A Compact Shape Representation for Linear Geographical Objects: The Scope Histogram

A. Schuldt
as@tzi.de

B. Gottfried
bg@tzi.de

O. Herzog
herzog@tzi.de

University of Bremen
Centre for Computing Technologies (TZI)
Am Fallturm 1, D-28195 Bremen

ABSTRACT

In the GIS domain we are often faced with a great amount of shape-related data. Therefore, it is a challenging task to find concise description approaches which support the efficient retrieval of specific objects. In order to address this demand we apply a method that has recently been introduced in the context of shape-based image retrieval of two-dimensional silhouettes, namely the scope histogram. Scope histograms pertain to the group of qualitative shape descriptions as they characterise a shape by the general configuration of its parts. In particular, scope histograms allow the comparison of two shapes with constant time complexity. Despite of its low complexity, the approach achieves promising retrieval results. However, up to now the definition of scope histograms is limited to closed polygons.

In this paper we investigate the application of scope histograms to the GIS domain. Since the contour of silhouettes is always closed, a restriction to closed polygons is no limitation in that domain. By contrast, it frequently is when dealing with GIS data. In this domain, we are rather often faced with open polygons; think for example of courses of rivers, borders, and coastlines. Therefore, we modify the original definition of scope histograms in order to be able to handle arbitrary polygons. Although our new definition leads to a more compact description than the original one, retrieval results are even improved by this modification.

Categories and Subject Descriptors

I.2.10 [**Vision and Scene Understanding**]: Shape; I.4.10 [**Image Representation**]: Statistical

General Terms

Algorithm, Performance

Keywords

Geographic information systems, linear objects, image retrieval, qualitative shape description, polygons, bipartite arrangements, scope histogram

1. INTRODUCTION

In the area of geographic information systems (GIS) we are often faced with a great amount of shape-related data. Handling this data efficiently, e. g. in order to enable low response rates for shape-based retrieval of objects, is a challenging problem. As motivated by [3] it is not always appropriate to apply the precise description of quantitative approaches. By contrast, qualitative approaches pose an alternative in that they take a coarser perspective and characterise rather general properties of objects. Thereby, knowledge about the relationship between objects (or their parts) is made explicit. Subsequently, user queries can be processed using this knowledge directly without the necessity to extract it again and again for each query. This approach has already successfully been applied in some areas, for instance by using topological relations [5, 13]. Nevertheless, the representation of shape information still remains an open issue to some extent. In order to address this issue we investigate the application of an approach that has recently been introduced in the context of shape-based image retrieval of two-dimensional silhouettes: the scope histogram [15].

As elaborated by [2], polygons form a compact representation for two-dimensional outlines in that they allow the approximation of contours [14] even with little influence on the perception of shape. Thereby, only the most salient contour points are kept, while the less important ones are simply abandoned. Using this representation as a foundation, scope histograms create an even more compact description as they characterise polygons with constant space complexity. Furthermore, it is even possible to compare two polygons with constant time complexity, $O(1)$. Despite of their low complexity, promising retrieval results are achieved in the MPEG test [11], which is a well-known reference measure for shape-based image retrieval. However, up to now the application of scope histograms is limited to closed polygons. By contrast, open polygons cannot be handled. While this may be acceptable in some domains (e. g. retrieval of silhouettes), it is frequently not in the GIS context. Think for example of courses of rivers [9]. It is obvious that open polygons form an intuitive way of representing streams, while closed polygons seem to be rather inappropriate.

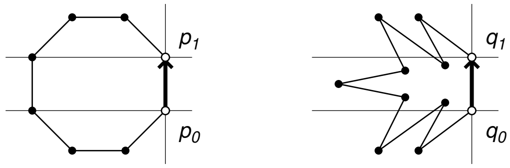

Figure 1: Two examples for orientation grids that are induced by line segments of polygons. Note that each of the polygons is solely located in the left half of its respective orientation grid

In this paper we present a modified version of the original scope histogram. Especially, our new approach additionally allows the characterisation of open polygons. In the following section we present a short review on previous work that underlies scope histograms. In Sect. 3 we introduce our modified definition of scope histograms and compare it to the original one of [15]. Subsequently, we evaluate our modification using the MPEG test in Sect. 4 before we conduct a case study surveying the scope histogram's application to linear geographical objects in Sect. 5. Finally, we give a short summary in Sect. 6.

2. CHARACTERISING SHAPES BY BIPARTITE ARRANGEMENTS

The concept of bipartite arrangements [7, 8] extends the 13 qualitative relations between time intervals [1] to a second dimension. Thus, it is possible to characterise two arbitrarily oriented line segments (e. g. of polygons) qualitatively by their position w. r. t. each other. Their configurations are distinguished by applying an intrinsic reference system, namely the orientation grid of [17]. As depicted in Fig. 1 the orientation grid is induced by one of the involved segments. It is built up by three auxiliary lines. The first one runs through the reference segment and allows the distinction whether a point lies on its left or right side. Two further lines are oriented orthogonally w. r. t. the first one, each passing either the reference line's start point or its end point respectively. Thereby, it can be decided whether a point is located in front of the reference segment, next to or behind it. Altogether, it can be determined, in which of the six orientation grid's sectors a point is located. Generalising this method to the description of line segments instead of single points is straightforward: Since each line segment is defined by a start and an end point, it can be characterised accordingly to the location of these two points. Due to the fact that both points can be located in any of the six sectors, altogether $6^2 = 36$ configurations are distinguishable. According to [7], this number can be reduced to 23 due to symmetries and the omission of intersections. The resulting 23 bipartite arrangements, in short $\mathcal{BA}_{23}$, are depicted on the left hand side of Fig. 2, their mnemonic labels are given in the centre of the same figure.

A useful property of this representation arises from the fact that the orientation grid is induced by the characterised line segments themselves. From this follows that the intrinsic reference system undergoes the same affine transforms that are possibly applied to the configuration of line segments. Therefore, the obtained description is invariant against scale, translation, and rotation. This invariance is generally desired as the respective transforms do not affect the shape of an object. All other qualitative descriptions basing on this representation inherit this property, unless they apply additional efforts to distinguish these transforms.

The field of application for the $\mathcal{BA}_{23}$ relations is not only limited to single line segments. Furthermore, it is also possible to characterise each of the n line segments of a polygon w. r. t. the reference segment. Therefore, a sequence of n $\mathcal{BA}_{23}$ relations is applied:

Definition 1 (Course). *x is a line segment of a simple polygon P. Its course $C(x)$ describes all $\mathcal{BA}$ relations between all lines of P and x:*

$$C(x) \equiv (x_{y_0}, \ldots, x_{y_{n-1}}), x_{y_i} \in \mathcal{BA}, i = 0, \ldots, n-1$$

Applying this definition to the left polygon in Fig. 1 we obtain the course: Id, F_l, F_l, F_l, C_l, B_l, B_l, B_l. The right polygon's course is as follows: Id, F_l, FO_l, FO_l, FO_l, D_l, D_l, BO_l, BO_l, BO_l, B_l. Considering only these descriptions it is possible to derive further knowledge about both polygons, e. g. that they are solely located in the left halves of their respective orientation grids.

In order to characterise a polygon completely it is not sufficient to use only one of its line segments as a reference line. On the contrary, each of them has to be taken into consideration, which results in a matrix comprising n^2 relations in total. Although exact lengths and angles are abandoned, this represents a rather detailed description which in turn leads to a high complexity. As already elaborated above, taking the number of involved relations as a basis, space complexity for such a description is quadratic, $O(n^2)$. Time complexity for the comparison of two of these descriptions is even higher. For a closed polygon each of its n line segments can be chosen to be the first reference segment. Therefore, every polygon can be characterised by a number of n matrices, whereby each matrix can be transformed into another one by cyclic permutations. Furthermore, two matrices might be different in size (the second polygon comprises m line segments). In this case, multiple line segments have to be mapped onto a single one and vice versa. These observations lead to a time complexity of $O(mn^3)$ for the comparison of two of these descriptions. The following section describes an approach to reduce both space and time complexity to $O(1)$.

3. A MORE COMPACT APPROACH

Starting from the concept of bipartite arrangements it is possible to derive another shape feature: the scope histogram that has originally been proposed in [15]. Despite of its definition on the basis of bipartite arrangements, the scope histogram offers both constant space and time complexity, $O(1)$. In Sect. 3.1 we start by introducing scopes in general, followed by scope histograms in Sect. 3.2. Thereby, we do not apply the original definition of [15]. By contrast, we introduce a useful modification that significantly enlarges the number of possible applications for scope histograms, especially regarding the GIS domain. In Sect. 3.3 we shall then compare both approaches in order to motivate our changes.

3.1 Scope

As elaborated in Sect. 2, a course $C(x)$ characterises a polygon through the position of each of its line segments w. r. t. a reference segment. As already seen above, this results in a space complexity of $O(n)$ for each course. As an

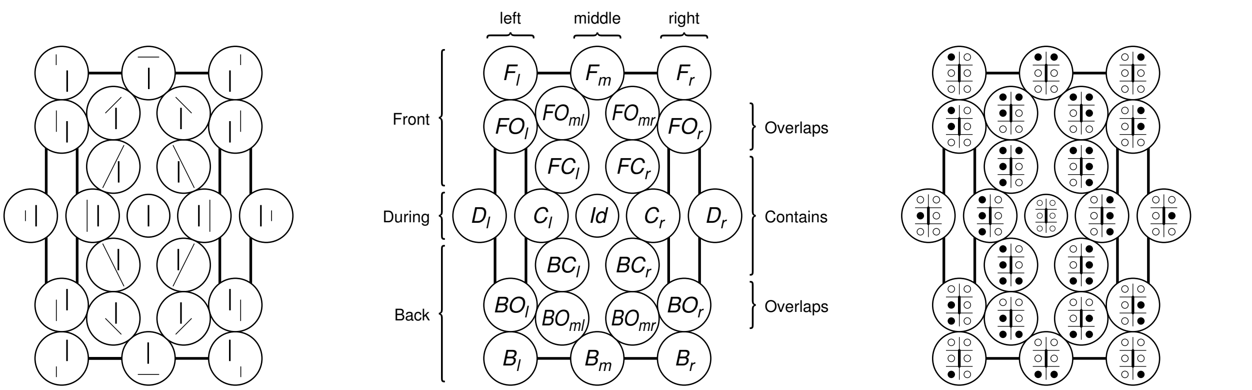

Figure 2: All 23 $\mathcal{BA}_{23}$ relations that can be distinguished qualitatively between two line segments in the two-dimensional plane. Left: Example arrangement for each relation. Centre: The relations' mnemonic labels. Right: Iconic representation of their respective scopes having taken only six atomic relations as a basis

alternative, [15] suggest to confine oneself to the position of the polygon as a whole w. r. t. a respective reference segment. The difference to characterising a polygon by the position of each of its line segment, one after another, can be illustrated using the polygons depicted in Fig. 1. Although they differ significantly regarding their courses, both of them are located solely in the left half of their respective reference systems. Thus, instead of n relations as before, i. e. one for each line segment, now only one single relation is needed for the whole polygon, namely "left" in this example. Proceeding this way leads to a reduced space complexity of only $O(1)$. In the following this approach will be referred to as a polygon's *scope* [8].

At first glance, the scope representation seems to come along with a major loss of information concerning the considered polygons: Both of them result in the same description although they can easily be distinguished by humans. But this is only a premature first impression. Like for courses (see Sect. 2), this description is not performed from the point of view of only one line segment, but from all of them, one after another. Inducing the orientation grid by each of the left polygon's segments in Fig. 1 leads always to the same characterisation, since the polygon is left w. r. t. to all of its segments. By contrast, the right polygon can clearly be distinguished as many different scope relations occur.

Up to now, we only dealt with scopes at a rather conceptual level. Thereby, we denoted the relation in our abovementioned example simply by "left". It is obvious, that this single relation does not suffice for the characterisation of arbitrary configurations. On the contrary, it is necessary to define a set of relations that are applicable for this purpose. The $\mathcal{BA}_{23}$ relations depicted on the left hand side of Fig. 2 are not suited for this purpose. They have originally been introduced for the characterisation of single line segments, which pass only up to four sectors of the orientation grid. By contrast, polygons are not restricted to being straight (as line segments are) and can therefore pass up to all six sectors. This means that there exists a number of configurations that cannot be covered $\mathcal{BA}_{23}$.

Nevertheless, a subset of $\mathcal{BA}_{23}$ comprising only atomic relations is worth a further examination. In this paper we regard a $\mathcal{BA}_{23}$ relation as being atomic if it is located in exactly one sector, i. e. none of the orientation grid's singularities is passed. This constraint holds for six relations, namely B_l, D_l, F_l, F_r, D_r, and B_r. In the following, these relations will be referred to as $\mathcal{BA}_6 \subset \mathcal{BA}_{23}$. The position of any other $\mathcal{BA}_{23}$ relation can be characterised by a set of atomic relations. For instance, the position of C_l is represented by the set $\{B_l, D_l, F_l\}$.

Every scope can be visualised by six circles, each of them is located accordingly to its respective atomic relation in the orientation grid. If an atomic relation is member of the scope, its respective circle is depicted opaque, transparent otherwise. The scopes of all $\mathcal{BA}_{23}$ relations are depicted on the right hand side of Fig. 2. Their definition is as follows:

Definition 2 (Scope of Relations). *x is a line segment of a simple polygon P. The set of atomic relations describing the position of a relation $x_y \in \mathcal{BA}_{23}$ is called the scope of the relation, in short $\sigma(x_y)$. It is defined by:*

$$\sigma(x_y) \equiv \{x_{y_1}, \ldots, x_{y_n}\}, x_{y_i} \in \mathcal{BA}_6; 0 \leq n \leq 4$$

Accordingly to our initial intention, we are not limited to characterising the position of single $\mathcal{BA}_{23}$ relations (i. e. single line segments). By contrast, the concept can also be applied to describe sequences of segments w. r. t. a reference line by one single scope relation. Since we deal with sets of atomic relations, it is possible to apply basic set operations, e. g. unions and intersections. In order to determine the scope of a whole course $C(x)$, we therefore simply create the union of the scopes of all participating relations r_i:

Definition 3 (Scope of Courses). *x is a line segment of a simple polygon and $C(x)$ is its course. The set of atomic relations describing the position of $C(x)$ is called the scope of the course, in short $\sigma(C(x))$. It is defined by:*

$$\sigma(C(x)) \equiv \bigcup_{i=0}^{n-1} \sigma(r_i), r_i \in \mathcal{BA}_{23}$$

Since we are dealing with sets, we are limited to a number of at most $|\mathcal{BA}_6| = 6$ atomic relations in any case. This means that space complexity for such a description w. r. t. a reference segment is indeed constant, $O(1)$. Summarising our efforts so far, we are now able to characterise a polygon w. r. t. one of its segments with constant complexity. Furthermore, a description w. r. t. all of its n segments now only requires n scope relations instead of n^2 bipartite arrangements as before. Time complexity for the comparison of two of these descriptions nevertheless remains the same, since two sequences of scopes might differ in size and concerning their first reference segment. As we shall see in the next section, a further reduction of complexity is possible.

3.2 Scope Histograms

In the preceding section we found one reason for the time complexity when comparing two scope descriptions: it coincides with the fact that we deal with ordered sequences of scopes. A further reduction of complexity can be achieved by abandoning the original order in which the scopes appear. Since the number of possible scopes is limited, we can simply determine the frequency of their occurrence. Thereby, we weight each scope by the relative length of its respective reference segment in order to achieve a certain robustness against different results of the underlying polygonal approximation algorithm. Due to its fixed number of entries, such a histogram representation has a constant space complexity, $O(1)$. Furthermore, two polygons characterised by scope histograms H and K can also be compared with constant time complexity, taking into account the sum of the distances of all corresponding histogram entries h_i and k_i:

$$d(H, K) = \sum_i |h_i - k_i|$$

In this context the question has to be answered, how many entries scope histograms comprise. This number depends directly on the number of possible scopes, i. e. the size of the atomic relations' power set. Since there exist six atomic relations, we deal with a number of $2^6 = 64$ different sets. This is already a manageable number of relations. But this is only the general case for open polygons. Whenever we are restricted to closed polygons the amount of scopes can even be reduced. It can be observed that simple, closed polygons are always characterised by scopes that are formed by chains of atomic relations without gaps in between. This observation can be explained by the fact that two consecutive line segments of the described polygon are also always directly connected to each other. The property of being gapless reduces the number of realisable scopes for this subset of polygons to 32. By restricting oneself to polygons that are oriented in a mathematically positive order, not all of the remaining scopes are realisable. This leads to a further decrease to those 16 scopes that are depicted in Fig. 3.

To summarise, by applying scope histograms we are able to characterise polygons with constant space complexity, $O(1)$. Furthermore, it is even possible to compare two of these descriptions with constant time complexity. Each scope histogram has a fixed number of 64 entries. Additionally, in domains in which we are restricted to closed polygons, it is even possible to confine oneself to a number of only 16 histogram entries.

3.3 Analysis of the Modified Concept

After having introduced our modified scope histogram, we shall now contrast it to the original definition of [15]. An example scope according to the original definition is depicted on the left hand side of Fig. 4. This definition applies a set of twelve atomic relations. The set of relations that are regarded as being atomic can thereby be divided into two groups, each containing six relations. One of them distinguishes itself by containing those relations that are only located in one of the orientation grid's sectors. The other

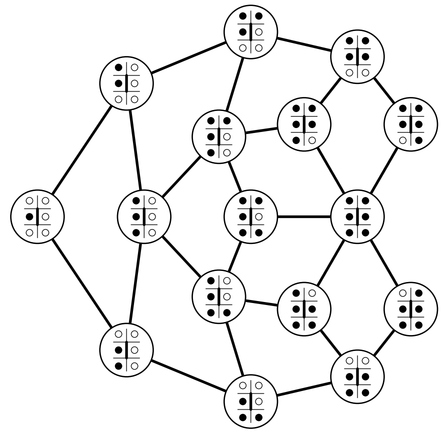

Figure 3: Conceptual neighbourhood structure for the subset of scopes that can be realised by simple, closed polygons

ones pass exactly one of the orientation grid's singularities, thereby connecting two adjacent sectors. Since F_m is an atomic relation according to this definition, its scope contains only the relation itself. In contrast to the previous approach our new description only regards those relations as being atomic that are listed on the right hand side of Fig. 4. This descriptions abandons the relations that pass the orientations grid's singularities. Instead, only those six relations that are solely located in one of the orientation grid's sectors form the basis for the scope. Hence, the scope of F_m in the example is represented by the union of the atomic relations F_l and F_r as these are the involved sectors.

For the previous definition it follows from the number of twelve atomic relations, that in total $2^{12} = 4096$ scopes can be distinguished for the general case of open polygons. This is quadratic compared to the 64 scopes of our new definition. What follows from this amount of relations is the fact that scope histograms are also required to comprise 4096 entries in order to cover all conceivable configurations. This is a rather high number. Especially, compared to the number of an average polygon's line segments, such a histogram would heavily inflate the description. This has also been recognised by [15], letting them restrict their definition to closed polygons. Like in our case (see Sect. 3.2) this allows them to massively reduce the number of relations to 86. Anyway, this is nevertheless much more than the 16 we apply for closed polygons and even more than the 64 relations we use for general polygons. As we distinguish similar configurations with a heavily confined number of scopes, the question arises, to what extent the more compact representation affects the retrieval performance of scope histograms.

In the following, we shall shortly investigate the consequences of compacting the scope definition. Thereby, we have to examine gapless chains of atomic relations. Such a chain is defined by its lower and upper bound, each of them itself defined by an atomic relation. For all relations between these bounds it is just a question of granularity whether or not they are listed. Much more interesting are the bounds themselves. As an example, it does not matter whether the scope of C_l is represented by $\{B_l, D_l, F_l\}$ or by $\{B_l, BO_l, D_l, FO_l, F_l\}$; the important point is that the bounds are in both cases defined by B_l and F_l.

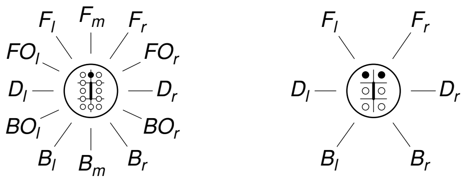

Figure 4: The scope of the F_m bipartite arrangement relation according to the previous (left) and the new (right) definition. In the previous representation F_m is itself an atomic relation, while it is characterised by the union of F_l and F_r in the new one

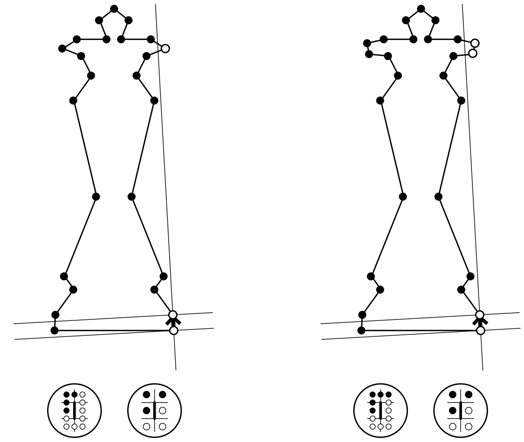

Figure 5: The approximations of the chess piece differ only slightly at the top. In the scope representation with twelve atomic relations this leads to different characterisations, while there is no difference when confining oneself to six atomic relations

As another example, let us consider the chess piece depicted on the left hand side of Fig. 5. In the top part of the piece there exists exactly one point that is located in the right half of the highlighted orientation grid. This means that both line segments that are connected to this point pass the orientation grid's singularity. The bound of the scope is therefore marked by the F_m relation in the original definition with twelve atomic relations. Let us now consider the more precise approximation that is depicted on the right hand side of Fig. 5. This polygon contains one further line segment that is located in the front right sector. Therefore, the scope's bound according to the original definition would now be F_r as one segment is completely contained in this sector. This example illustrates that already a minor change in approximation leads to a different description in the previous approach.

Let us now examine both polygons with our new approach. Thereby, already the left chess piece's bound is defined by the F_r relation. This is due to the fact, that F_m is no atomic relation in this approach and therefore represented by the union of F_l and F_r (as depicted in Fig. 4). The inclusion of F_r can also be motivated by the fact, that the respective line segments are (at least partially) located in the front right sector. Proceeding this way leads to identical descriptions for the left and the right polygon according to the orientation grids which are highlighted in Fig. 5. This example illustrates that our new scope definition is more robust against variations of the underlying polygonal approximation algorithm. From this observation we can conclude that the original scope definition is more precise for some cases, but concurrently less robust for exactly the same cases. Reducing the number of atomic relations should therefore not have much influence on the retrieval results. In this context the question may arise how often such configurations actually occur in the original approach. The polygons in Fig. 5 differ only regarding a few line segments. Although this may lead to some different scopes, the overall histogram does not change significantly. A more detailed statistical investigation of this question is conducted in Sect. 4.2.

Eventually, it is worth mentioning that the compact representation allows a much simpler computation of scopes. While [15] have to apply three auxiliary functions in order to arrive at a gapless scope for closed polygons, we are not faced with this problem. By contrast, since we abandon those relations which cause their problems, we can simply create the unions of all participating relations (see Def. 3).

4. COMPARISON TO THE ORIGINAL SCOPE HISTOGRAM

The comparison of the original scope definition with our new one in Sect. 3.3 suggests that our modifications should not influence retrieval results significantly. Since this is nothing more than an assumption, it has to be proven by further investigations. Before applying scope histograms to the GIS domain in Sect. 5, we shall investigate this issue. In order to measure the results of our modified scope definition, we conduct the core experiment CE-Shape-1 [11] for the MPEG-7 standard. This allows the comparison of both approaches, since the same test has already been performed for the original definition in [15].

4.1 Retrieval Performance

Core experiment CE-Shape-1 comes along with a database of 1400 binary raster images, each containing the silhouette of a single object. The database is grouped into 70 classes, each of them comprises 20 instances. During the test each of the images is used as a query, one after another. All other images are ordered by their similarity accordingly to the approach examined. For each query the top 40 results are considered and the number of correct matches is counted. Since each class comprises 20 instances, at most 20 correct matches can be found per query. In total, this leads to 28000 possible matches for all 1400 queries. The result of the experiment is the ratio of found matches to the maximum number of matches that can be obtained in theory. It is worth mentioning, that retrieval rates near 100% are highly unlikely if only shape knowledge is taken into consideration. This is due to the fact that all classes have been grouped together by semantical aspects. What follows from this is that some of them differ significantly concerning their shape.

As motivated in [15] the scope histogram has to be compared especially with other shape features that pertain to the same complexity class. This holds for example for a group of features that is already well-known in the GIS context, namely those features characterising shapes by a single numeric value. This group comprises the compactness as defined by [4], which corresponds to the ratio $\frac{4\pi A}{P^2}$ of area and perimeter. Further examples are the radius ratio $\frac{R_{min}}{R_{max}}$ of the minimum enclosing circle and the maximal contained circle [6] as well as the aspect ratio $\frac{H_r}{W_r}$ of the minimal enclosing rectangle [4]. As listed in Table 1 the retrieval results of these features range from 17% to 24%. This is already a notable result, especially when having in mind that we are dealing with single numbers. By contrast, a random ordering would achieve a retrieval rate of only about 3%. Our modified scope histogram achieves a result of about 47% and thereby outperforms all of the above-mentioned numeric features. It shows that this result is even slightly better than the 46% that are achieved by [15] when applying the original scope definition.

Table 1: Classification results of compactness (CO), radius ratio (RR), aspect ratio (AR), and scope histogram (SH) for CE-Shape-1 Part B. Furthermore the combined results of the three numeric features (NF) as well as their combination with the scope histogram (NS) are examined

CO	RR	AR	SH	NF	NS
21.86	16.82	24.12	46.78	51.58	**64.67**

Furthermore, [15] also suggest evaluating the combination of the scope histogram with the numeric features. With our modifications this leads to a result near to 65%, which is again slightly better the result that is achieved by the original definition (which is 64%). From these results we conclude, that confining oneself to a set of only six atomic relations does even slightly improve retrieval results. Eventually, it is worth mentioning that a retrieval result of about 65% is only about twelve percentage points less than the result achieved for instance by the correspondence of visual parts of [10] (which is 76.45%). Nevertheless, their approach has a significantly higher time complexity of $O(mn^3)$ for the comparison of two objects while our results are achieved with constant time complexity, $O(1)$.

4.2 Statistical Distribution

Subsequent to the scope histogram's retrieval results we shall now examine the statistical distribution of the occurring scope relations for the MPEG dataset. Thereby, we address the question how frequently those scopes appeared in the previous representation that are abandoned in our new one. To recall, according to the previous representation there exists a number of 86 realisable scopes for simple, closed polygons. By contrast, the new definition maps these relations onto a set of only 16 remaining scopes. The analysis shows that already according to the old definition these 16 relations covered 86% of all occurring configurations. The abandoned 70 scopes only appeared in 14% of all cases. This outcome is another argument for the confinement to only 16 scope relations, especially since the abandoned ones are meaningfully mapped onto the remaining ones.

5. APPLICATION TO LINEAR GEOGRAPHICAL OBJECTS

After having shown that our modifications even improve the retrieval results slightly, we shall now concentrate on applying the scope histogram to the GIS domain. As noted before, we are quite often faced with open polygons in the context of GIS. Due to the introduced modifications we are now able to characterise e. g. the course of rivers qualitatively. In this context it is worth mentioning that [9] also suggest an approach for the description of linear objects. Like the scope histogram, their method also bases on bipartite arrangements of line segments. In contrast to scope histograms, which do not require the extraction of special shape properties, they concentrate on counting the number of meanders a river comprises. In Sect. 5.1 we conduct a case study on the application of the scope histogram to linear geographical objects. Subsequently, we investigate the influence of the underlying polygonal approximation in Sect. 5.2. Finally, we categorise our approach in comparison to the method of [9] in Sect. 5.3.

5.1 Case Study

As an example for the application of our modified scope histogram we consider some North American rivers. More specifically we take six rivers into consideration that flow through Virginia into the Chesapeake Bay. These are in alphabetical order Appomattox, James River, Mattaponi, Pamunkey, Potomac, and Rappahannock (Fig. 6). Thereby, we only regard the rivers themselves and not the confluences of their numerous tributaries.

Before analysing the rivers concerning their scope, we start with applying a polygonal approximation. Therefore we use the method of [12], choosing a scale-invariant factor of a half percent of the respective river's length. Subsequently, we compute the scope histogram for each river. The bottom part of Fig. 6 depicts the three most frequent scopes for each river. Most of the scopes in this group contain atomic relations that are located in front of or behind the reference segment. By contrast, only one of the depicted scopes comprises an atomic relation that is located next to the reference line. This observation can be explained by the fact that each of these rivers flows more or less straightforward from its source to its confluence to the bay. Although there are deviations and meanders the overall direction remains the same. So, although other scopes may appear, they are not the most important relations for these rivers. By contrast, if a river would have a more spiral-like course, also scopes with atomic relations next to the reference segment would appear more often.

Although the most frequent scopes of the considered rivers are similar to some extent, a distinction of the respective rivers is nevertheless possible. This is due to the fact that the scopes appear with different frequencies, depending on the course of the rivers. In order to illustrate this observation we visualise the resulting scope histograms. Thereby, we denote each of the 64 conceivable scopes with a unique identifier from 0 to 63. These identifiers can be obtained by regarding each scope as a number in its binary representation. Starting with B_l, ending clockwise with B_r each atomic relation can either be one if it belongs to the respective scope, or zero otherwise.

Proceeding this way allows us to cover all scopes with the histogram's visualisation. However, it is worth mentioning that this visualisation significantly differs from that one that has been introduced in [16]. In their approach the conceptual neighbourhood structure of scopes underlies the visualisation so that two neighbouring scopes are always similar to

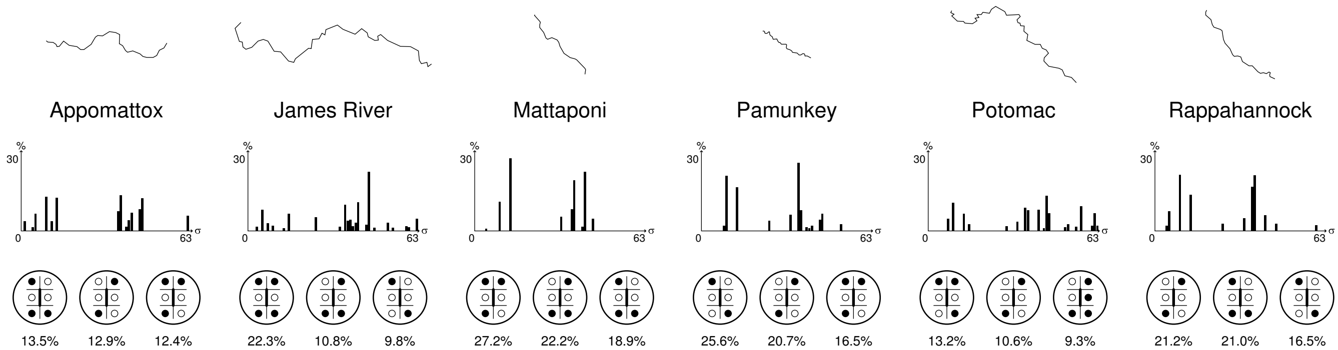

Figure 6: Six rivers flowing through Virginia into the Chesapeake Bay. Top: The polygons depicting their course. Middle: Visualisation of the scope histograms showing the frequency of occurring scopes when characterising the rivers. Bottom: The most frequent scopes for each river

each other. Although this visualisation can also be applied to the new scope definition it is limited to closed polygons. This is due to the fact that the neighbourhood structure for scopes of arbitrary polygons spans in three dimensions (plus one for the scopes' frequencies). Since a visualisation in just two dimensions is not straightforward more work has to be spent on this topic. Nevertheless, the simple approach applied here is at least appropriate to estimate the similarity of two scope histograms.

To summarise, accordingly to their histogram's visualisations the considered rivers can clearly be distinguished by the frequencies of their scopes. As already elaborated above, scope histograms form a rather compact characterisation for polygons in that they offer constant space complexity for the description. Apart from low complexity, the concept of scope has another useful property. Due to the underlying intrinsic reference system, scope histograms are invariant against scale, translation, and rotation. Scale means thereby scaling an already approximated polygon. Additionally, it is worth investigating the influence of scale to the original shape as this could potentially lead to different approximation results and therefore different polygons. This concern is dealt with in the following section.

5.2 Influence of the Underlying Polygonal Approximation

A general issue when dealing with shape description methods is the question in how far they are influenced by an underlying polygonal approximation. In order to address this topic we consider one of the above rivers in more detail. Especially, we take the James River as it exhibits one of the most complex courses (e. g. compared to the course of the Pamunkey). The James River is examined at the six different levels of approximation that are depicted in Fig. 7. The maximally allowed approximation error e_{max} ranges from 4% down to 0.125% of the polygon's length. Thereby, decreasing the error leads to a finer approximation.

Already the visual inspection reveals a significant difference between the polygon on the left hand side of Fig. 7 and that one on the right hand side. This observation manifests in the different number of line segments: the left polygon has six, while the right one comprises 94. The difference in granularity causes that the scope histogram of the former polygon comprises only six entries while the latter one's histogram entries are more distributed. In Fig. 7 the level of detail increases rather significantly between the left three polygons. By contrast, the right three polygons are already quite detailed so that there is not so much difference between them. This is also reflected in the scope histograms as they distinguish themselves quite clear for the three polygons on the left hand side. The two rightmost histograms have their three most frequent scopes in common. The fourth polygon has at least its two most frequent scopes in common with them. This example shows that the scope histogram is to a certain extent robust against different levels of approximations. However, approximation poses especially a problem if polygons are approximated in a very rough way.

This observation could be regarded as a potential limitation of the scope histogram. Nevertheless, this is not the case since it is common to all polygonal description methods and not a specific property of the scope histogram. Furthermore, there exists a simple solution that addresses this problem: Choosing a fixed factor of the polygon's length leads to a scale-invariant approximation error. Thereby, the approximation error becomes invariant against scale. Although it is an open issue which factor is appropriate, it is at least ensured that a polygon is always approximated in a similar way independent of its scale.

5.3 Categorisation of the Approach

Having applied the scope histogram to the characterisation of rivers, we shall now categorise it through the comparison with [9]. As already elaborated above, they describe a linear object like a river by counting its meanders. Our approach does not require the extraction of such a specific shape property. Instead, scope histograms consider the whole shape of the object. Nevertheless, both space and time complexity of the scope histogram do not exceed that of the other method: they are constant for both approaches. While the method of [9] allows to locate the position of a reversal, the original order of line segments is abandoned in our approach. This is the tribute to be paid for low complexity. The meaning of scope histograms can nevertheless easily be comprehended since each scope represents a specific configuration. For instance, a scope comprising the atomic relations B_l, D_l, and F_l characterises a polygon that is located left w. r. t. its reference line. This holds for example for the two polygons depicted in Fig. 1. To summarise, in contrast to [9] the scope histogram takes a more general view on the shape of linear objects.

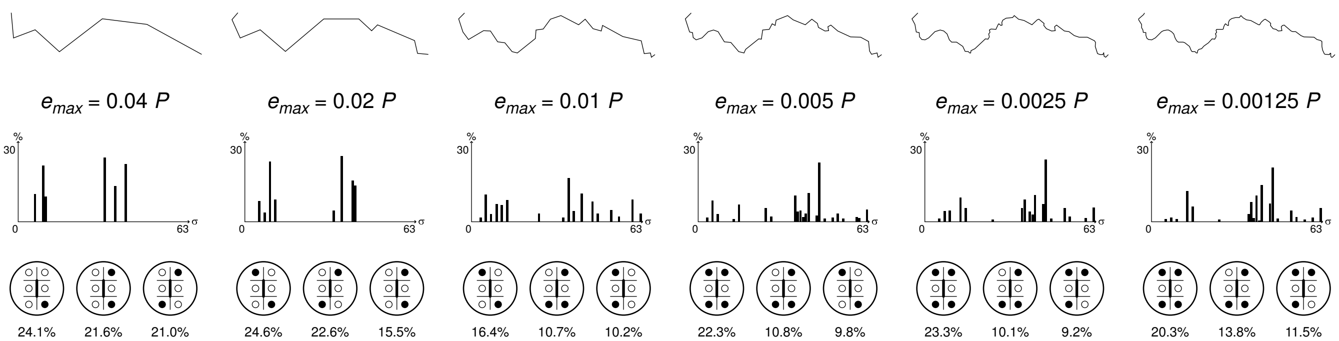

Figure 7: The course of the James River at six different levels of approximation. The maximum error e_{max} varies from 4% (rough approximation) of the polygon's length to 0.125% (fine approximation). The resulting polygons vary between six and 94 line segments

6. SUMMARY

In this paper we investigate the application of scope histograms to the GIS domain. Up to now, according to the original definition of [15] scope histograms are limited to closed polygons. Since this restriction is not appropriate for linear geographical objects we suggest a modification of the original method. Thereby, we reduce the number of underlying atomic relations from twelve to only six. In proceeding this way the number of scopes that have to be distinguished decreases from 4096 to now only 64.

As discussed in Sect. 3.3 compacting the scope definition does not pose a major problem. By contrast, the description becomes even more precise and invariant against different degrees of approximation. This assumption is supported by our evaluation which shows that, compared to the original definition, retrieval results even improve slightly. Applied to the GIS domain, it shows that the scope histogram forms an expressive description for open polygons. It allows to characterise and distinguish e. g. the course of rivers with both constant space and time complexity.

Future work on scope histograms should especially focus on two topics. The first one is, extending the visualisation based on conceptual neighbourhoods to scope histograms of open polygons. This is an important issue since it allows to easily estimate the similarity of two shapes. The second topic is concerned with the extension of scope histograms to self-intersecting polygons. In the GIS domain this feature is e. g. useful to model crossroads.

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