Handling Geometric Objects with Free Form Curves in Spatial Databases

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1 Introduction

The increasing demand for the use of database systems (DBS) as an integrating factor in CAD/CAM applications has necessitated the development of DBS with appropriate modelling and retrieval capabilities. One essential problem is the treatment of geometric data which has led to the development of spatial DBS. Unfortunately, most proposals only deal with simple geometric objects like multidimensional points and rectangles. On the other hand, there has been a rapid development in the field of representing geometric objects with free form curves or surfaces, initiated by engineering applications such as mechanical engineering, aviation or astronautics. Therefore, we propose a concept for the realization of spatial retrieval operations on geometric objects with free form boundaries, such as B-spline or Bézier curves, which can easily be integrated in a database management system. The key concept is the encapsulation of geometric operations in a so-called query processor. First, this enables the definition of an interface allowing the integration into the data model and the definition of the query language of a DBS for complex objects. Second, the approach allows the use of an arbitrary representation of the geometric objects. After a short description of the query processor, we propose some representations for free form objects determined by B-spline or Bézier curves. The goal of efficient query processing in a database environment is achieved by using a combination of decomposition techniques and spatial access methods (SAM). Finally, we present some experimental results indicating that the performance of decomposition techniques is clearly superior to traditional query processing strategies for geometric objects with free form boundaries.

2 Spatial Database Systems

The major difference of spatial DBS in contrast to standard DBS (like relational DBS) is the facility to answer queries on sets of geometric objects using a geometric query condition. In this paper we concentrate on manifold objects. While the methods defined can be applied in principle to any type of manifold objects, we only consider 2-manifolds with free form boundaries (free form regions for short). In the context of spatial DBS, research was restricted in most cases to points, lines and polygonal regions in two-dimensional space.

Typical queries with a geometric selection condition are the PointQuery, WindowQuery and the RegionQuery ([GB90]). Other useful operations are the computation of the intersection, union or difference of pairs of manifolds. These queries and operations can be seen as the building blocks for the computation of more complex queries like geometric similarity retrieval in CAD/CAM applications or map overlay in GISs.

We define: Given a scene S, i.e a set of (2-) manifolds distributed in a (normalized) Euclidean 2-space:

- a PointQuery (S,P) selects all manifolds of the scene S containing the query point P as an interior or boundary point;
- a WindowQuery (S,R) selects all manifolds having a non-empty intersection with the query rectangle R.

3 Efficient query processing

We try to achieve efficient query processing of geometric queries using three key concepts:

1.) A check-in check-out mechanism (see [Ka85] for example) is used, that also includes the translation of the geometry of CAD-objects in a neutral format.

2.) Spatial access methods are used as a geometric index.

3.) A decomposition method is applied to the 2-manifolds with free form boundaries.

A spatial DBS has to be independent of a special representation of free form regions, so that a neutral format is necessary. Traditionally, efficient query processing is achieved by using an approximation (usually the minimum bounding rectangle, MBR) and a SAM handling the approximations (see [GB90]). Query processing can then be divided into a filter and a refinement step. More recently, representations were considered, which use more than one reference to one region. While in [OM88]) redundancy is only considered as an improvement of the approximation (filter), Kriegel et al. [KH91a] simultaneously tried to reduce the computational effort of the refinement step by using decompositions (e.g. a triangulation). For decomposition based query processing, a filter for redundant answers has to be added.

Especially in the case of complex CAD/CAM objects, the decomposition of geometric objects seems to be a promising approach. Here we apply this approach to CAD objects bounded by free form curves, restricting ourselves to B-spline and Bézier curves in Euclidean 2-space.

4 Representations for free form regions

As representations for free form regions bounded by B-Spline or Bézier patches we consider:

1.) exact representation: the MBR of the complete object is used as a key in a SAM

2.) decomposition based representations

a) a trapezoid decomposition scheme (based on [He92])

b) a heterogeneous decomposition scheme (based on [BD89][KH91b][FM92]).

The representations vary in different ways; the algorithmic complexity of query processing is determined majorily by the number of components and the complexity of the parts produced. In the case of the trapezoid decomposition only trapezoids with two horizontal sides and two free form curves are produced, while the heterogeneous decomposition generates rectangles and spherical triangles. The number of components of the heterogeneous decomposition is usually twice as much as for the trapezoid decomposition ([FM92][He92]).

5 Query processing strategies

The key concept for the implementation of a flexible interface is the encapsulation of query processing in a component called query processor. This abstraction allows the use of different representations for the geometric objects. Furthermore, it enables the use of different representations for query processing ([He92]).

The query processor as implemented allows four different query processing strategies using three indexes based on the MBR approximation of the free form regions, the MBR approximation for the trapezoid and the MBR approximation for the heterogeneous decomposition.

I: a query processing strategy using only the index based on the MBR approximation of the original free form region is called identity representation.

T1: the use of the index based on the MBR approximation of the trapezoid decomposition is called the one step trapezoid method.

T2: the two step strategy using the MBR approximation of the original free form region as well as the MBR approximation of the trapezoid decomposition is called the two step trapezoid method.

H: indexing the MBR approximation of the different components of the heterogeneous decomposition is called the heterogeneous method.

6 Experimental results

In a set of test series, we compared the four different query processing strategies. We only consider two types of queries, i.e. the PointQuery and the WindowQuery. Due to space limitations, we only present results for one test scene given by a set of two hundred free form regions with an average of 100 control points per region. The (midpoints of the) regions are equally distributed in a normalized Euclidean 2-space.

The performance of the different query processing strategies is measured by the overall computation time related to one resulting object. The value is an average over 100 PointQueries with equally distributed points in normalized 2-space. The average time per answer is depicted as the y value for x=PQ (PointQuery) in figure 1. This shows that decomposition based query processing strategies are clearly superior to the identity representation, which is the standard query processing strategy used in spatial DBS.

The comparison of the query processing strategies for WindowQueries is based on seven sets of differently sized query rectangles. Here again the average time for one resulting region is given in figure 1. The results especially for small query regions are quite similar to the PointQuery. Only for query rectangles covering more than 10% of the whole data space the identity representation seems to outperform decomposition based methods.

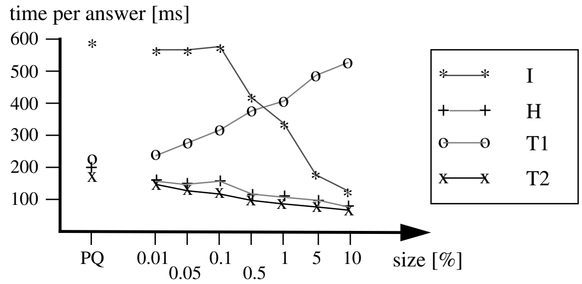

Figure 1: Performance of Point- and WindowQuery

7 Summary and conclusions

In this paper, a concept is proposed for querying CAD data with free form boundaries with respect to geometric selection conditions in spatial database systems. This is due to the encapsulation of the geometric computations in a query processor. Different types of representations and query processing strategies are suggested and the comparison of selected representations shows the superiority of decomposition based representations over the traditional query processing strategy. In particular, the trapezoid decomposition turns out to be a good choice for free form regions bounded by B-spline or Bézier curves. This is strengthened by the observation that this decomposition scheme can easily be extended to other bounding curves and to three-dimensional manifold objects.

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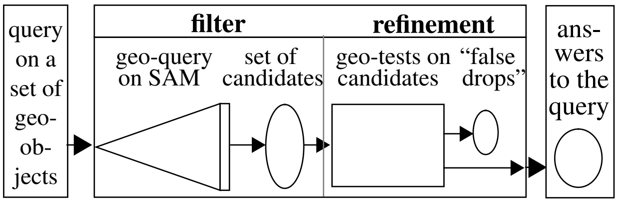
query on a set of geo-objects
filter
refinement
geo-query on SAM
set of candidates
geo-tests on candidates
"false drops"
answers to the query