitioning scheme (left), and its application to a model of a F-1 car (middle and right).*

We experimented with our prototype system by querying for objects from different query classes. The main question of concern was if and how our proposed architecture retrieves relevant and/or interesting query answers. More specifically, we wanted to know how the provided results compare to those of the standard (global-only) retrieval approach. To this end, we used a color-coding scheme to highlight relevant answer objects as follows. In all query rows, light yellow (white) indicates answers relevant (irrelevant) to the query according to the benchmark classification. For the partial query rows, bright yellow (orange) indicates answers relevant and *not* occurring among the top 12 (96) answers of the global query. The latter highlighting visualizes cases where the partial queries are successful in retrieving additional relevant objects.

4.2. Results

Figure 2 shows answers to a global query (first row) and two corresponding partial queries (second and third rows), each for three different query objects from the KNDB data set. In the case of the bike query (top block), the partial queries return each two relevant objects and one remotely relevant object (circled), while the global query fails to return any relevant object on the first 12 ranking positions. In the case of the query for human models (middle block), the partial queries return relevant objects also in different poses, some of which are not found among the first 96 positions of the global query. Finally, the partial chair queries (bottom block) return several relevant and one remotely relevant object, which the global query fails to find.

Figure 3 shows a query for an object from the ESB data set. The figure shows all 8 partial queries simultaneously. It can be seen that, in addition to the relevant objects returned by the original query (top row), the partial queries (rows 2 to 9) yield additional relevant objects not revealed on the first 12 and 96 positions of the original query. Note that the additional relevant answers comprise the same structure as the relevant objects from the global query, yet they show certain extensions to their main structure which prevented them to be retrieved by the global query.

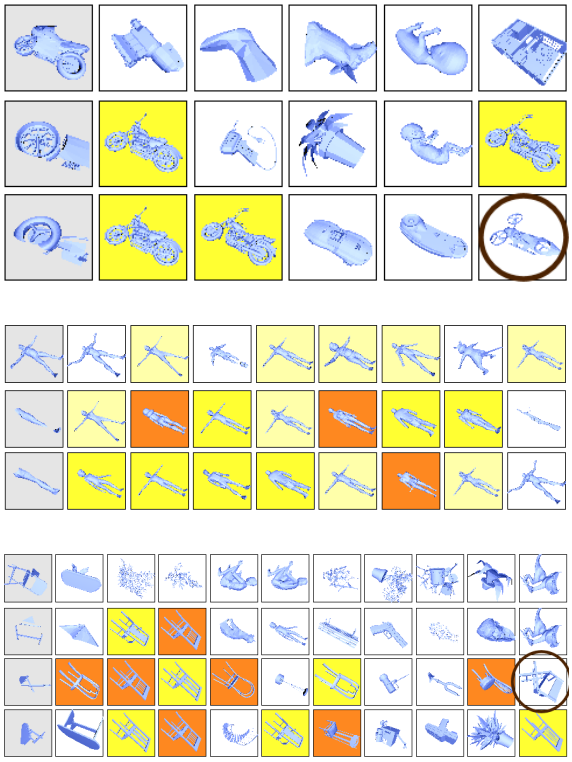

Figure 2: *Example global (top row) and partial (bottom rows) queries for different KNDB query objects.*

5. Conclusions

A concept for integrated global and partial retrieval of 3D objects was introduced. An implementation of the concept based on an existing simple Octree segmentation was applied on a number of example 3D queries. We observe that for several query classes, this simple segmentation scheme already yields meaningful retrieval results, and produces additional relevant answers, as compared to the global approach alone. However, these results are considered preliminary and require further substantiation by more formal quantitative and qualitative evaluation.

We note that among the data sets we tested, there are also query classes for which this effect does not occur, or it is not as strong as in the presented examples. Thus, more careful analysis of the relationship between the Octree segmentation, the characteristics of the query classes, and the effectiveness of the approach, including a more formal retrieval precision evaluation, should be addressed in future work. The extension of our system by more intelligent segmentation algorithms considering also model characteristics in the segmentation is left for future work. Also, d epending on the segmentation scheme applied, the number of rankings the user possibly likes to inspect may be large. To this end, ad-

Figure 3: *Global (row 1) and local (rows 2 to 9) query results for an examples ESB query. The answers to the partial queries provide additional relevant objects not provided by the global query alone.*

vanced result visualization techniques, e.g., based on cluster analysis, are considered promising.

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