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Reconstruction of Surfaces From Scattered Points

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1   Introduction

Digitization devices and scanners generate very large point
sets representing complicated geometric models. Data sets
typically result from multiple scans, frequently even multiple
viewpoints. We discuss a method that constructs a B-Spline
surface from scattered data points, usable for further pro-
cessing in a CAD system.

The basis for our reconstruction is the decomposition of
the scattered points into a 3D strip tree data structure. Our
data structure is an extension of the original strip tree pre-
sented in [3]. It is similar to a quadtree, except that each
node in our tree represents a bounding box whose orienta-
tion is defined by the best-fit plane approximating the data
points inside the box.

2   Re-orienting Bounding Boxes

Given a set of points (x,y,z), a bounding box is defined as a
box that contains all the points. Typically a bounding box
is a parallelpiped and is oriented with respect to the axes of
the global coordinate system. To obtain a tighter bounding
box, i.e. , one with smaller volume, the bounding box should
be re-oriented by using the three principal directions of the
underlying point set. The re-orientation process consists of
the following steps:

1. Given a set of points (x_i,y_i,z_i), compute the best-fit
   plane for the point set. A coordinate frame in 3D space
   consists of three basis vectors and an origin. (We use
   principle component analysis (PCA) to determine the
   basis vectors see, [1].)

2. The normal vector of the best-fit plane defines the ordi-
   nate direction in the local frame. We express all points
   associated with a box in terms of its local coordinate
   frame, using the average of the points as the local ori-
   gin.

An example of this is shown in Figure 1.

3   Our Generalized Strip Tree

Our strip tree is a quadtree in 3D space whose nodes are
bounding boxes. Given a set of points, the root of the tree
is a single, properly re-oriented bounding box that contains
all points. A node in the tree is subdivided by first dividing
its bounding box into four sub-boxes and then re-orienting
these sub-boxes relative to the points inside them. As the
strip tree is refined, the bounding boxes of the leaf nodes
provide "tighter approximations" to the underlying points.

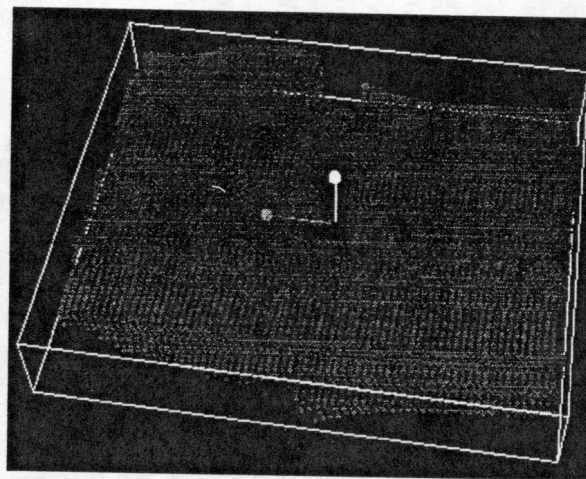The subdivision process of a box consists of three steps:

Figure 1: A "tight bounding box" for a set of points.

1. First, we determine a subdivision point within the
   bounding box around which to form the four sub-boxes.
   This subdivision point is defined as the actual data
   point closest to the center of the bounding box. This
   point is used to divide the bounding box into four sub-
   boxes, all having parallel faces.

2. Once the four sub-boxes have been determined, the
   points associated with the original box are now asso-
   ciated with the four sub-boxes. The sub-boxes are re-
   oriented using the procedure outlined in Section 2.

3. The *box points* for the new re-oriented sub-boxes are
   computed. The box points are either the four midpoints
   of the four box edges parallel to the normal vector of
   the best-fit plane or four original points closest to the
   midpoints of these edges.

The subdivision process is illustrated in Figures 1 - 3.

Figure 1 shows the root bounding box. Figure 2 shows
the strip tree after one subdivision step. Figure 3 shows the
strip tree after four subdivision steps.

4   Progressively Fitting Surfaces

Once the data points have been approximated well enough,
the strip tree approximation is used to fit surfaces that
approximate the data points. The approximation process
starts from the next-to-last level in the strip tree and pro-
ceeds upward towards the root of the tree. The approxi-
mation process for a given node in the tree consists of the
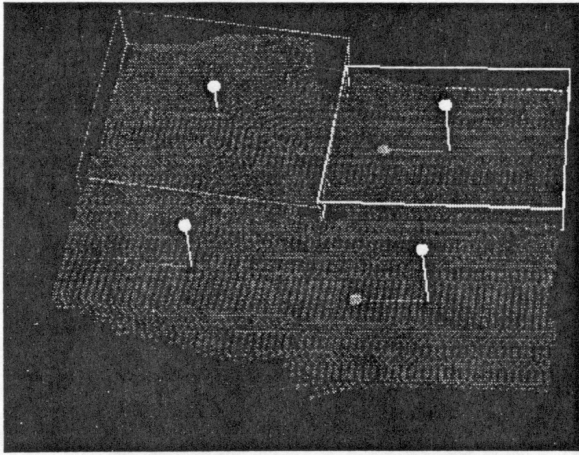following steps:

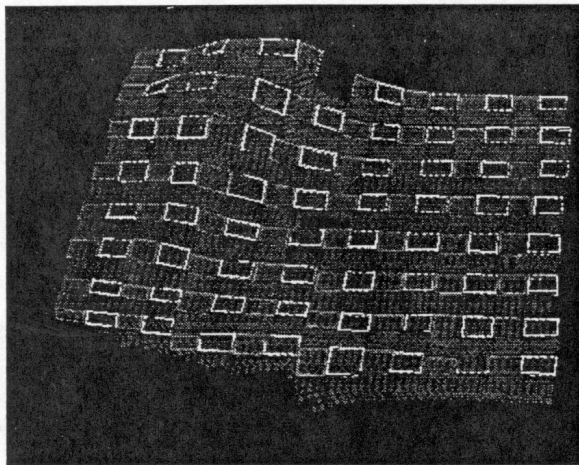Figure 2: Strip tree after one subdivision step.

Figure 3: Strip tree after four subdivision steps.

Figure 4: Final approximating surface for strip tree shown in Figure 3. All surface patches have been blended together.

1. If the node's children have not yet been approximated, a single bi-quadratic Bezier patch is fitted to the box points of the node's children. The 3x3 control points used to determine the patch are obtained from the four box points and by averages of interior points. This surface is degree-elevated to a bi-cubic Bezier patch.

2. If the node's children already have been approximated, the four underlying surfaces are blended together to form a new, C^1-continuous B-Spline surface that describes the four Bezier patches of its children.

In the curve case, this process consists of three steps:

1. The two curves become C^0-continuous by forcing the last control point of the first curve and the first control point of the second curve equal.

2. The two curves are combined into one curve by turning the double control point at the joint into a single control point and by removing one interior knot.

3. The curve becomes C^1-continuous by removing one of the interior knots and the corresponding control point. The knot removal algorithm we are utilizing is described in [2].

5 Results

We have tested our algorithm on a scattered data point set originating from a car door, provided by Alias-Wavefront. Figure 4 shows the final B-Spline surface (Gouraud shaded) obtained by blending all surfaces for the strip tree shown in Figure 3 .

6 Conclusions and Future work

We have presented a new method for reconstructing surfaces from scattered points. Our algorithm introduces a generalization of the strip tree data structure that is used to approximate the given points initially. This initial approximation is then used to construct a set of surfaces that approximates the actual data points. The strip tree needs to be enhanced to allow for a non-uniform subdivision of the data in regions with more data points or more complicated behavior. We also need to refine our error estimate. The error is currently approximated from the relative height of the bounding boxes and the error resulting from the knot removal process. These error metrics need to be integrated into a single measurement.

References

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[3] Hanan Samet. *The Design and Analysis of Spatial Data Structures*. Addison-Wesley, Reading, Massachusetts, 1990.