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Image Indexing by Spatial Relationships between Salient Objects

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***Abstract*—In this paper, we presented our technique to extract and to use the spatial relationships between two or more salient objects. Using an object oriented hypergraph data structure, the spatial relationships are determined and stored in an object-oriented database. This work aims to unified the phases of processing, indexing and retrieval of images. The proposed model can be applicable to other types of data (video) and to semantic relations hidden in an image. The structure of the database used for image storage allow the construction of the indexes classes hierarchy in order to improve the results of image retrieval. Our method requires more experiments for datasets which come from different areas and for images which contain more salient objects.**

I. Introduction

GROWTH rate for multimedia information (image, audio, video, text) involves new approaches to the problem of information retrieval. This paper describes research done to build an object-oriented database that allows storage and content-based querying of images. The main goal of this work is spatial relationships-based indexing and querying of images using hypergraph data structure. The main steps needed to achieve this goal are (I) object-oriented approach to image processing; (II) use the syntactic features of the salient objects for spatial relationships determination; (III) indexing techniques for efficient content-based image retrieval with an object-oriented database. The technique proposed uses hypergraph data structures to determine and to store the spatial relationships between two or more salient objects. In the graph approach, the edges stores information about spatial relationships between only two neighboring objects. Using a hypergraph, we represent relationships among several salient objects detected in the image processing phase. In [1] was described a hypergraph-based image representation that considered Image Adaptive Neighborhood Hypergraph ($IANH$) model. Our object oriented model is based on an initial hexagonal representation of an image and hypergraph stucture is constructed on this representation. This method allows to assign semantics to an image and the developing of content-based query language for image retrieval. The object-oriented database is implemented on top of $HyperGraphDB$ ($HGDB$) [2]. The presentation will focus on salient objects detection, object-oriented image modeling of spatial relationships, query language and image indexing. Section II presents the technique for salient objects detection and the algorithms for determination spatial relationships between objects. Section III describes our proposed method for representation, storing, indexing and image retrieval. Section IV gives our experimental results and Section V concludes the paper.

A. Related Work

The concepts of spatial relationships can be grouped into three categories [3]: orientation relationships, distance relationships and topological relationships. The orientation relationships describe the relations between two spatial positions of visual objects. These relationships are established according to two basic concepts: salient object and reference object. Cohn et al. [4] provides a spatial distribution in terms of space used entities (regions) and ways of describing the spatial relationships between these entities (topological distance or direction). In [5] was presented a method to identify relations between two salient objects in images. They used spatial relationships to homogenize, reduce and optimize the representation of relationships with the 9–Intersection model proposed by [6]. An other approach, Δ–TSR (Triangle Spatial Relationships) [7] is used for similarity search in image database. In this research, image descriptions is based on co-occurrences of triplets of objects whose geometric relationships are encoded using the angles of the triangle formed by the objects. All these descriptions are invariant to rotation in $2D$, translation or scaling of the image. An extension of Δ–TSR is given in [8], where a B+ tree is constructed for all images by using the low level color feature and create multidimensional B+ tree by combining it with the B+ tree that we made it for symbolic images by using TSR. In $DISIMA$ project [9], the spatial relationships are modeled using for each salient object, the minimum bounding rectangle (MBR) whose projections are taken on the ox and oy axes. As indexing technique, are used $2D$–h tree [10], which is based also on B+ tree. In [11] are presented the main fuzzy approaches to define spatial relationships and comparative discussions. Such approaches are useful to express the linguistic terms as: $close$, far, $very$ $close$ and $very$ far. The problem of all these researches which are based on 2–D string representation is failure to take into account the all spatial relationships between objects (for example inclusion) and reference to pairs of neighboring salient objects. In this paper, these shortcomings have been overcome by using structures such as object oriented hypergraph.

II. Object Oriented Model for Representation of Spatial Relationships

The introduction of the hypergraph structure was in [12] and is a generalization of graph theory. The main idea refers to consideration of sets of edges and then a hypergraph is the family of these edges (called hyperedges). For the segmentation phase of the image processing processus, we use the hypergraph structure and a dual representation of images, as in Figure 1, hypergraph and forest tree.

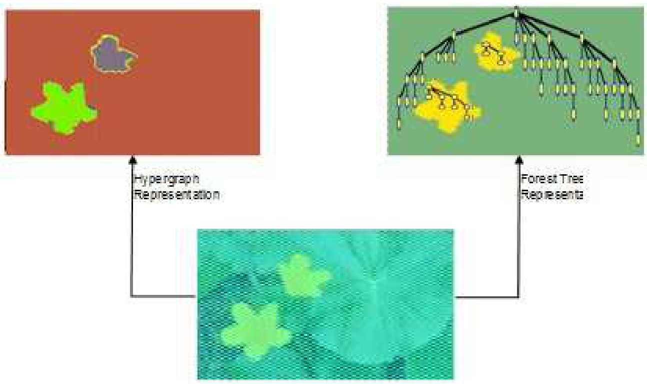

Fig. 1. Dual representation (hypergraph/forest tree) of image

This approach allows the implementation of the algorithm for minimum spanning tree for image segmentation [13] and construction, as a result of segmentation, of hypergraph which is used for all steps of image processing. The hypergraph data model and object-oriented model make join to define the spatial relations between regions from images and their features; the composite model is called hypergraph object-oriented model [14]. Depending on hypergraph structure the complex spatial relations can be described easily and the attributive data can also be integrated more efficiently. The object-oriented model allows to define the methods by which messages are exchanged between objects and to implement the inheritance mechanism which offers classes which have new definitions based on existing definitions.

A. Image Segmentation and Image Annotation

Useful information available after segmentation phase (syntactic information) are correlated with semantic data. These category of information are stored using object-oriented hypergraph ($HOOG$), that results from the processus of segmentation and annotation. Semantic information of each segmented region are assigned through a semi-automatic procedure for images that represent the set of training images, and for the rest of the images processed using an inference algorithm which is based on decision tree [15]. The structure of the $HOOG$ is based on instances of a set of classes that described the syntax and the semantic of image. Each class has three specific parts: a description of the list of attributes for each object, a semantic of object, and spatial relationships which give links between objects. The set of classes consists of two hierarchies: the first corresponds to data extracted from the training set of images resulted after the segmentation and manual annotation, and it is specific to the domain from which images came. The second hierarchy of class is generated automatically using attribute graph grammars results of the inference algorithm that takes as input the corresponding hypergraphs to the representative images of the domain. In both hierarchies, classes are divided into two categories: classes which refer to images syntax, respectively classes that relate to their semantics.

B. Spatial Relationships Determination

The first category of spatial relationships is used to describe the position of an object in image; representation often used to describe the absolute positions which are the cardinal points: north (N), south (S), east (E), west (W), north-east (NE), south-east (SE), north-west (NW) and south-west (SW). The space allocation of a $2\text{–}D$ image is divided it into nine zones, each zone corresponds to a cardinal point and middle zone is the center of the image. Each salient object is represented by the minimum bounding rectangle and center of gravity. Absolute position is determined by establishing membership of gravity center to the nine areas described above. The relative positions are calculated by comparing the coordinates of centers and frontier of the bounding rectangles of two neighbors salient objects. In a similar mode, that shown in Figure 2 for a spatial relationship of type $left/right$ are determined all relative spatial relationships.

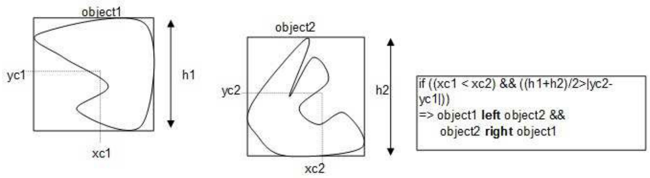

Fig. 2. Spatial relationship type left/right

Distance spatial relationships imply distance concepts between objects. As in the orientation relationships, in determining distance relationships are necessary the three basic concepts: the reference, the primary object and the reference object. Spatial relationships concepts specified above can be put in correspondence with pairs of salient objects, to determine whether or not they check those concepts. For this step, geometric inference, we use object-oriented hypergraph structure because can be model for semantic of each spatial relationship. For object-oriented hypergraph we propose the implementation of dynamic semantics of their through an algorithm similar to the $RETE$ algorithm from expert systems. After the processing phase (segmentation and annotation), each salient object resulted, O has the following information attached: dominant color, $color(O)$; hexagons list that forms the area of the object, $la(O)$; ordered list of hexagons that forms the border of the object, $lc(O)$ and $semantic(O)$. On the basis of lists $lc(O)$ and $la(O)$ are determined other attributes: the area of object, $area(O)$; the perimeter of the object contour, $perimeter(O)$; the center of gravity, $g(O)$; eccentricity, $e(O)$; compactness, $comp(O)$; the minimum and the maximum value of X coordinate of the pixel of the object, x–$min(O)$ and x–$max(O)$; the minimum and the maximum value of Y coordinate of the pixel of the object, y–$min(O)$ and y–$max(O)$. In addition, for two each pair of neighbors objects, $O1$ and $O2$, the algorithm of segmentation determines the common part of the contour, $cb(O1, O2)$. All these salient geometric features are represented by the group of local geometric descriptors that correspond to neighbors objects. In this stage of extraction of spatial characteristics is generated a dual hypergraph by creating hyperedge that store the relationships by neighbors objects. The result of processing algorithm is stored as a hypergraph whose nodes are represented detected areas and through the hyperedges are represented neighborhood relationships. The geometric properties specific to each detected object are available from the segmentation phase and are used as input for the algorithm of the dual hypergraph construction. Dual hypergraph structure can be defined as: HGs = (HNs, HEs), where HNs is the set of nodes created to show the spatial relationships by neighbors objects, and HEs is the set of hyperedges which makes connection between nodes with spatial information. The number of newly added nodes (spatial nodes) is equal to the number of hyperedges from the hypergraph obtained after segmentation image. The algorithm 1 is used to determine dual hypergraph.

The link between the initial hypergraph and the hypergraph corresponding to the spatial relationship is done through HE hyperedges that are referenced by HNs nodes. Dual hypergraph thus determined is used to complete the structure of indexes used in the indexing information in the database. Based on the information stored at each node of initial hypergraph (HG), the edges of dual hypergraph (HGs) are decorated with labels that are specifying the spatial relationship. For each topological relationship is using a rule based on a salient feature that enables the geometric relationship. Rules have been written using the $CLIPS$ language, which is a forward chaining rules-based system, built on the $Rete$ algorithm and which also supports the object-oriented programming paradigm - $COOL$ (CLIPS Object-Oriented Language). To determine the relations $Inside/Outside$, $Above/Bellow$ and $Left/Right$ were defined the following rules that are using geometric feature value corresponding to the common border of two objects $o1$ and $o2$:

Algorithm 1: The algorithm for constructing dual hypergraph

Input: Segmented and annotated image hypergraph
HG=(HN, HE)
Output: Dual hypergraph HGs
Procedure dualHGConstruction (HG; HGs);
* initialize HNs; initialize HEs;
for $i \leftarrow 1$ **to** $sizeof(HN)$ **do**
  $hn\_i \leftarrow$ node i from HN
  * determine the list of hyperedges HE_i for hn_i from HE
  * reset the list of nodes HN_ij
  for $j \leftarrow 1$ **to** $sizeof(HE\_i)$ **do**
    $he\_j \leftarrow$ hyperedge j from HE_i
    if $!find(he\_j, HNs)$ **then**
      * create node hn_ij
      * add hn_ij to HNs
    end
    else
      $hn\_ij \leftarrow$ find (he_j, HNs)
    end
    * add hn_ij to HN_ij
  end
  for $j \leftarrow 1$ **to** $sizeof(HN\_ij)$ **do**
    for $j \leftarrow j+1$ **to** $sizeof(HN\_ij)$ **do**
      * add hyperedge (hn_ij, hn_ik) to HEs
    end
  end
end

III. Image Storing and Representation Using Object Oriented Database

This section presents the structure of object-oriented database that is used to store and query semantic information obtained by $2D$ image processing. Object-oriented approach for representing information related to image processing provides a direct binding with object-oriented database scheme that will store combinations by the objects corresponding to the processed images. The choice of object oriented model for representing images is based on two arguments: first argument relates to the separation of structure of a class by its content, and the second refers to the specificity of each image that does not allow an implicit modeling using predefined data structures such as those used in relational databases. Relational model has several limitations in the representation of complex objects corresponding to an image. Looking on representation of data in relational databases, links between the two relationships are represented through foreign key type attributes in a relationship that refer to primary key type attributes in another relationship. Tuples that have the same values for foreign keys, respectively primary, those are logically linked, although they are not physically associated (logical references). In case of object model, relationships are represented by reference through an object identifier (OID - Object Identifier) which provides a structural association of tuples. On the other hand, object-oriented model, unlike the relational model, supports complex object structures with the possibility of using sets, lists or other complex data structures [16]. It also allows defining the methods by which messages are exchanged between objects and implements the inheritance mechanism that provides the possibility to have new classes definitions based on existing definitions. Given the complexity and variety of objects that may be finding within the scene of an image processed and the properties of object model above

```
(defrule Inside_r1_r2
    (= perim (r1) common_perim)
    =>
    ins (r1, r2)
)
(defrule Outside_r1_r2
    (<> perim (r1) common_perim)
    =>
    ots (r1, r2)
)
(defrule BelowAbove_r1_r2
    (< yc1 yc2)
    (> (w1+w2) |xc1 - xc2|)
    =>
    blw (r1, r2)
    abv (r2, r1)
)
(defrule LeftRight_r1_r2
    (< xc1 xc2)
    (> (h1+h2) |yc1 - yc2|)
    =>
    lft (r1, r2)
    rgt (r2, r1)
)

(defrule Inside_r2_r1
    (= perim (r2) common_perim)
    =>
    ins (r2, r1)
)
(defrule Outside_r2_r1
    (<> perim (r2) common_perim)
    =>
    ots (r2, r1)
)
(defrule BelowAbove_r2_r1
    (< yc2 yc1)
    (> (w1+w2) |xc1 -xc2|)
    =>
    blw (r2, r1)
    abv (r1, r2)
)
(defrule LeftRight_r2_r1
    (< xc2 xc1)
    (> (h1+h2) |yc1 - yc2|)
    =>
    lft (r2, r1)
    rgt (r1, r2)
)
```

Fig. 3. Rules for determining spatial relationhips

mentioned, in the paper was chosen the object-oriented model. Object-oriented modeling involves using instances of classes that are defined above and whose properties are defined by attributes and the communication between them is done through exchanging messages implemented by methods of classes. This approach of problems, based on algebraic, for collections of objects and relationships between them was taken by many researchers in studies and conducted implementations. The implementation from [17], Λ–DB is a database management system based on object-oriented database ($OODB$) based on standard $ODMG3.0$ [18]. In [19] was introduces a model for $OODB$ representation ($GOOD$ - Graph-Oriented Object Database) that is based on a graph data structure, operations on database objects translate into the transformation of the graph. Taking the approach used for image processing (segmentation and annotating), we use as kernel the database $HyperGraphDB$. The set of definitions of classes whose instances are intended to be serialized by the database compose the schema of $OODB$. In our case, the schema is divided in two hierarchy: the classes which refer the syntactic characteristics of images, respectively classes that relate to their semantics. The syntactic schema are indepedent from the image domain and is presented in Figure 4.

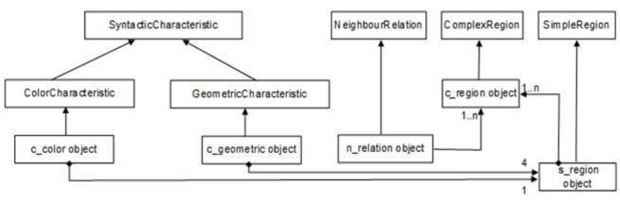

Fig. 4. Syntactic Schema for Object-Oriented Database

In the database there are two types of groups: at image level, respectively, at salient objects level. The first group contains information extracted from the whole image and allows queries that can be expressed as follows: "Find all images that have the same color with the specified image". The grouping of relevant objects level allows queries of the form: "Find all images that contain objects $O1$, $O2$ and between $O1$ and $O2$ exists spatial relationship R". For both types of queries we need a semantic schema. An example of semantic schema to represent the information of images which came from the soccer domain is presented in Figure 5.

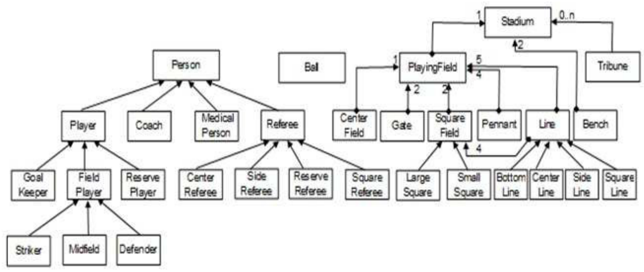

Fig. 5. Example of Semantic Schema for Object-Oriented Database

A. Image Indexing and Image Retrieval

Indexing problem is approached using graph theory, the indexing relationship is represented by indexes allocated within classes and forming a directed graph. Other approaches [20] refer to the database schema, thus the necessary time for the selection of optimum index is of high complexity. Based on the database scheme, developed a new approach to the problem of indexing by exploiting the graphical structure. Index information are used as the OID related to the objects in the database; we use as index information, the spatial relationships of salient objects. In figure 6 is presented the structure of node which corresponds to a region. The field $active$ is a

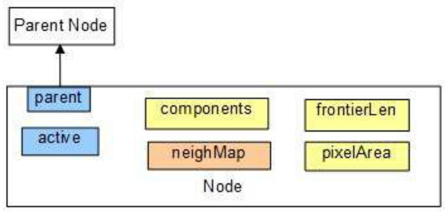

Fig. 6. Indexing Node Structure

boolean value specifying if the corresponding region is the root of a tree representing a salient object. The rest of fields are used only if the field $active$ is true. The attribute $parent$ represents the index of the salient object which is the parent of the current region. The field $components$ is a list of indices of the pixels belonging to the associated region. The attributes $frontierLen$ and $pixelArea$ represent the length of contour region and respectively the value of area region. The field

$neighMap$ is a $hashMap$ instance which store all the spatial relationships between current region and all neighbors regions. The elements of the attribute $neighMap$ are extracted from dual hypergraph determined with the algorithm 1. The nodes are organized in a tree with links up and $spatialRel$; the reference for up link is given by $parent$ attribute and the $spatialRel$ references are given by instances of the hyper-edges objects from dual hypergraph. This dual representation of data, through a tree and through an hypergraph, allows the construction of dual indexes. The first type of indexes refers to the runtime necessary query indexes and is based on tree structure. The second group of indexes are the indexes used by the $OODB$ and is based on hypergraph structure. Choosing hypergraph to represent indexes was made because this type of structure is a good framework for query processing and the information retrieval corresponding to processed images.

Image retrieval systems have been developed using a variety of technologies based on various disciplines of computer science. The development of new technologies has emerged the possibility of improving existing retrieval systems. Thus, is the case of using concepts of object-oriented programming for recognition objects. Using the object model for storing images is based on complex and different structure of each image that does not allow a simple data model that uses predefined data structures such as those used in relational databases. We develops an interpreter that translate the semantic queries based on symbolic language in $SPARQL$ (Protocol and RDF Query Language) query language [21]. To define the symbolic language we use as the lexical atoms, the concepts of domain corresponding to the annotation process and the elements which corresponds to the spatial relationships. The interpreter generate $SPARQL$ corresponding to the symbolic query, which are specific only to the $SELECT$ operation.

IV. Experiments

The experimental results demonstrates that the method produces a good image processing, an indexing of image and an optimal retrieval of the visual objects from different images. We used for experiments the $jpegs$ files of $TRICTRAC$ dataset [22]. The images of the dataset refers to progressive image in $jpeg$ format for synthetic video sequence of soccer. The specification of query assumes a simple graphical interface enabling the introduction of symbolic language query and view images obtained as a result ordered by the metric value that determines the distance between the query and response. The metric value determines intrinsic information in accordance with [23] and involves determination of the distance between hypergraph-query and each hypergraph corresponding to each image obtained. The translation from semantic query to a format accepted by the database, it requires a complex transformation. The first part of query processing done in the format switch $HGOQL$ symbolic language; in phase two, $HGOQL$ query is transformed into a $SPARQL$ query, which allows implementation of structural matching algorithms graph type. A $SPARQL$ query that corresponds to the initial query "$player\ inside\ red\ square$" (search for all images where a player in red is inside square) is shown in Figure 7.

```
SELECT  ?hgImage
FROM    hgSoccerDb
WHERE   {
        ?p Player (?c ColorAtribute);
        ?s Square;
        ?p INSIDE ?s;
}
FILTER eq(?c,"red");
```

Fig. 7. Example of SPARQL query

The query in $SPARQL$ format has three components: selection operator $SELECT$ clause corresponds to the specific database, the $WHERE$ clause specifies criteria for selecting the hypergraph objects within the database and allows the results restriction $FILTER$. In the example, in the set of results should be included only images that contain a player in red and is in the square. A subset of the images obtained are shown in Figure 8.

Fig. 8. Image results of semantic query

V. Conclusions

This paper presents the algorithms for image processing, indexing and retrieval which are based on hypergraph data structure. The image processing implies the segmentation and annotation of the salient objects from the image. Using an object oriented hypergraph data structure, the spatial relations are determined and stored in an object-oriented database. This work aims to unified the phases of processing, indexing and retrieval of images. The kernel database used for experiments is the $HypergraphDB$, an object-oriented database, which allows to add modules for indexing and retrieval visual information. The results of the experiments on the $TRICTRAC$

dataset show that using object-oriented database allows storing and retrieving of complex objects within images. The future work implies the using of the hypergraph theory with the goal of searching and retrieving complex images based on the complex query formulated in a symbolic language.

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