Representing concave objects using Virtual Images

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Abstract

Recent research in the design of image database systems emphasizes the necessity of defining an indexing methodology which is not based on form features but rather on invariant numerical, topological or geometrical characteristics of the images. In this paper, we concentrate on the spatial data and relationships which represent the most important method for recognizing images. In particular, we focus on iconic indexing methodologies based on order theory and symbolic projections and we address the problem of ambiguity arising from the description of concave objects with these representations. Towards this end, we extend the cutting mechanism of the 2D C-string iconic index to perform cutting lines whenever a concave point (split point) might lead to ambiguity during the reconstruction process. The iconic index obtained according to this set of rules can be managed by the Atomic Relation Extraction Method to derive the corresponding virtual images which represent the normalized pictorial information.

Keywords

Iconic indexing, spatial reasoning, image data model, content-based query

1 INTRODUCTION

In designing image database systems, to obtain a representation which is independent of the user's point of view (and therefore more flexible), it is necessary to define an indexing methodology which is not based on form features but on invariant numerical, topological or geometrical characteristics of the images.

With this observation in mind, the most attractive approach takes into account the requirement of a unified framework for image representation, indexing, visualization and for spatial reasoning (Chang, 1988). Conventional data models are not particularly suitable for pictorial information because of the complex nature of images. Images incorporate a huge amount of information. In particular, it is possible to distinguish explicit information concerning the objects contained in the image, and implicit information, such as that concerning the relative positions of the objects in the image. It is also essential to decide which features should be stored. Generally speaking, the data can be classified as non-spatial, spatial and

graphical, i.e. attribute-based information, implicit information, and information used mainly for display, respectively.

We concentrate on the spatial data and relationships which represent the most important method for discriminating among the images. In particular, we focus on the iconic indexing methodologies based on order theory and symbolic projections and we address the problem of ambiguity arising from the description of concave objects with these representations.

An image can be described by an iconic index which is constructed by projecting the objects along a chosen system of axes. Then, by applying the spatial operators according to the relations existing between the projections, the index is obtained and the representation of the visual content of the image is derived. However, when a concave object has to be represented, the concavity point (*split point* (Jungert, 1993)) recognized according to an axis, can cause ambiguity during the reconstruction process since the position of the objects cannot be uniquely derived from the index.

This paper aims to avoid the ambiguity arising from the split point incorporated in the 2D C-string knowledge structure (Lee, 1990). In particular, we extend the cutting mechanism of this iconic index by introducing further cutting lines whenever a split point of a concave object might produce ambiguity.

The rest of this paper is organized as follows. In Section 2, we review iconic indexing methodologies. The definition of a virtual image is given and the normalized (with respect to reversing and rotation) iconic indexing approach is recalled. In Section 3 we propose a representation of images with concave objects by virtual images. The representation inherits the properties of the normalized iconic indexing methodology. Conclusions are given in Section 4.

2 ICONIC INDEXING METHODOLOGIES

In order to describe the kinds of spatial objects present in an image and to determine what their particular properties are, it is necessary to introduce a spatial data model. A spatial data model is a formulation of the spatial concepts used to organize and structure human perception of the space (Egenhofer, 1991). The role of a spatial data model is similar to the conceptual schema in the 3-schema view of traditional databases. Without such a formal framework it would be impossible to investigate and discuss the formalization of spatial relationships, because it may vary considerably depending on the data model selected.

A compact and exhaustive way of managing spatial relationships is to apply mathematical order theory (Egenhofer, 1991). The formalism on which our data model is based is the segmentation of the plane with respect to a system of axes, called *symbolic projection*. Symbolic projections translate exact metric information into a qualitative form and allow reasoning about the spatial relationships among objects in a 2-D plane. In particular, an image can be described by an iconic symbolic representation (Tanimoto, 1976). This iconic representation is itself an image used as an index which preserves the visual information and allows different levels of abstraction and management (Chang, 1992), (Tanimoto, 1976). The Query-by-Pictorial-Example (QPE) approach introduced by Chang and Fu (Chang, 1980), is a methodology in which the objects and the spatial relations among them in the image to be retrieved are expressed by a symbolic image which serves as the query and which is matched against the images in the database. Thus, the query contains both explicit and implicit information, since the query itself is a symbolic picture.

In successive works the QPE approach has been further developed. In IIDS a pictorial query is converted into 2-D strings and an image is retrieved by matching the iconic indexes (Chang, 1988). The problem of pictorial information retrieval then is reduced to the problem of 2-D subsequence matching (Chang, 1987).

However, the 2-D string iconic index is not sufficient to give a complete description of the spatial knowledge for complex images since every object is considered as a point, thus, an image with many objects with complex sizes and shapes may not be completely described.

In order to describe more accurately the spatial relations, Chang and Jungert (Chang, 1991) extended the idea of symbolic projections by introducing the cutting mechanism concept and defining the generalized 2D string (2D G-string) knowledge structure for pictorial databases. In order to establish the relations among the objects in terms of spatial operators, they partition the real image by drawing cutting lines at the beginning and ending points of the overlapping objects, thereby decomposing the image into many smaller subpictures.

A more efficient cutting mechanism has been introduced by Lee and Hsu in the knowledge structure of 2D C-string (Lee, 1990), where they introduced the concept of dominating object. The 2D C-string uses a cutting line only at the ending point of the dominating object. The spatial operators used in the 2D C-string representation are shown in Table 1.

Table 1 The definition of 2D C-string spatial operators

<i>Notation</i>	<i>Meaning</i>	<i>Condition</i>
$A < B$	A disjoins B	$end(A) < begin(B)$
$A = B$	A is the same as B	$begin(A) = begin(B)$ $end(A) = end(B)$
$A B$	A is edge to edge with B	$end(A) = begin(B)$
$A \% B$	A and B have not the same bound and A contains B	$begin(A) < begin(B)$ $end(A) > end(B)$
$A [B$	A and B have the same begin bound and A contains B	$begin(A) = begin(B)$ $end(A) > end(B)$
$A] B$	A and B have the same end bound and A contains B	$begin(A) < begin(B)$ $end(A) = end(B)$
A / B	A is partly overlapping with B	$begin(A) < begin(B)$ $< end(A) < end(B)$

As an example, for the picture in Figure 1 the cutting mechanism uses two lines in the x-direction (Figure 1(a)) and no line in the y-direction (Figure 1(b)).

Figure 1 The 2D C-string cutting mechanism.

The corresponding 2D C-string representation (u, v) is

u: A] B [B] C [C
v: B [C % A

2.1 Normalized iconic indexing

It has been shown that symbolic projections are suitable for powerful spatial reasoning, as well as topological relations (Egenhofer, 1991). However, unlike topological relations, which are invariant under topological or geometrical transformations, symbolic projections depend on the orientation of the objects, i.e., the relative spatial positioning and ordering of objects in 2-D space is preserved. Thus, a spatial relation $A \text{ op } B$ differs from $B \text{ op } A$ and it is possible to recognize of the specific spatial arrangement of two objects.

On the other hand, the conventional methodologies based on orthogonal projections do not lead to two identical indexes for an image and its transformation (e.g. reverse, rotation), even though their visual content is essentially the same. In such cases, an iconic index like those discussed earlier is not sufficient to guarantee that the solution to a query is complete, since pictorial information is positional information.

In (Petraglia, 1994) this problem is faced by introducing a normalized indexing methodology based on virtual images. The aim of this indexing methodology is to satisfy the previously stated requirements. In particular, the limitation of the reversing problem is overcome by defining a transformation law which allows one to obtain the index of a reverse image starting from the index of the original one. Moreover, in order to obtain rotation invariance, the rotational iconic index 2-R string is introduced. A system of polar axes whose origin, the rotation center, coincides with the centroid of a chosen object (Petraglia, 1993), is used. As with the 2D C-string, the 2-R string is obtained by a cutting mechanism. Here, however, the cutting lines along the x- and y-direction are replaced by circles having the rotation center as center, and radial segments around the rotation center, i.e. cutting lines along the ring-direction (c-direction) and sector-direction (s-direction), respectively. Consequently, every spatial relation and operator is described in terms of conditions over the beginning point and the ending point along the s-direction and the c-direction.

In order to make our discussion concrete, let us recall the definitions of virtual image and normalized virtual image on which the normalization process is based (Petraglia, 1994).

Definition 1

The virtual image P associated with an image is a pair (Ob, Rs) where

Ob = $\{ob_1, \dots, ob_n\}$ is a set of objects;

Rs = (Rs_u, Rs_v) is a pair of sets of the form: $\{r(p_i, p_w) \mid r \text{ is a spatial operator, } p_i, p_w \in Ob\}$. Each $r(p_i, p_w)$ in Rs_u (resp. Rs_v) represents the spatial relation, called *atomic relation*, holding between the objects p_i and p_w along the projections of a chosen system of axes.

Definition 2

A normalized virtual image can be defined as a pair (NOb, NRs) where

NOb = $\{ob_1, \dots, ob_n\}$ is a set of objects;

NRs = $((Rs_c, Rs_s), (u, v))$ where

(Rs_c, Rs_s) is the pair of sets of atomic relations corresponding to the 2-R string, and (u, v) is the 2-D string over the centroids.

In order to derive the virtual image corresponding to an image, the Atomic Relation Extraction Method (AREM) is introduced, which allows us to obtain all the spatial relations among the objects, starting from an iconic index extracted according to a chosen system of axes (Petraglia, 1993).

For sake of clarity, in the following, AREM methodology is described with respect to the Cartesian system.

Given objects A and B where A is the dominating object, let $\{A_1, \dots, A_n\}$ and $\{B_1, \dots, B_m\}$ be the sets of their subparts derived from the cutting mechanism of the 2D C-string. The spatial relations holding between (A_1, B_1) , (A_n, B_m) , and (A_n, B_1) are called characteristic relations, while the subparts A_1, B_1, A_n and B_m are called the characteristic subparts.

Table 2 describes the correspondence between the characteristic relations of two objects A and B and the relations holding between their borders.

Table 2 The characteristic relations and the corresponding conditions on the borders

<i>Condition on the borders</i>	<i>Condition on the characteristic subparts</i>
$\text{begin}(A) < \text{begin}(B)$	$A_1 < B_1$ or $A_1 \supset B_1$ or $A_1 \% B_1$ or $A_1 \mid B_1$
$\text{end}(A) > \text{end}(B)$	$B_m < A_n$ or $A_n \supset B_m$ or $B_m \mid A_n$ or $A_n \% B_m$
$\text{end}(A) = \text{end}(B)$	$A_n \supset B_m$ or $B_m \supset A_n$ or $A_n = B_m$
$\text{begin}(A) = \text{begin}(B)$	$A_1 \supset B_1$ or $B_1 \supset A_1$ or $A_1 = B_1$
$\text{end}(A) = \text{begin}(B)$	$A_n \mid B_1$
$\text{end}(A) < \text{begin}(B)$	$A_n < B_1$
$\text{end}(A) < \text{end}(B)$	$A_n < B_m$ or $A_n \mid B_m$ or $B_m \supset A_n$ or $B_m \% A_n$
$\text{end}(A) > \text{begin}(B)$	$B_1 < A_n$ or $A_n \supset B_1$ or $A_n = B_1$ or $A_n \% B_1$ or $B_1 \mid A_n$ or $A_n \supset B_1$ or $B_1 \supset A_n$ or $B_1 \% A_n$ or $B_1 \mid A_n$

Then, given a 2D C-string for a picture f , AREM produces a virtual image, i.e., a description of the picture f in terms of objects and atomic relations. AREM uses the spatial operators defined in Table 1 and consists of three steps:

- (1) starting from the 2D C-string index, all the objects and the subparts are numbered in a progressive way, deriving the indexed 2D C-string;
- (2) all the binary spatial relations are derived from the indexed 2D C-string using the picture algebra laws (Lee, 1991);
- (3) starting from the binary spatial relations over the characteristic subparts obtained from the second step, the atomic relations are derived according to Table 2.

3 HANDLING CONCAVE OBJECTS

The interest in using normalized virtual image as an iconic index is motivated by the possibility of exploiting conventional database methodologies for the complete solution of pictorial queries, since the virtual image representation is independent of any indexing method and provides a virtual description of the image.

In this section, we focus on the cases where the reconstruction process is not unique. An iconic index should satisfy the properties of compactness, constructability and reconstructability, i.e., an image and its iconic index should be uniquely related. The aim of this section is to manage the problems arising when the property of reconstructability is not satisfied.

In particular, we distinguish two different ambiguous cases. We deal with the ambiguity which derives from physical features of the represented objects and we analyze the situation where the ambiguity is dependent on the choice made to describe the pictorial information. That

is, we deal with objects with irregular shapes (concave objects) where the ambiguity is due to the nature of the objects, apart from the representation used to describe them. We also consider objects which have regular shapes but may lead to ambiguity due to their spatial arrangement.

We note that the normalized virtual image describes the visual content of an image in terms of objects and spatial relations among them independent of any orientation, since the 2-R string can be extracted with the respect to the centroid of each object and the positional information is given by the 2-D string with respect to the orientation used to store the image in the Image Database. Then, the presence of several independent systems of axes allows one to derive different representations which contain complementary information; i.e. the normalized pictorial information is the result of these representations and derives from the analysis of the spatial arrangement of the objects along both axes of specific selected systems.

The result of this orientation independence assures the possibility of deriving unique representations even if the atomic relations, which describe the spatial arrangements of the objects, imply ambiguity during the reconstruction process. When the ambiguity arises from the spatial arrangement of the objects and from the choice of a particular point of view, moving the point of view to another rotation center eliminates the ambiguity, since the analysis of the complementary information which is in the normalized virtual image gives enough information to overcome the previous ambiguity.

As an example, consider the pictures in Figure 2. The pictures are described by the same iconic index with respect to the Cartesian system, thereby introducing ambiguity during the reconstruction process:

u: $A < B \% C$

v: $B \% C < A$

Figure 2 Pictures that lead ambiguous reconstruction processes.

The corresponding normalized virtual images (NOb, NRs), where the rotation centers correspond to the centroid of the object A are:

Figure 2a):

NOb = {A, B, C};

NRs = ((Rs_c, Rs_s), (u,v)) = ((Rs_c={B<C}, Rs_s={B% C}), (A<B<C, C<B<A)).

Figure 2b):

NOb = {A, B, C};

NRs = ((Rs_c, Rs_s), (u,v)) = ((Rs_c={B% C}, Rs_s={B% C}), (A<B=C, C=B<A)).

Then, by analyzing the normalized virtual images, it is possible to recognize the exact spatial arrangement of the objects, since the positional information is derived from the 2-D string indexes and the relative positioning of the objects is contained in the virtual images, which can be obtained according to the rotation center of each object.

We now concentrate on concave objects and their representations. In particular, to satisfy the requirement of a uniquely reconstructable index we introduce a solution which is based on the AREM methodology and extends the 2D C-string cutting mechanism by determining further conditions to fix cutting lines. In fact, it is necessary to use the AREM methodology since the

normalized virtual image does not solve the ambiguity arising from the presence of concave objects.

As an example, consider the images of Figure 3, where the rotation center corresponds to the centroid of the object C. The projections of the beginning points and the ending points of the objects are drawn along the c-direction, where the split point is recognized. Both pictures are described by the same set of atomic relations along the c- and s-direction and their corresponding iconic index is:

c: A%B

s: A%B.

Figure 3 The projections of the objects along the c-direction.

Obviously, this representation is ambiguous, since the property of reconstructability is not satisfied: it is not possible to recognize the position of object B with respect to the split point of object A since this information is not contained in the index. In order to represent concave objects uniquely, it is necessary that the index contains information about split points to determine the spatial arrangement of the objects exactly.

To this aim we distinguish the two situations depicted in Figure 3 and extend the 2D C-string cutting mechanism by introducing cutting lines to be performed whenever a split point produces ambiguity in the reconstruction process. In particular, we recover the *empty space* object of the 2D G-string mechanism (Chang, 1991), (Jungert, 1993), which plays an important role in discriminating between the two cases represented in Figure 3.

Basically, the algorithm of the cutting mechanism of the normalized iconic indexing is defined as follows, where the conditions are checked both in the c- and s-direction.

Let I be an image made up of two objects A and B, where A is a concave object, then

- 1) if $\text{split\_point}(A) < \text{end}(B) < \text{end}(A)$ or $\text{begin}(A) < \text{begin}(B) < \text{split\_point}(A)$, then A is partitioned by the cutting lines projected with respect to the beginning point and the ending point of the object B. The iconic index corresponding to the derived subpicture could contain the empty space object e ;
- 2) otherwise the 2D C-string cutting mechanism is applied.

As an example, let us consider the pictures in Figure 3, again. The corresponding cutting lines along c-direction are shown in Figure 4(a) and 4(b). In particular, the picture 4(a) is segmented according to the extended cutting mechanism, since condition 1) is satisfied. The corresponding iconic index is:

c: A|AeB|A|A

s: A%B

On the contrary, the picture 4(b) needs no cutting lines and the iconic index is:

c: A%B

s: A%B

Figure 4 The cutting mechanism applied to the pictures of Figure 3 along the c-direction.

By applying the Atomic Relation Extraction Method, the corresponding virtual images are obtained. In particular, the picture 4(a) is represented by the following set of binary relations according to the c-direction:

$\{A_1|A_2, A_1|A_3, A_1|A_4, A_1|B_1, A_1|e, A_2|A_3, A_2|A_4, A_2=B_1, A_2=e, B_1=e, e|A_3, B_1|A_3, B_1|A_4, e|A_4, A_3|A_4\}$.

Then, by collecting the characteristic relations, the following set of atomic relations are derived: $\{A\%B, A\%e, B=e\}$.

Therefore, the virtual image corresponding to the picture 4(a) is:

$P = (Ob, Rs)$ where $Ob = \{A, B\}$ and $Rs = (Rs_c, Rs_s) = (\{A\%B, A\%e, B=e\}, \{A\%B\})$;

while the virtual image corresponding to the picture 4(b) is:

$P = (Ob, Rs)$ where $Ob = \{A, B\}$ and $Rs = (Rs_c, Rs_s) = (\{A\%B\}, \{A\%B\})$.

Note that each spatial arrangement where the first condition in the algorithm above is not satisfied, is covered by the 2D C-string mechanism, completely. As a matter of fact, Figure 5 describes two possible spatial arrangements along the c-direction, which do not satisfy the first condition. In particular, the image of Figure 5(a) requires a cutting line at the ending point of the object B, since B is dominating with respect to the object A. The corresponding iconic index is:

c: B|A|A

s: A%B

Figure 5 Two spatial arrangements which do not satisfy the first condition.

On the contrary, the image of Figure 5(b) does not require any cutting line, since B is totally disjoint from A. The corresponding iconic index is:

c: $B < A$

s: $A \% B$

In these cases no ambiguity arises during the reconstruction process, since the indexes describe the spatial arrangements of the objects A and B uniquely.

4 CONCLUSIONS

In this paper we have shown how the concept of virtual image may be extended to handle the case of images with concave objects. Previous approaches led to ambiguity. We are currently implementing a prototype image database system which will incorporate the methodology described in this paper.

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