# An Image Retrieval Method Using Inquiries on Spatial Relationships

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People often want to retrieve images by referring to pictorial features rather than a bibliographic index. For example, "find a person's picture with Mt. Fuji in the center" requires that the language query match the pictorial arrangement. This paper proposes a two-dimensional image retrieval method based on the assumption that objects in an image are extracted as polygons. The method uses natural language words referring to spatial relationships between objects in an image as queries, and the objects coordinates as pictorial indexes. First, the problems of spatial relationships are discussed. Next, a proposal is made to represent the spatial relationships together with their fuzziness by using the coordinates of the objects in rule representation form. Our method is implemented in a spatial relationship-based feature retrieval/description system (SPADE). Examples of two SPADE databases, one containing Japanese "ukiyoe" images and another containing document images, are discussed.

## 1. Introduction

Database (DB) retrieval has become widely known as a result of many published studies on the subject. The methods used include natural language queries and query understanding by questions and answers [1]. Multi-media DBs include pictorial information, such as photographs, figures, and tables. People often want to retrieve images from multimedia DBs by referring to pictorial arrangements rather than a bibliographic index. For example, the query "find a person's pictures with Mt. Fuji in the center" contains as retrieval information not only the author's name but also a description of Mt. Fuji's location.

Images contain more information than that explicitly given in a text. Various types of indexing image data have been proposed.

1. Key words representing the pictorial features are indexed in image data. Images are retrieved by means of these text key words, in the same way as documents.
2. Abstract pictures are used as image DB retrieval indexes. Images with structures similar to the abstract pictures are retrieved.
3. Image processing features such as run length are used to classify the image data [2, 3].
4. Qualitative words such as "elegant" and "cute" are used to represent an image's characteristics. An image corresponds to points in a space formed by the dimensions of the characteristics. The quantified values are used to index the image data.

An image retrieval method requires pictorial arrangement indexing of the image data and an interface method that includes query understanding.

SPADE retrieves images by referring to a bibliographic index. It also takes account of the attributes of the objects and the spatial relationships between them. Several retrieval systems have used spatial relationships as image data indexes. PROBE [4] models spatial objects by using a mathematical abstraction called POINT-SET. The spatial relationships between objects are obtained by POINT-SET operations and are used to retrieve data. IIB [5] uses 2-D strings, which are orthogonal relations between objects. These orthogonal relations are defined in terms of minimum enclosing rectangles. However, PROBE and IIB both treat spatial relationships as geometrical ones.

Spatial relationships have been dealt with in some studies that combine symbol and image data [6, 7]. Takagi et al. [8] generated sentences from a picture by representing pictorial data in table form (which is commonly used to represent language data). Their study specifies the geometrical relationships between objects in a pictorial image.

Spatial relationships in everyday life are different from geometrical ones. They have a fuzziness to which they correspond. To retrieve images by using spatial relationships as data indexes, it is necessary to represent the fuzziness and match the spatial relationships involved in the query with the pictorial arrangement.

In this paper, we propose a two-dimensional image retrieval method that retrieves images by using the

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spatial relationships between objects as well as a bibliographic index. This method uses polygonal vertex coordinates as pictorial indexes, based on the assumption that an object in an image can be extracted as a polygon by image processing techniques. The user asks a query in natural language containing the spatial relationships. Although the fuzziness in the relationships makes accurate image identification difficult, SPADE supports spatial reasoning and imge data retrieval.

In the next section, we discuss the fuzziness of natural language spatial relationships and their representations. We then define a lexicon of spatial relationships in representation rule form, and describe SPADE and two experimental DBs-an "ukiyoe" DB consisting of 32 images of Japanese woodblock prints, and a document image DB consisting of 66 front pages of scientific papers.

## 2. Problems of Spatial Relationships

Generally speaking, a spatial relationship word is defined by using other spatial relationship words. For example, in the Oxford Advanced Learner's Dictionary of Current English, the spatial relationship "right" is defined as "of the side of the body which is toward the east when a person faces north," using the other spatial relationships "east" and "north." It is difficult to formalize spatial relationships and represent them in a computer. The spatial relationship representation is one of the major problems in artificial intelligence [9].

Typical problems involved in spatial relationships are as follows:

1. Fuzziness accompanies spatial relationships, which bridge image data and natural language words. Image data are quantitative and language data are qualitative.
   1) The following are satisfied when A is "right" of B.
      a) An object A is to the right of a straight line passing through an object B's center.
      b) Objects A and B are not in contact with each other.

Even if conditions a) and b) are satisfied, the relationship between object A and object B is sometimes referred to as an "up" relationship rather than a "right" one [10]. (Fig. 1)

   2) A psychological "inside" relationship between objects is different from a geometrical one. An object that is geometrically "outside" another concave object may be considered psychologically "inside." [11]

2. Spatial relationships and natural language words do not correspond on a one-to-one basis.
   1) The same word, for example, "right" may be used in two different ways. One describes a spatial relationship that directly refers to an object's location; for example, "A is 'on the right.' " The other is a relative relationship in which the object's location is described with reference to another object, for example, "A is 'right' of B".
   2) The Japanese word "ue" indicates the spatial area covering the English words "on," "over," and "up." The same spatial relationships are referred to in a different way according to the natural language used.

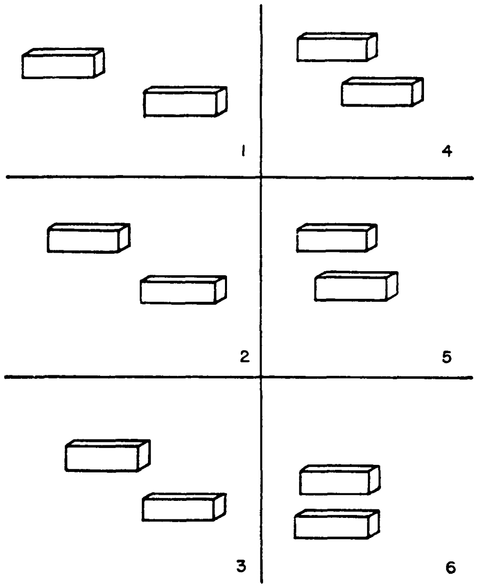


Fig. 1 Vagueness in spatial relationships [10].

3. Not only the positions of the objects but also their surroundings influence the spatial word selection process.
   1) The selected word depends on one of several directions—the direction that the object itself has, the direction that the object's arrangement determines, or the direction that the viewer has.
   2) The selected word describing a relationship between two objects may change when a third object appears.
   3) The selected word describing a relationship between two objects changes according to the semantic content of the image. "Down" relationships in a two-dimensional image may be referred to as "south" relationships in a map or as "in front of" relationships in a three-dimensional landscape image.

The fuzziness in 1.1) and the correspondence between spatial relationships and natural language words in 2. become problems for two-dimensional image retrieval, as will be discussed in the next section.

## 3. Rule Representation

In this section, we will discuss two kinds of spatial relationships. The first are geometrical quantities or relationships such as the coordinates of an object's center and the distance between two objects, which are geometrically calculated from an object's shape by approximating a polygon. The second are natural language words, such as "up," "down," "right," and "left," which are qualitative. We propose a lexicon of spatial relationships. With this lexicon, the geometrical relationships and the qualitative relationships are bound by the if-then rule, and the fuzziness of the relationships is represented by membership functions that have physical quantities.

### 3.1 Representation of Fuzziness

Representing fuzziness in spatial relationships is necessary in order to retrieve images by their pictorial features.

(1) Fuzziness in spatial relationships

Spatial "right" ness was measured by subjective experiments. The results of the experiments show a common feature—that the nearer or the more horizontal the objects are, the more spatially right they are, even though the "right" ness varies according to the person being tested [12].

(2) Exclusiveness of spatial relationships

"Left" relationships and "up" relationships are different, but may be interchangeably used for some object layouts. In Fig. 1, for example, the spatial relationship between two objects changes from "left" in 1 to "up" in 6. In 3 and 4, both "left" and "up" relationships seem to hold.

The degree of fuzziness in spatial relationships is represented as a heuristic function of geometrical quantity. Figure 2 shows an example of rule representation and a heuristic function of spatial "right" ness. The function's value increases to 1 as the degree of "right" ness increases.

### 3.2 Correspondence between Geometrical Relationships and Natural Language Words

The spatial concept varies with the employed natural language; for example, the Japanese word "*ue*" (Japanese words are printed in italics in this paper) means "on," "over," and "up" in English. We assume a layer of spatial relationships; this layer is independent of natural languages. Therefore, when considering the relationships in this layer as basic ones, we represent the correspondence between the geometrical relationships and the natural language words in rule representation form.

"*A no ue ni B ga aru.*" involves the relative spatial relationship *ue*(A, B). *Ue*(A, B) is defined as the OR (disjunctive form) of two basic relationships: r-ue1 and r-ue2. R-ue1 (A, B) corresponds to "above" and assumes that object A is not contacting object B. R-ue2 (A, B) corresponds to "on" and assumes that object A is contacting object B. "Upper-right" is defined as a relationship combining "up" and "right." We assume three

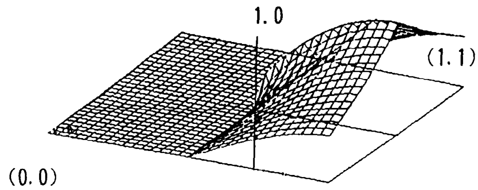
```
Spatial right:
if ( a's left end is in the right half-plane)
      then (a is right )
           with  fuzziness( a )
             where
```

$$s(a) = (-3r^2+3r+0.25)*(1-\theta\frac{2}{\pi})$$

r : distance between a's center and the plane's center

$\theta$ : azimuth between a's center and the plane's center

(a) Defintion rule




(b) Fuzziness function defined as heuristic

Fig. 2 Representation of spatial "Right".

types of combination forms—AND, OR, and COMBination—to express the spatial relationships. Figure 3 shows the hierarchy of spatial relationships.

### 3.3 Fuzziness of Combined Relationship

The fuzziness of a combined relationship reflects the fuzziness of the individual relationships used to define the combination. For AND and OR, the Min and Max values of fuzziness are used, respectively, to evaluate the combined fuzziness. This is the same as the method employed in MYCIN to calcualate the certainty factor (CF) [13]. MYCIN's COMB combines two pieces of evidence to infer a fact. The two pieces of evidence are assumed to be independent of each other. MYCIN's combination function gives the estimated value as 1 when the CF value of one of the pieces of evidence equals 1.

The spatial relationships "right" and "up" are not necessarily exclusive relationships, on account of their fuzziness. Therefore, the more "right"ness or "up" ness increases, the more "upper-right"ness increases. However, an object whose "right"ness equals 1 does not necesarily have an "upper-right"ness of 1.

SPADE uses the COMB combination function, which has the following characteristics:

1. The fuzziness of a combined relationship becomes 1 when the fuzzines of both defining relationships is equal to 1.
2. The fuzziness of a combined relationship changes monotonically according to the fuzziness of the defin-

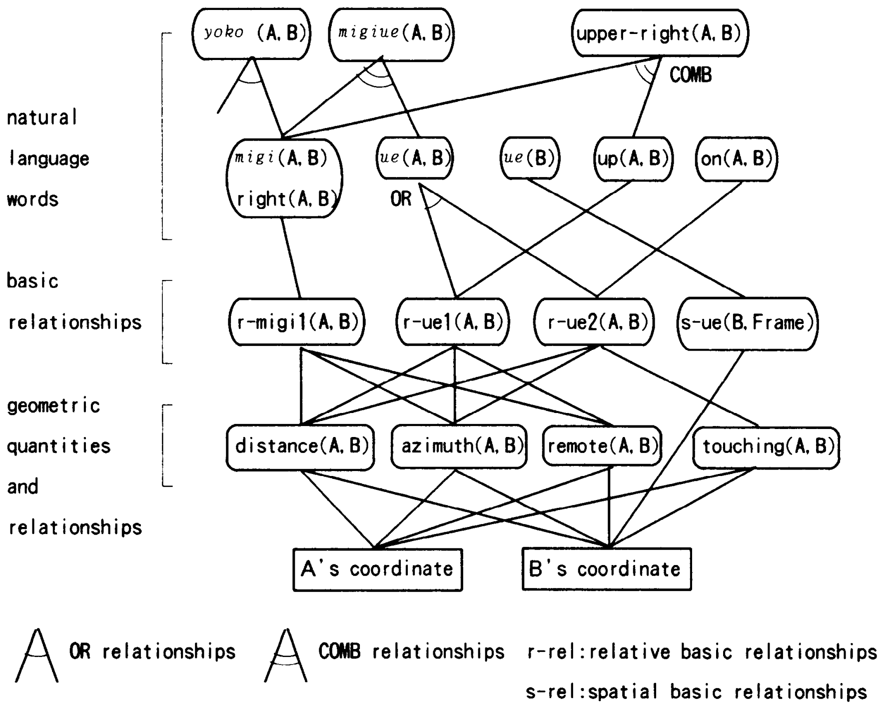



Fig. 3 Hierarchy of spatial relationships.

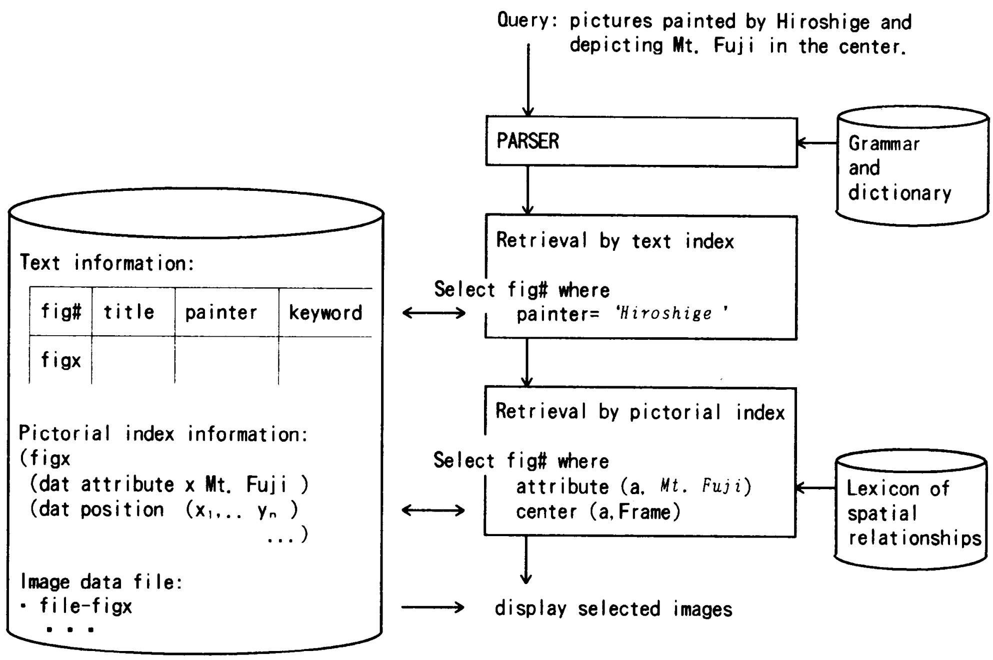



Fig. 4 SPADE system configuration.

```
(defrel comment
  (definition (rel <level> defining name (object list)
      <= (conditions)
          (fuzziness function))
  conditions::=
      (and  { <spatial relationships> | <attribute> | <test-type> } ) |
      (or   { <spatial relationships> | <attribute> | <test-type> } ) |
      (not    <spatial relationships> | <attribute> ) |
      <spatial relationships> | <attribute> | <test-type> | <bind-type> ) |
  spatial relationships ::=(rel <level> name (object list)  {(value) } )
  attribute ::=(dat  attribute object attribute-value)
  test-type ::=(test S-expression)
  bind-type ::=(bind variable  S-expression )
```

(a) Expression rule of spatial relationships

```
(defrel definition of spatial right
  (definition (rel 2 sright (?A))
      <= (and (rel 1 distance1 (Frame ?A) (?Distance))
              (rel 1 azimuth1 (Frame ?A) (?Azimuth1))
              (rel 1 azimuth3 (Frame ?A) (?Azimuth3))
              (test (and ( <= ?Azimuth3  half-pi)
                         ( <= minus(half-pi)  ?Azimuth3)))))
         (cf-calc (* (+ (* -3 ?Distance (- ?Distance 1))(/ 4))
                     (- 1 (/ (abs ?Azimuth1)  half-pi)))))
```

(b) An example of 'spatial right' definition

```
(defrel definition of "upper-right"
    (definition (rel 3  upper-right (?A ?B))
        <=     (rel 3  up (?A ?B))))
(defrel definition of "upper-right"
    (definition (rel 3  upper-right (?A ?B))
        <=     (rel 3  right (?A ?B))))
    •
(defrel definition of "fumoto"
    (definition (rel 4  fumoto(?A ?B))
        <= (and  (rel 3 shita (?A ?B))
                 (dat attribute ?B  yama))))

(defrel definition of "three-column style"
    (definition (rel 4 three-column style  (  ) )
        <= (and  (dat attribute ?A  text)
                 (dat attribute ?B  text)
                 (dat attribute ?C  text)
                 (rel 2 aida (?C (?A ?B)))))
```

(c) Examples of other spatial relationships

Fig. 5 Examples of spatial relationship definition.

ing relationships.

3. The fuzziness of a combined relationship is less than those of the defining relationships.

$$s(\mathrm{comb}(x, y)) = \frac{s(x)+s(y)-\lambda\cdot s(x)\cdot s(y)}{2-\lambda}$$

$S(rel)$ means the degree of relationship *rel*'s fuzziness, and $\mathrm{comb}(x, y)$ is a COMB combination of the relationship between $x$ and $y$. $\lambda$ is heuristically determined from $0<\lambda<1$.

## 4. An Image Retrieval System (SPADE)

### 4.1 Overview of the System

SPADE is implemented on SUN 3 in LISP. Figure 4 shows the SPADE system configuration. The image DB consists of the following information:

1. Text information: bibliographic indexes of painters' names, picture titles, and key words, are stored in a relational DB.

Table 1 Japanese spatial relationships defined in SPADE.

| Level | Sub-level* | Defined quantities and spatial relationships |
|---|---|---|
| Geometric quantities and relationships | | |
| | Object's quantities (10) | list of vertex coordinates, list of edges, area and center coordinates of a polygon, radius of a circle circumscribing a polygon, leftmost (rightmost, highest, lowest) vertex coordinates, ratio of a polygon's length to its breadth |
| | Quantities & relationships between objects (11) | distance between objects' centers (distance1)**, shortest distance between objects, azimuth between object A's center and object B's center (rightmost, leftmost, highest, lowest) vertex (azimuth1 ~ azimuth5)**, remote, overlapping, touching containing |
| Basic relationships | | |
| | Spatial relationships (8) | up[s-ue]***, down, left, right, center, right-end, left-end, corner |
| | Relative relationships (17) | up[r-ue1, r-ue2, r-ue3]****, down, left, right, far, near, along, between, among |
| Natural language (Japanese) words | | |
| | Spatial relationships (11) | *ue, shita, hidari, migi, migi-ue, migi-shita, hidari-ue, hidari-shita, migi-hashi, hidari-hashi, yoko* |
| | Relative relationships (15) | *ue, shita, hidari, migi, kasanari, rinsetu, sesshoku, tooi, chikai, ue-ni-notte-iru, haruka-ue-ni-aru, temae, fumoto*, two-column-style, three-column-style |

Japanese words are types in *italic* style.
*a number in ( ) indicates the number of defined quantities and relationships.
**a notation in ( ) is the same as in Fig. 5.
***a notation in [ ] is the same as in Fig. 3.
****the same three kinds of relationships are defined for 'down,' 'left,' and 'right'.

2. Pictorial index information: the arrangement of objects in a picture is stored in a list of polygonal vertex coordinates and attributes.
3. Image data: image data are used to display the retrieved images.

Text information and pictorial index information are normally input by an operator using a keyboard or a mouse. They can be automatically indexed for specific images [14].

The PARSER program analyzes natural language queries; this involves both bibliographic text information and spatial images of objects in SQL-like form.

SELECT pictorial index part FROM
WHERE the images (SELECT text index part)

The bibliographic index contains no ambiguity. Retrieval from the relational DB is done first by using text information as an index. Next, retrieval from the selected images is done by pictorial arrangement.

```
" yama no fumoto ni kawa no aru .."

  after PARSER
    → (attribute  ?x yama)
      (attribute  ?y kawa)
      (fumoto ( ?x  ?y ))

  reasoning using a lexicon of spatial relationships
    (fumoto ( ?x  ?y ))
    ← (and (shita (?x ?y))
           (attribute ?y yama ))

    (shita (?x ?y))
    ← (and (remote (?x ?y))
           (test (and ( < minus(pi)  azimuth(?x ?y))
                      ( < azimuth(?x ?y)  0 ))))

    → (attribute  ?x yama)
      (attribute  ?y kawa)
      (and (remote (?x ?y))
           (test (and ( < minus(pi)  azimuth(?x ?y))
                      ( < azimuth(?x ?y)  0 ))))
```

Fig. 6 Examples of spatial relationships using backward reasoning.

### 4.2 A Lexicon of Spatial Relationships

The spatial relationships referred to in a query are defined by the polygonal vertex coordinates. Figure 5(a) shows the representation rule and Figure 5(b) shows a definition example of "spatial right" and its heuristically defined fuzziness. Figure 5(c) shows the spatial relationship "upper-right" as a combination of "up" and "right," and definitions of "*fumoto*" ("at the foot of a mountain" in English) and "three-column style." "*Fumoto*" and "three-column style" involve the semantics of the image's content: "*fumoto*" is used only in landscape pictures and "three-column style" is used only in printed documents.

Table 1 shows the spatial relationships defined in SPADE. Taking the extent of the objects into consideration, twenty-one kinds of quantities or geometrical relationships are defined. Twenty-five kinds of basic relationships are defined as basic qualitative spatial relationships with their fuzziness. Spatial up/down, relative right/left, and far/near are involved in this basic relationship level. Twenty-six spatial relationship types dependent on image content are defined as relationships used in queries. Natural language words such as "*temae*" ("in front of"), "*fumoto*," and "three-column style" are also involved.

### 4.3 Retrieving Procedure

The retrieval of images from DBs involves using text indexes and pictorial indexes.

Step 1: Retrieving by using a text index

Retrieve an image DB by specifying an object's attributes involved in queries such as a picture title and


Fig. 7 Retrieval by SPADE from an Ukiyoe image database.

the painter's name.

Step 2: Retrieving by using a pictorial index

Match the spatial relationships involved in queries with polygonal vertex coordinates, which are used as pictorial indexes. Apply the if-then rules defining the spatial relationships backwards, and select the images satisfying the specified spatial relationships.

Step 3: Displaying the selected images

Display the selected images with their identification numbers and the estimated degree of fuzziness of the relationships.

An image query such as "*yama no fumoto ni kawa no aru e*" ("a picture with a river running by the foot of a mountain") is parsed into a conjunctive of three relations.

attribute ($X$, mountain)
attribute ($Y$, river)
*fumoto* ($X$, $Y$)

The spatial relationship *fumoto* is made into a spatial relationship *shita* and attribute information. The resultant conjunctive form of the relationship is used to retrieve an image from the DB (Fig. 6).

The PARSER in SPADE parses a query into an SQL-like form without semantic interpretation. For exam-

(a) (b)

Fig. 8 Examples of Ukiyoe images retrieved by SPADE.

ple, a strange query such as "*ie no fumoto ni kawa no aru e*" ("a picture with a river running by the foot of a house") is transformed into an SQL-like form. The resultant conjunctive form contains conditions under which the object has two different attributes: attribute ($X$, *yama* ("mountain")) and attribute ($X$, *ie* ("house")). No image is retrieved with strange queries like this.

### 4.4 Examples and Discussion

Figure 7(a) shows SPADE's windows. Queries are input in the main window on the right. In the lower-left window, the identification numbers of the retrieved images are displayed with the calculated fuzziness values. In the upper-left window, the image is displayed.

Using the lexicon of spatial relationships, SAPDE infers spatial relationships involved in queries backwards, and creates relevant spatial relationships. The spatial relationships inferred thus far are used to retrieve images as original pictorial indexes. SPADE provides some commands that can be used to store the inferred spatial relationships as indexes or to browse through them.

1. Ukiyoe DB

The Ukiyoe DB consists of 32 images of Japanese woodblock prints. The pictorial index of an ukiyoe image is created by an operator. The operator selects the vertices of polygons, which approximate objects in the image.

[Example 1] Three ukiyoe images are retrieved by inputting "*Fujisan ga chuuou ni aru e*" ("pictures with Mt. Fuji in the center"). One of them is displayed in the upper-left window of Fig. 7(a). The other two are shown in Fig. 7(b).

[Example 2] Two ukiyo images are retrieved by inputting "*Hiroshige no e de, hashi ga Fujisan no temae ni aru e*" ("pictures by Hiroshige in which a bridge is in front of Mt. Fuji"). The query contains bibliographic information (the author is Hiroshige) and a relative spatial relationship (a bridge is in front of Mt. Fuji). The retrieved ukiyoe images are shown in Fig. 8.

In the above examples, the retrieved ukiyoe images satisfy the queries. The ukiyoe image in Fig. 8(b), however, is not retrieved as an image in which Mt. Fuji is in the center [Example 1]. This suggests a problem as to how to estimate the pictorial feature retrieval factor of image DBs.

2. Document Image DB

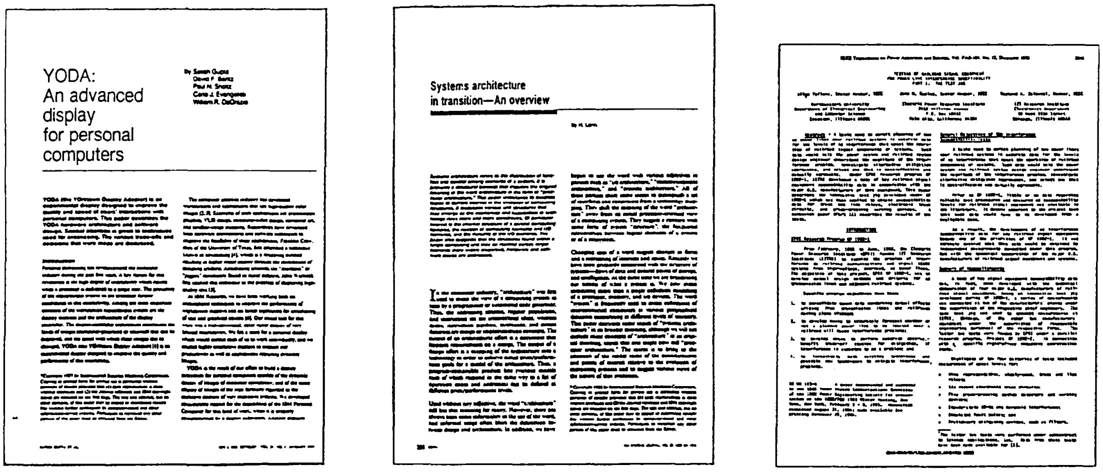
The front page of the document contains a variety of bibliographic information such as the title, author(s), and key words. This information can automatically be extracted from a front page's image by using layout knowledge [14, 15]. The document image DB consists of front pages from 66 different scientific journals.

[Example 3] Three images are retrieved by "*chosha ga taitoru no migi ni aru bunken*" ("a paper in which the name(s) of the author(s) appear(s) on the right of the title"). They are shown in Fig. 9.

The papers in Figs. 9(a) and (b) satisfy the query. In the paper in Fig. 9(c), "the name(s) of the author(s) appear(s) under the paper's title"; therefore, "under" is a better choice than "right." The last image was retrieved because SPADE matches the title area individually to each author area, whereas a human man would consider the entire area.

## 5. Conclusion

This paper has proposed methods of representing two-dimensional spatial relationships and retrieving pictorial features. The spatial relationships are represented by if-then rules and fuzziness in relationships by a heuristic function of vertex coordinates. The spatial relationships involved in the queries were matched with the vertex coordinates, which are pictorial


YODA:
An advanced
display
for personal
computers

Systems architecture
in transition—An overview

(a) (b) (c)

Fig. 9 Examples of document images retrieved by SPADE.

indexes of image DBs, by inferring backwards from the if-then rules. We showed the possibility of retrieving pictorial features through examples of an ukiyoe image DB and a document image DB.

The semantic interpretation of situation-dependent spatial relationships and an estimation method for retrieving image DBs by pictorial features remain subjects for further research.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