

# Hole Boundary Detection of a Surface of 3D point clouds

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**Abstract**—Processing surfaces with data coming from an automatic acquisition technique always generates the problem of unorganized 3D point sets or presence of geometric deficiencies (i.e. in some regions of the surface, the obtained data points are sparse or without containing any points). It leads to what we call “holes”, and a mandatory surface reconstruction process. Applying the process to the whole set of 3D points in order to explore and detect all these holes that can be served to process in a further step. In this paper, we propose a method to detect the hole-boundary on a surface of 3D point clouds structured in a 3D volume. The method consists of two steps. In the first step, we extract the exterior boundary of the surface based on the neighborhood relationship between the 3D points and our particular definition of these points. In the second step, we detect the hole boundary by using a growth function on the interior boundary of the surface. Our method could process very fast and extract exactly the boundary of all holes on the surface.  
**Keywords:** *Exterior Boundary, Interior Boundary, Hole Boundary, 3D point clouds.*

## I. INTRODUCTION

Reconstruction of a 3D object means reconstructing that object in order to get the best model that approximates its initial shape. As a matter of fact, acquisition techniques of 3D point clouds often produce a huge amount of data. These data are then simplified to reduce a number of points that can be adapted memory capacity for storing while keeping the original shape of its model. Our problem is to process a big data coming from a seismic data acquisition technique. The main issue is a huge number of data points belonging to the surfaces that represent for the oil reservoirs. Although with an important simplification step, memory requirements are too high. A careful study showed us that actually, such data was obtained from the treatment of seismic data organized in 3D volumes as defined by Philippe Verney [5]. We thus decided to start our processes directly with this seismic data cube. In order to preserve the shape of the surface has not distorted, we first processed by extracting the exterior boundary of the surface. This exterior boundary is then simplified while keeping its initial shape. This works have been done and presented in [2]. Based on this research work, we now go on to process these surfaces by extracting the interior boundaries. They are the boundary of holes for the future holes filling step. Therefore, in this paper, we propose a completed method for extracting all boundaries of a surface of 3D point clouds

defined in a 3D grid. The method consists of two steps. In the first step, we recall our method for extracting the exterior boundary of a surface of 3D point clouds [2]. In the second step, we present our method for detecting all boundary of holes inside of the surface.

The remainder of the paper is organized as follows: we first present the existing methods for boundary extraction of a surface (both in the triangular meshes and surface of 3D point clouds) in section II. Our method is presented in detail in section III. Section IV is the implementation and results. Discussion and evaluation are presented in section V. The last section (VI) is our conclusion.

## II. RELATED WORKS

In this section, we study some existing methods for processing the boundary of a surface (both on a triangular mesh and a 3D point cloud). As we known, determining the boundary of a surface is an important step in surface reconstruction and preserving the shape of these surfaces. Normally, in a 3D point set, approaches computed the boundary of a surface either using its convex hull or convex envelope of a set of 3D points [15], [21], [25]. Other approaches are based on the calculation of an angle or of the distance between points and their neighbors [23], [24]. In the case of a triangular mesh, the existing methods mostly based on the determination of triangles that only share with a triangular face [7], [19], [21]. In the state of the art of boundary extracting methods, different methods have been studied and developed to extract the boundary. Although, in some cases, the computation seems too slow. For example, in order to determine the boundary of a 3D point set, Sampath et al [25] suggested a method by modifying the convex hull approach to trace the boundary from airborne Lidar point clouds. For each point on the boundary  $p_b$ , the computation is repeated to compute the smallest angle between  $p_b$  and its neighboring points for finding the next boundary points. This led to a high time-consuming computation. The other method [23] based on the well-known “Alpha Shapes algorithm” of Edelsbrunner [22]) to extract the boundary. This method need  $O(n^2)$  to detect all boundaries of the surface, which also leads to costly computations. The computation of angle between a point and its neighbors to consider which points are boundary points is also presented in the method

[24]. However, in the case of dense data located on one side of a concave surface, such a method (the empty slices criterion) may fail and hence space has to be split with angles lesser than  $60^\circ$ .

The methods for boundary extraction based on the computation of convex hull have been widely applied. In order to detect the boundary of a surface of 3D points set, Xianfeng [21] proposed a method by triangulating the convex hull  $C$  of the surface first.  $C$  is then optimized by computing and removing some outward triangles to obtain the exterior boundary of the surface. While the method in [15] computed the convex hull of a group of points starting from an initial core point and its neighbors (called cluster). Then, this cluster is iteratively expanded by repeating the process taking as core points those of the convex hull, and each of the convex hulls of core points is combined with the main body of the cluster (i.e. this operation corresponds to the union of two polyhedra). The expansion and the combination of clusters will be stopped until no more point is found and the last boundary comprises all the outer points.

The above methods are suitable for scattered data but are time consuming. As we use voxels and their neighborhood information we can adapt these methods, to obtain faster computation.

### III. PROPOSED METHOD FOR BOUNDARY EXTRACTION

#### A. Overview

As previously mentioned in the introduction, our data are organized in a 3D volume, which allows determining easily the neighborhood of a point. This is also the advantage of our approach for boundary extraction. In order to extract the boundary of a surface, we research and focus on the question: “What is the boundary?” or “What is the hole?”; and then, we will apply some mathematical characteristics on our data to define and denote the boundary and hole in our context. Thereafter, we propose a method for extracting both the exterior boundary of a surface of 3D point clouds and the boundary of the holes inside.

#### B. Definitions and notation

As we known, different notions of boundary have been studied and precisely defined in fields of research such as differential geometry (for continuous surface studies) and topology [6]. The topological definition has also been extended to discrete surface (such as meshes) and has been widely used in this setting. Most boundary notions coincide with topological definitions: a point belongs to a boundary if none of its neighborhoods are included inside the surface. In such a setting, boundary points therefore correspond either to the peripheral points of an open surface, or to the boundary of holes. As presented in the previous work [2] that we have used the following notations and definitions.

##### 1) Notation:

- $G$ : the 2D grid (bounding box of the projection of the 3D point clouds on the x,y plane.)
- $S$ : the subset of cells containing projected points ( $S \subseteq G$ ).

##### 2) Definition of a square neighborhood:

*Definition 1:* Let  $p$  be a cell of a 2D grid  $G$ , we define the  $k$ \_square neighborhood of  $p$  as:

$$SN_k(p) = \{p' \in G; \|p - p'\|_\infty \leq k\} \quad (1)$$

where  $\|p - p'\|_\infty$  denotes the discrete infinite distance of  $R^2$

*Remark 1:* Given a point  $p \in G$ , we call  $k$ \_ring neighborhood of  $p$  (denoted by  $RN_k(p)$ ) the set of  $p'$  such that  $\|p - p'\|_\infty = k$ . The  $k$ \_ring neighborhood of  $p$  contains  $8k$  points. (see figure 1)

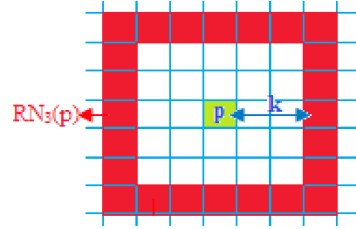


Fig. 1: The  $k$ \_ring neighborhood with  $k=3$  [2]

In addition, we have also used the below notations to denote the elements in  $SN_k(p)$ :

- $E_k(p)$ : the subset of empty cells in  $SN_k(p)$ .
- $NE_k(p)$ : the subset of non-empty cells in  $SN_k(p)$ .
- $SN_k(p) = E_k(p) \cup NE_k(p)$

In our case, we are interested in identifying the periphery of an elevation surface and we will define the concept of “exterior boundary”, which will be computed according to the  $k$ \_square neighborhood connectivity. It is important to recall that some points are missing which requires specific processing. Therefore, our definition of exterior boundary based on the following descriptions (detailed in [2]):

*Definition 2:* Topological boundary: A point  $p$  belongs to the topological boundary if its neighborhood (classically for 4 or 8-connectivity) contains at least one point outside  $S$ .

*Definition 3:* Closed discrete  $SN_k$  - curve: A closed discrete  $SN_k$  - curve is a sequence of pixels where each pixel is  $SN_k$  - connected with the previous and the next of the sequence.

*Definition 4:* Exterior boundary: An exterior boundary of  $S$  is a closed discrete  $SN_k$  - curve  $\mathcal{L}$  of points of  $S$  such that  $S$  is in the interior of  $\mathcal{L}$ . We will denote this boundary by  $EBL_k(S)$ .

*Remark 2:* Such an exterior boundary line is a compromise between the topological boundary (or boundary of the connected component) and the convex hull envelope, and is suitable when data are missing (see figure 2).

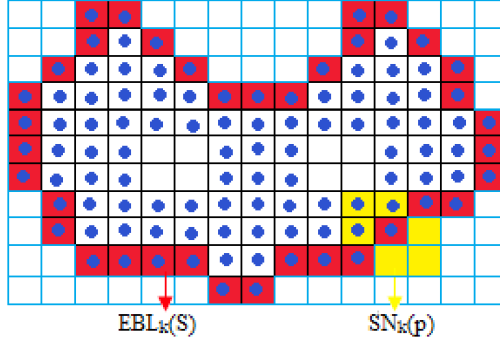


Fig. 2: An exterior boundary (red points) with  $k=1$  [2]

### C. Extracting the exterior boundary

In this section, we review the method for extracting the exterior boundary of the surface that has been done in [2]. The method is called growth function and following clockwise direction to compute and extract the exterior boundary of the surface  $S$  as follows:

- Begin with the first boundary point  $pFirst$ ;
- Growth on the boundary following the clock-wise direction;
- Find and connect to the next boundary point  $pNext$  in  $SN_k(p)$ , starting from the previous point  $pPrev$ ;
- Stop when  $pNext$  hits  $pFirst$  (see figure 3).

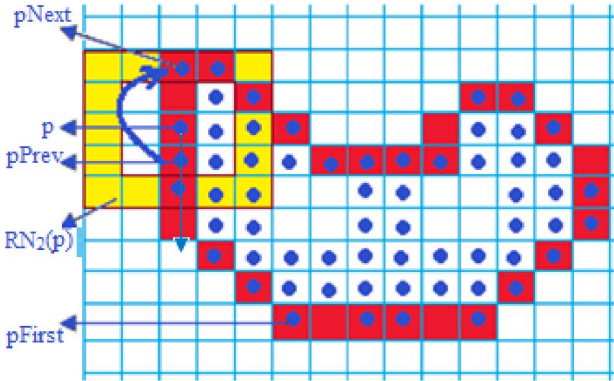


Fig. 3: An exterior boundary (red points) with  $k=2$

As described in figure 3, this algorithm computes an hybrid boundary: connected components of the surface normally separated in the classical 4 or 8-connectivity, can be simultaneously outlined if the gap between them is less than  $k$ . And hence, our boundary is intrinsically a simplified contour of the surface adapted to sparse data and possible (small) holes. This algorithm is presented as follows:

### Algorithm 1 GrowthClockWise( $p$ )

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1: //we describe  $SN_k(p)$  by enumerating the ring  $RN_k(p)$ 
   around  $p$  in a clockwise order starting from the direction
    $p, pPrev$  (see figure 3).
2: stop  $\leftarrow$  false;
3: while !stop do
4:   compute  $pPrev_k$ , find  $\leftarrow$  false;
5:   for any  $q \in RN_k(p)$  enumerated starting from  $pPrev_k$ 
     and !find do
6:     for  $i=1$  to  $k$  do
7:        $q_i \leftarrow$  intersection between  $RN_i(p)$  and discrete
       segment  $(p, q)$ .
8:       if one of the 4-neighborhood of  $q_i$  is empty
       then
9:          $pPrev \leftarrow p$ ;
10:         $pNext \leftarrow q_i$ ;
11:        find  $\leftarrow$  true;
12:      end if
13:    end for
14:  end for
15:  if  $p = pFirst$  then
16:    stop  $\leftarrow$  true;
17:  end if
18: end while

```

### D. Extracting the holes boundary

1) *Definition of hole:* As previously mentioned [2], our data come from an automatic acquisition technique. The obtained data are surfaces of 3D point clouds structured in a 3D volume. The particularity of such surface is that the 3D points are distributed irregularly. The density is often drastically lesser in some areas than in others because of points-loosing or the data points are not located continuously. For this reason, these regions are called “holes”(see figure 4).

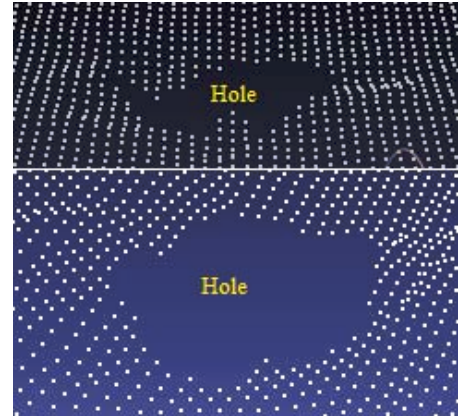


Fig. 4: The holes on the surface of 3D point clouds

2) *Algorithm to extract hole boundary:* After extracting the exterior boundary of the surface  $S$ , the 3D points that belong to  $S$  are now classified into two kinds of points. One of them

is called exterior boundary points (for the previous processing step); and the other called inter points (the points inside its exterior boundary). Therefore, our method for detecting the hole boundary is very simple and described as follows: We loop for all point of  $S$ , if each of them is not an exterior boundary point, and one of its neighbors (in 4-connectivity) is empty, it is determined as a boundary point of a hole. The corresponding algorithm (Algorithm 2) is as follows:

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**Algorithm 2** BoundaryHole( $S$ )

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1: for each point  $p_i \in$  surface  $S$  do
2:   if it is not an exterior boundary point and one of the
     4-neighborhoods of  $p_i$  is empty then
3:      $p_i$  is a boundary point of hole;
4:   end if
5: end for

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#### IV. IMPLEMENTATION AND RESULTS

In this section, we present the implementation of our algorithms. We use Meshlab [4], the open source based on VCG library and implemented by using C++ programming language. We test on both methods (extracting the exterior boundary of the surface, and determining the boundary of holes on this surface), the processing time is very fast. As we can see on figure 5, the exterior boundary (red color points) and the boundaries of hole (yellow color points) are extracted exactly.

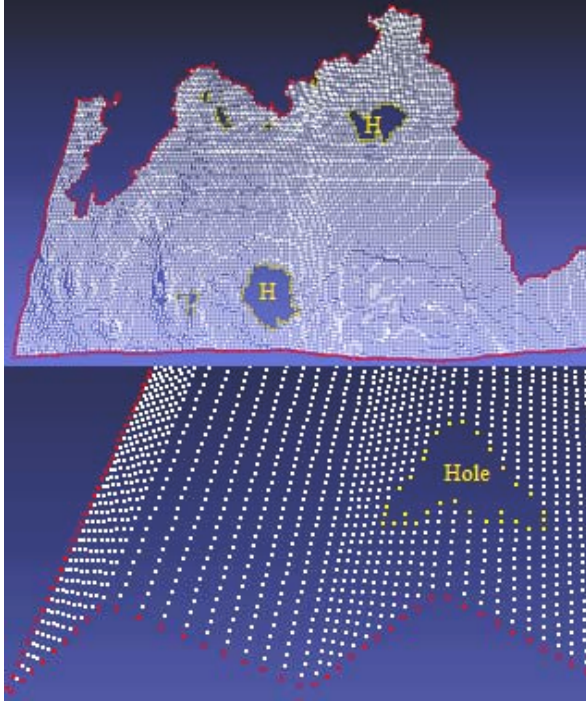


Fig. 5: The exterior boundary of the surface (red color points) and the boundaries of holes (yellow color points).

The computing time for extracting the exterior boundary is mostly depending on the value of  $k$ . However, in some cases it also depends on the shape of the surfaces (see figure 7 for an illustration). This results show that the worst case complexity  $O(N \times k^2)$  is not reached, and that the average complexity with respect to  $k$  seems linear.

In our method, the shape of the exterior boundary on the convex parts is not affected by the values of  $k$ , but it has affected on the concave parts of this boundary. During the exterior boundary extracting process, the next point (on the boundary) is always scanned in a distance  $k$  from the current point  $p$  starting from the previous point  $p_{Prev}$  and following the clockwise direction. Therefore, the resolution of the exterior boundary on a convex part is very high with any values of  $k$  (see figures 8 and 9). On the contrary, the resolution of the exterior boundary is higher if  $k$  close to 1 (highest if  $k = 1$ ) and lower if  $k$  far from 1 (especially on the concave parts). If we choose  $k$  greater than 1, some holes could be created on the surface (the higher values of  $k$ , the bigger holes are created, see figures 9). For this reason, our method allows to obtain different results of the exterior boundary depending on  $k$ . While the boundaries of holes are also extracted very fast and exactly.

#### V. DISCUSSION AND EVALUATION

In this section, we present some discussion and evaluation of our method for extracting the boundary of the surface. Let us give some elements on the efficiency of our boundary extraction approach compared to existing algorithms (we will first study their respective complexities).

In the method of Sampath [25]: given a boundary point  $P$ , next point  $Y$  on the boundary is computed as the neighbor of  $P$  of minimal angle  $\angle XPY$ . Therefore, each step of this method involves the computation of the neighbors of  $P$  (located within a sphere centered at  $P$ ) together with their angular slope with respect to the  $(PX)$  line. Hence, the total complexity of this approach for a  $N$  points boundary is  $N \times k$  angle computations, where  $k$  is the average number of neighbors. (see figure 6a).

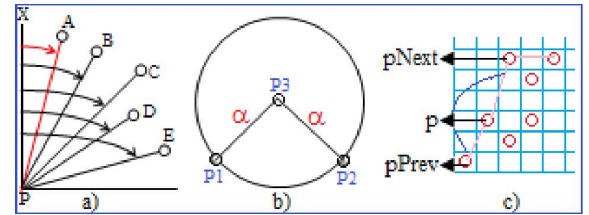


Fig. 6: Comparison of computing strategies between the methods: Sampath (a), ShenWei (b) and Sinh.N.V (c).

While the method of ShenWei [23] based on alpha-shapes. The method tests in the worst case,  $M \times (M - 1)$  pairs of points, where  $M$  is the number of points of the surface  $S$ , that is  $M = O(n^2)$  with the previous notations (see section 2: Related works for more details). For all of these pairs ( $P1$ ,  $P2$ ), the center  $P3$  of the circle of radius  $\alpha$  (see figure 6b)



and leaning on (P1, P2) must be computed and all points belonging to this circle must be detected, which leads to costly computations.

In our method: for each boundary point  $p$ , next point ( $p_{Next}$ ) is computed by enumerating the  $k$  square neighborhood clockwise starting from the direction ( $p$ ,  $p_{Prev}$ ), see figure 6c. Hence, the complexity of this step is at most  $O(k^2)$ ; but as we stop the enumeration as soon as a neighbor is encountered, the average case is far lower. As a consequence, the complexity of our method is only  $O(N \times k^2)$  where  $N$  is the number of boundary points.

Therefore, with respect to both previous methods, our approach proves more efficient. Figure 7 illustrates the computing time required by our method for numeric results.

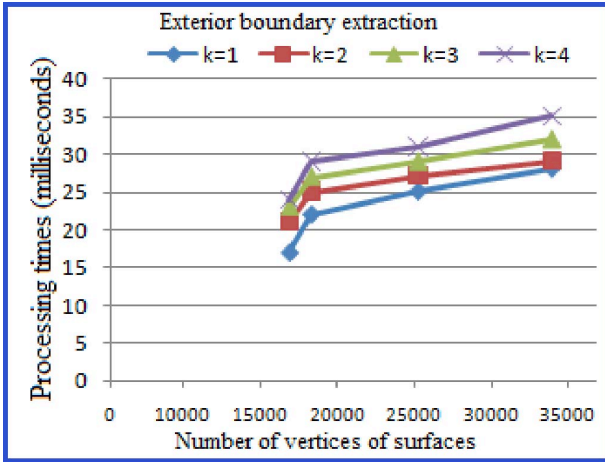


Fig. 7: The processing time of exterior boundary extraction usually depends on the parameter  $k$ , although sometimes it may be affected by the shape of the surface.

Comparing to the existing method [25], the processing time of our method for extracting the exterior boundary is faster. We implemented both our algorithm and Sampath's algorithm with the same number of points for each input surface (see table 1).

Number of input points	Sampath's method (millisecond)	Our method (millisecond)
15626	52	31
60511	570	300
68956	920	733
89270	1156	873
140073	1723	920
886639	2297	1217

TABLE I: Comparison of the processing times between the methods. We use the same input data points and run on the same computer (Intel 2CoreDue, 2GB of Ram).

## VI. CONCLUSION

In this paper, we have presented the method for extracting all boundaries of the surface of 3D point clouds structured in a

3D volume. The important point of the method is that we based on the previous work [2] to extract the exterior boundary of the surface first. This algorithm is evaluated efficiently comparing to the existing method [23], [25] as presented in Discussion and Evaluation. After extracting the exterior boundary of the surface, we then suggested a method to extract all boundaries of the holes inside of the surface. This method is simple but the processing time is very fast. In the future work, we go on to reconstruct this surface by filling the holes in order to have an optimal geological surface as our final goal for the surface reconstruction.

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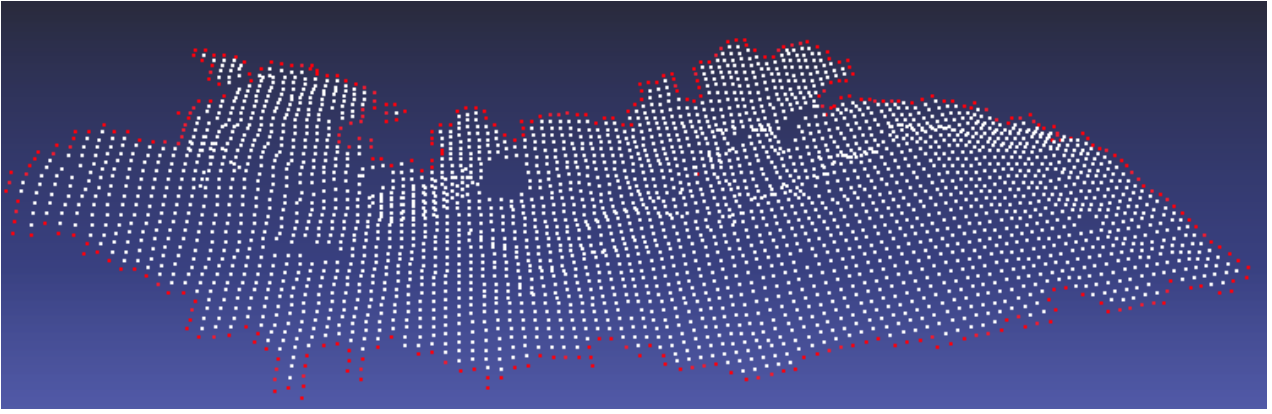


Fig. 8: The resolution of the exterior boundary of a geological surface is highest with  $k = 1$ .

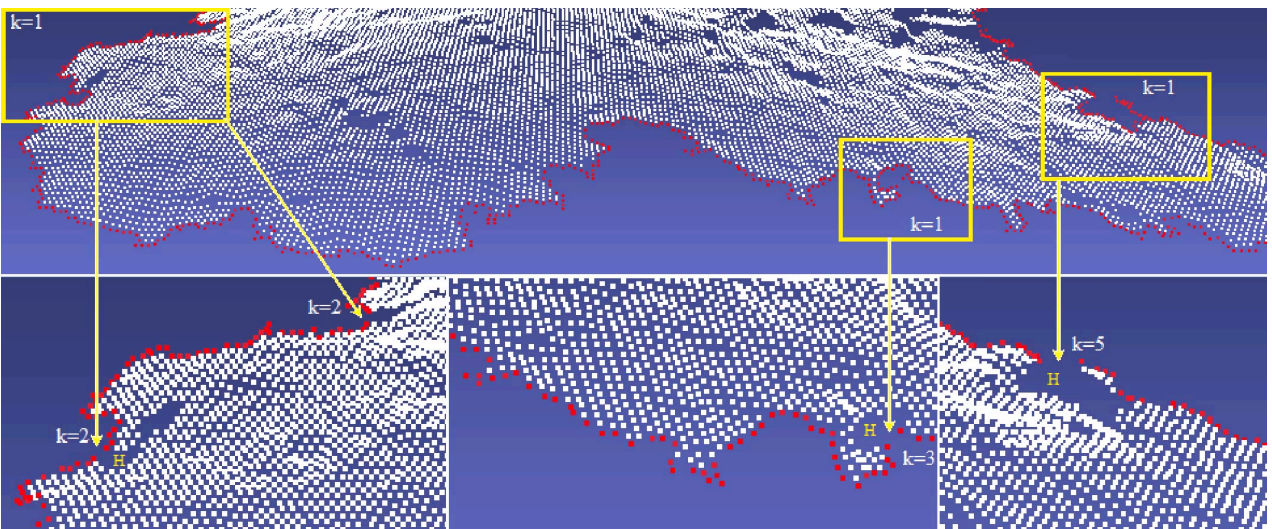


Fig. 9: An exterior boundary of a geological surface after extracting with many values of  $k$  (if  $k = 1$ , the resolution of the boundary is high (highest); otherwise, the resolution of the boundary is low and some small holes  $H$  are created).

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