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Imagery and Classification

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SUMMARY

Research in cognitive psychology has suggested that images can be represented in terms of the spatial relationships of their meaningful parts. This paper discusses a technique for knowledge representation that captures both the spatial and descriptive features of an image. This formal technique can be used to construct a theory for class determination that involves pattern matching a depictive representation of an image with reconstructed images of known classifications.

1. MENTAL IMAGERY

Mental simulations can provide insights that contribute to effective problem solving techniques. Einstein stated that his abilities did not lie in mathematical calculations but in "visualizing ..., effects, consequences and possibilities" [1]. The statement ''pairs of adenine residues whirling in front of my closed eyes'' was reported by Watson at a time when he and Crick were on the verge of solving the genetic code [2]. Similarly, the German chemist Kekule reported that it was spontaneous imagery that led him to the discovery of the molecular structure of benzine [3]. Researchers in many areas, including artificial intelligence and cognitive psychology, are attempting to understand the processes involved in mental imagery. Toward this understanding, both cognitive and computational models of imagery are being constructed. Although imagery has been defined in many ways, for the purposes of this paper we interpret it as the ability to construct and reason about images in creative and unique ways.

Cognitive psychology research has long been concerned with the mental processes involved in imagery [4,5]. Numerous experiments have been carried out to determine how human subjects represent and manipulate images. The approach to knowledge representation considered in this paper is based on some of the underlying principles of mental imagery resulting from these experiments. These principles include the notions that: images are represented spatially; complex images are organized as hierarchies of parts [6,7]; images may be represented and manipulated in three dimensional space; imagery is affected by knowledge of the domain; and that imagery involves both sequential and parallel processing.

2. DEPICTIVE AND DESCRIPTIVE INFORMATION

An ongoing debate in cognitive psychology involves whether an image is represented descriptively in terms of propositions or as a distinct domain where an image is organized as a depiction of its meaningful parts. The descriptive approach to representing images is appealing since it provides an abstract representation without significant loss of information. Although this representation is sufficient, it has been argued that it may not always be the most desirable. By studying the way that people make inferences concerning spatial relationships, Kosslyn has argued that mental imagery is used extensively and that the processes involved use both

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descriptive and depictive representations of images [5].

In our approach to classification we assume that images are represented using both depictive and descriptive information. For example, if we were representing an image of a house, knowledge such as the color and address of the house could be stored descriptively as propositions, whereas the meaningful parts of the house and their spatial relationships to one another could be represented as a depiction. Illustrations of how this is achieved using symbolic arrays and a frame data structure are presented in the next section.

3. KNOWLEDGE REPRESENTATION

A primary characteristic of a good formalism for knowledge representation is that it makes relevant concepts explicit. Thus to depict the spatial relationships of an image, we use an embedded, multi-dimensional array realization [8]. We refer to such an array representation of an image as a symbolic array, where the symbolic elements of the array denote the meaningful parts of an image. For example, a view of a house might be represented as the symbolic array:

roof	roof	roof
window		
	door	

where door, window, and roof are the meaningful parts of the image of the house. The symbolic array representation is typically three dimensional and viewer independent, but transformation functions such as *rotate, translate*, and *project* allow an array depiction of an image to be viewed from a variety of perspectives. For example, applying a rotation function to the depiction of the house above would result in a view from a different angle. These functions and others will be summarized later in the paper.

Hierarchical organization is a fundamental aspect of imagery. Theories of attention suggest the need for an integrated spatial/hierarchical representation: when attention is focused on a particular feature, the brain is still partially aware of other features and their spatial relation to the considered feature. Our symbolic array representation supports such theories by considering an image as a recursive data structure: a symbolic element of an array can itself denote a subimage. Consider the example of the house above. The symbol for door could itself evoke a symbolic array depicting the details of the door. This image could be depicted as a symbolic array embedded in the array for house. A *focus* function can shift attention to a particular component of an image.

As discussed in the previous section, we wish to include both descriptive and depictive knowledge in our representation for an image. To facilitate this we use a frame data structure in our implementation. In the long-term memory model (database) representation for an image, the depiction is stored as a description of the locations of the parts within the image as illustrated below.

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FRAME: house		
isa:	image	
parts:	roof	(0 0) (0 1) (0 2)
	window	(1 0)
	door	(2 1)
color:	blue	
address:	1 Hopkins Place	

The procedural attachment facility of frames allows us to generate the symbolic array "as needed" from the descriptive representation. This is performed by a *retrieve* function. Since a frame also supports hierarchical structure, we can also use it to support the parts hierarchy for the depictive representation. In the house example there might also be a frame for the image of "door".

Merely storing these symbolic array representations is not sufficient. We also need to define and implement functions that operate on these representations and that correspond to processes involved in mental imagery. We have mentioned some functions already (*retrieve, focus*, and some transformation functions). As shown below, fourteen primitive functions on symbolic arrays have been developed [8], falling into three categories based on type of operation they perform on images: construction, transformation, and access. The functionality of these operations was greatly influenced by Kosslyn's computational model [5]. These functions can also be categorized as either generic or domain-specific. Generic functions operate on symbolic arrays of any dimension and interpretation. These include the construction functions *construct, compose*, and *symop*; all transformation functions; and access functions *find* and *focus*. Implementation of the remaining, domain-specific functions rely on a particular domain of interpretation. The primitive functions have been implemented in the Nested interactive array language, Nial [9].

Functions on Symbolic Array Representations

Category	Name	Operation
Construction	Retrieve	Retrieve image representation from long-term memory.
	Construct	Construct symbolic array depiction of image from descriptive representation.
	Compose	Compose two images into single complex image with given spatial relationship.
	Symop	Use symmetry information to retrieve regularities in image.
	Resolve	Use pattern matching information and world knowledge to transform image into one of higher resolution.
	Compare	Compare images and determine similarity measure.
	Consistent	Determine if image is consistent with world knowledge.
Transformation	Rotate	Rotate array depiction of image specified number of degrees around one of axes.
	Translate	Translate position of component within symbolic array.
	Zoom	Increase or decrease apparent size of depiction of image.
	Project	Project three dimensional array onto two dimensions.
Access	Find	Scan depiction of image to determine location of component.
	Focus	Shift attention to particular component of image.
	Query	Retrieve propositional information from array depiction of image.

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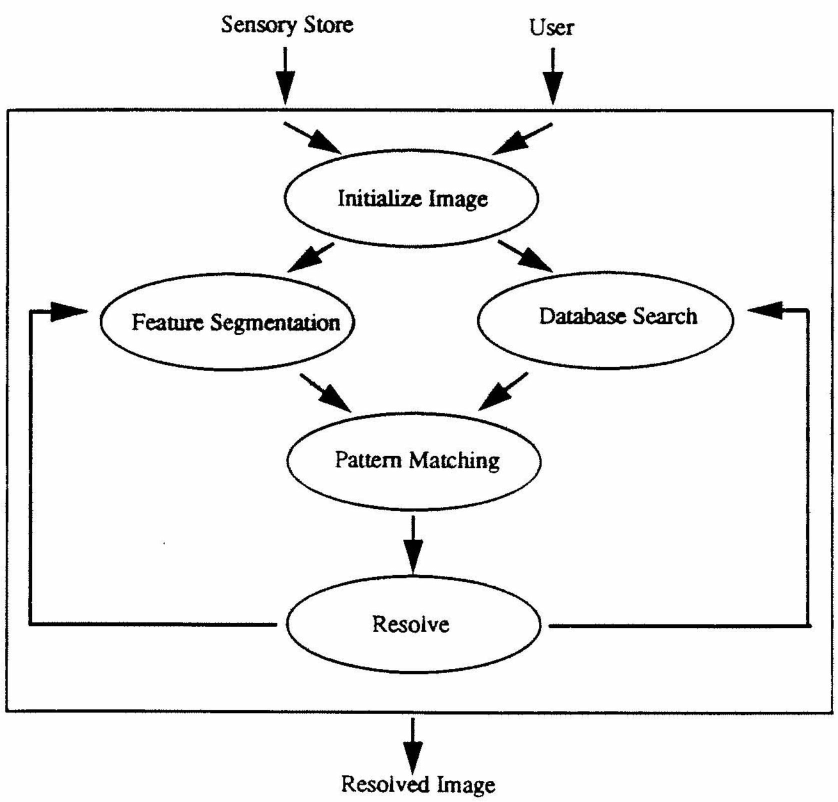
4. USING CLASSIFICATION TO IDENTIFY PARTS OF IMAGES

A goal of artificial intelligence (AI) research is to develop computer programs that are able to reason about and solve difficult problems. The problem area of classification, to include both development and use of classifications, can make use of AI techniques, including those techniques for representing and manipulating images.

Our approach to classification assumes a database of previously identified images. Parts of these images are instances of categories in a "parts classification", and are labeled as such in a descriptive representation using a frame data structure. This descriptive information can be used to generate a corresponding depiction of each image in the database in the form of a symbolic array. When a new instance of an image is encountered, both descriptive and depictive information are used to class the instance, i.e., to identify the parts of the new instance in terms of the parts classification. If once again we consider the example of the house, this process would correspond to perceiving a fuzzy image of a house and ultimately identifying the parts of the house using a database of houses that categorize house parts. Once the door, roof, and window have been recognized, we have determined the overall structure of the house. What is unique about the imagery approach is that it involves comparing depictions of an uncategorized instance with depictions generated from symbolic array representations of categorized images in the database. Two and three dimensional pattern matching techniques are being developed that transform images by translation, rotation, zooming, etc., to find likely matches. These techniques will use heuristic search strategies to transform the images for pattern matching.

The process of recognition using imagery can be divided into five steps, as shown in the following diagram and then explained individually.



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1. Initialize Image

   Given input from the user and/or a sensory store, a descriptive representation for the unidentified image is initialized in the form of a frame data structure. This frame may contain some initial descriptive information. Providing depictive information, a low-resolution depictive representation is generated from the sensory store in the form of a grey level array, which makes explicit information such as intensity changes, blobs, and contours.

2. Feature Segmentation

   The input to this process is a grey level array depiction of the image, which makes explicit information such as intensity changes, blobs and contours. Mathematical tools developed in low-level vision applications (such as noise removal, local averaging etc.) are used to preprocess images. Some of the various algorithms under development for segmenting three dimensional images incorporate world knowledge about the domain as well as descriptive knowledge from the frame structure of the image being considered. The choice of what segmentation algorithm to use depends on the current level of resolution of the image.

3. Database Search

   The input to this process is the currently known descriptive information for the image, as represented in the frame. This descriptive representation is matched against descriptive representations in a frame database in order to retrieve frames that may correspond to segments of the image isolated in Step 2.

4. Pattern Matching

   In this step we attempt to identify the parts of the image by comparing two depictive representations: [a] the depictive representation of the features of the image from Step 2 and [b] the depictive representations generated from symbolic array representations in frames retrieved in the database search of Step 3. Before a comparison can take place it may be necessary to adjust the resolution of the symbolic array depiction of the retrieved image to match the level of resolution of the image of the feature being considered. Functions that allow array depictions to be rotated and translated are used to determine the best matches. The use of these and other functions described in the previous section correspond to visualization techniques used in human pattern matching.

5. Resolve

   Information gathered from successful pattern matches is used to update the descriptive information in the frame representation of the image as well as the grey level array. If there are still some unidentified parts in the image there is another iteration, returning to processes in Step 2 using the updated grey level depiction, and in Step 3 using the updated descriptive information.

The processes described above may be repeated several times before an image is resolved to the stage where it is totally determined. Domain knowledge may be incorporated to determine whether the resolution of an image is consistent. For example, if we derive an image of a house where a door is spatially situated above the roof, this could be interpreted as an inconsistent

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image.

Currently, an application is underway for the development of a knowledge-based system for determining crystal structures [10]. The general approach taken in this system involves segmenting a depictive array representation of a crystal into molecular features and identifying the class for each of these features by pattern matching them with previously determined classes of molecules. This identification process is iterative. Once each of the features has been recognized, it is possible to generate a symbolic array representation for the image.

The initial image is a three dimensional electron density map, in the form of a grey level array, resulting from an irradiation experiment on the crystal. The initial frame representation includes its molecular formula. Initially, feature segmentation uses standard image processing techniques, including (for the crystallography domain) density modification procedures (contouring around density peaks, since high density regions imply presence of molecular structure) and world knowledge about the unidentified crystal, specifically, its molecular formula.

We are using the Cambridge Crystallographic Database as our source of knowledge on previously recognized structures against which pattern matching will take place. This database currently contains information on over 80,000 fully determined crystal structures, in particular on their significant molecular features. Descriptive information from the frame about the molecular structure of the crystal (its molecular formula) is matched against descriptive representations in this database. To enhance the knowledge base of these molecular fragments, cluster analysis techniques are being developed to attempt to categorize retrieved molecular fragments during this database search step; categorization may vary at different levels of resolution.

To identify a feature of a crystal structure it may be necessary to rotate and translate the depictive representation of the feature to have it match with a depictive representation of a structure generated from categories retrieved from the database. This corresponds to the processes of visualization and mental transformations carried out by expert crystallographers when determining the class of a structure.

The resolution phase in this application integrates new information into probabilistic methods to update the entire electron density image, as well as to update descriptive information in the frame representation, as features of the crystal are identified. If necessary, the system loops back to the feature segmentation and database search phases.

5. DISCUSSION

Although the use of imagery in classification is still in the very early stages, it appears to be an appropriate approach for determining the structure of complex images where pattern matching based on visual and/or structural knowledge is important. Currently research is also being carried out to incorporate imagery into learning systems. This work involves looking at ways to update the classifications of images through experience. We are also investigating an approach for predicting classifications that may not have previously been determined. Again, we are testing these ideas on the crystallographic database.

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