Integration of Case-Based and Image-Based Reasoning

Janice Glasgow
Department of Computing and Info. Sc.
Queen's University, Kingston, Canada
janice@qucis.queensu.ca

Igor Jurisica
Faculty of Information Studies
University of Toronto, Toronto, Canada
juris@cs.toronto.edu

Introduction

Within the psychology community, mental imagery is considered as a major medium of thought. People often describe the sensation of visualizing, manipulating and inspecting "pictures in their heads" during problem solving. Recently, researchers in artificial intelligence have been considering how to best reason with image or diagrammatic representations (?). This paper is concerned with how we can incorporate such work on computational image-based reasoning in the context of case-based reasoning (CBR). In particular, we discuss how CBR might be applied in domains where reasoning and decision making relies heavily on visual or spatial information derived from images. Examples of such domains are medicine, where information derived from X-rays, NMR images, etc. may be important to decision making, geographical information systems, where satellite image information plays a crucial role, and molecular biology, where the understanding of the three-dimensional geometry of a molecular structure is often essential to problem solving. Combining imagery and CBR could also prove fruitful for robotic motion planning, where sensory data could be effectively integrated with experiential knowledge. Although these applications appear diverse, they are similar in the sense that they can benefit from CBR systems, and they all rely on the ability to represent, pattern match and possibly adapt image representations.

Following, we briefly review some of the related research in the area of image-based reasoning. This is followed by a discussion on how such reasoning techniques can be integrated with techniques from CBR, particularly for the purpose of building decision-support systems that rely on image data stored in a computer. We conclude the paper with a description of some existing application areas that we are currently considering.

Reasoning With Images

Reasoning with images (pictures, diagrams, analogical representations) has been the topic of recent interest in the artificial intelligence community. The issues involved in this research are not so much how to interpret image data (as in image processing or machine vision), but rather how to represent image information in order to carry out the problem solving.

The concept of constructing knowledge representations that mirror the structure of the world is not unique to the array models described in this paper. Hayes (1974) discusses *direct* representations in which there exist similarities between what is being represented and the medium of the representation. Sloman (1975) has also argued the pros and cons of analogical representations, and has concluded that a variety of representation formalisms – including those specialized for spatial reasoning – are important to AI problem solving (?). Other hybrid approaches have been suggested for visual-spatial and model-based reasoning. Barwise and Etchemendy (1992) have proposed a system called *Hyperproof* which integrates diagrammatic reasoning with sentence-based logics. Hyperproof uses both diagrams and logic notation to teach students how to reason logically. In subsequent work, Barwise and Etchemendy (1993) present a formal semantics for reasoning with Hyperproof diagrams. Habel and colleagues (1993) have developed a hybrid system consisting of a propositional and depictorial partonomy (organization of parts) for reasoning, where the depictorial partonomy reflects the hierarchy proposed in representations for visual processes. They suggest that the advantage of the depictorial representation in their system is that it facilitates an efficient attention-driven method for reasoning. Myers and Konolige (1992) treat model-based manipulations as a form of inference within a classical logic system. More specifically, they store partially interpreted sensor data using an analogical representation that interacts with a general-purpose sentential language. A similar approach has been taken by Chandrasekaran and Narayanan (1990) , who have proposed an architecture where analogical representations derived from visual perception are used in combination with symbolic (propositional) representations. A technique for qualitative spatial reasoning, based on the directional orientation information made available through perceptual processes, has been presented by Freksa and Zimmermann (1993) . In this work, orientations in two-dimensional space are defined by the relation between a vector and a point.

Visual-spatial reasoning techniques have also been considered in the context of specific application domains. Funt (1980) represents and manipulates a visual analog of a world in order to predict potential instabilities and collisions in a physical domain. Several others have applied diagrams or analogical representations to qualitative physics problems (?; ?; ?; ?). For the domain of route planning, Kuipers (1978) has developed a program that determines a path between points by considering a hierarchical network of region representations. McDermott and Davis (1984) describe a more general representation for route planning that stores the shapes and locations of entities in the world. Facts in this system are represented as propositions and spatial reasoning is carried out by special-purpose modules that incorporate both theorem proving and numerical computations. Other problem domains where diagrammatic reasoning has been applied include biology, architecture, geometry and theorem proving (?).

Research in geographical information systems and spatial databases has long been concerned with the issue of representing spatial knowledge. Samet (1989) has proposed a method for storing geographic knowledge based on the recursive decomposition of space. In this work, the term *quadtree* is used to describe binary array data structures that iteratively subdivide regions into segments until blocks are obtained that consist entirely of 1s or entirely of 0s. These structures (and their three-dimensional counterpart, termed *octrees*) are efficiently stored and implemented as trees, where each node of the tree corresponds to a region in the decomposition hierarchy. The idea of quadtrees has also been explored by Ahmad and Grosky (1997) for spatial similarity-based retrieval. Similarity of images is computed as similarity of quadtrees. Authors use signature files for identifying relevant portions of the image database quickly (Faloutsos & Christodoulakis 1984). Samet's data structures and algorithms for querying spatial data bases could potentially aid in the development of efficient implementations for the knowledge representation scheme proposed in Section 3. An alternative approach to reasoning in geographic systems has been described by Papadias and Sellis (1993 . In their work, a symbolic two-dimensional array structure is used to preserve a set of spatial relations among geographic entities. Their approach is similar to a model for geographic information systems based on the array representation scheme proposed in this paper (?).

Spatial representations have also been considered in machine vision research. According to Biederman (1987) , the representation of objects can be constructed as a spatial organization of simple primitive volumes, called *geons*. The process of image analysis, as defined by Marr and colleagues (1982) , depends on a series of representations culminating in a three-dimensional model of the spatial relations among entities which makes explicit *what* is *where*. As in Marr's approach to computational vision, *molecular scene analysis* (?) is concerned with discovering what is present in the world and where it is spatially located. The act of determining the structure of a molecule is an interactive process consisting of a state space search of partially interpreted scenes, which can be represented and evaluated as three-dimensional symbolic array models (?).

The ideas presented in this paper have partially evolved from research in the area of computational imagery (?; ?; ?), which involves the study of AI knowledge representation and inferencing techniques that correspond to the representations and processes for mental imagery. In the previously proposed scheme for computational imagery, a mathematical theory of arrays provides a basis for representing and reasoning about visual and spatial properties of entities in the world. Although results of cognitive studies offered initial motivation for the representations and functionality of the formalism, the ultimate concerns of research in computational imagery are expressive power, inferential adequacy and efficiency.

Integration of Imagery and CBR

This section will consider the issues of case representation, retrieval and adaptation in the context of image-based reasoning.

Case Representation

How is image information best represented in a case? Unfortunately, there is no one answer to this question; how we choose to represent an image depends on the type of questions we seek to answer. By making particular features of the image explicit, we can provide for efficient pattern matching, retrieval and adaptation in our CBR system. Take, for example, the multiple representations of a molecular structure illustrated in Figure 1. If we wish to determine how many atoms of carbon are contained in a molecule, then the formula in Figure 1 a) is sufficient. However, if we need to derive connectivity, angle, distance or shape information, then more complex image representations, such as those in Figure 1 b) and c) are more appropriate.

We propose that image information may be stored explicitly, such as in a digital bit map, or implicitly, perhaps using shape descriptor that could be used to reconstruct a bit map. An image may be stored preserving all relevant visual information, or a simplified model (such as a graph or an array representation) might be the most appropriate form to extract and compare image features. Some form of indexing is required for sizeable image databases and manual indexing is not an option. Next we will discuss several possibilities, such as image analysis – automatic image feature extraction, and combination of symblic and visual information during retrieval.

Image Retrieval and Adaptation

As with any CBR system, a key issue in image domains is to determine what features are important

Figure 1: Alternative representations for molecule

for determining similarity for the purpose of case retrieval. There are many dimensions over which images can be compared: shape, color, size, spatial configuration, component membership, etc. Following, we discuss some mechanisms for image comparison.

Previously we have considered issues in structural similarity and equivalence (?). In this work, we measured the similarity between two images in terms of the transformations necessary to bring them into equivalence, where transformations may include replacing, deleting or moving a part, or rotation of the entire image. This approach to spatial analogy has been applied to the problem of comparing and classifying molecular structures (?; ?).

In addition to traditional symbolic approaches to similarity assessment, biomedical domains require visual/spatial similarity comparisons among image representations. Most of the current applications that combine CBR and image databases are passive in a sense that they use images only as a reference (Macura & Macura 1995). Haigh and Schewchuk (1994) use a case-based planning system is extended to handle two-dimensional graphs that are used as an index into the case base. In contrast, our goal is to combine CBR systems with active image processing.

There are several ways of combining image- and case-based reasoning:

- Perform both image- and case-based reasoning and combine the result. For example, in order to provide a diagnosis for a given patient, find patients with similar symptoms and patients with similar X-ray results.
- Use image-based reasoning to focus case retrieval. Suggest treatment plan by finding patients with similar X-rays and then explore the symbolic representation. This requires that either fast image retrieval is available (Petrakis & Faloutsos 1997) or that fast model-based shape recognition is in place ().
- Use case-based reasoning to focus image analysis only on the relevant portion of the image database. Efficient case retrieval can focus the search space of applicable images and thus reduce the image analysis complexity.
- Use image analysis to extract inportant features from images. This approach will loose some visual information but will enable traditional symbolic retrieval and reasoning techniques to be applied efficiently.

Regardless of the method chosen, image retrieval and adaptation would require *image segmentation* – a process that identifies objects within the image, and *image analysis* – a process that analyzes image and objects within the image.

Image segmentation algorithms can be applied to locate objects within an image (Xu, Olman, & Uberbacher 1996) or to separate objects during classification (Agam & Dinstein 1997). There are two main apporoaches available: region-oriented segmentation, which are based on searching for connected regions with similar gray level values, and edge-oriented segmentation, which search for abrupt change in gray levels that are likely to indicate an edge between neighboring objects. An interesting step toward integration of knowledge-based techniques to help during segmentation task is presented in (Tresp *et al.* 1996). Here, a knowledge base is used to determine what objects should be recognized when they have fuzzy boundaries. The method allows for specifying a bias, i.e., a domain knowledge about the object.

Automatic image indexing is used to make complex visual image comparison algorithms scalable for large image databases (Zheng & Leung 1996). Feature-based retrieval methods (Adam & Gangopadhyay 1998) use image features, such as color, shape or texture to access relevant images. Because these features describe content of an image, such techniques are also referred to as content-based retrieval. Current query-by-image-content retrieval techniques (Flickner*et al.* 1995; Ogle & Stonebraker 1995) use symbolic or numeric features that characterize images. Image features are either encoded by human experts or only simple features are used (such as color or texture). The query features can be provided by the user in several forms: by selecting an example (forming a query-by-example retrieval), by providing drawings or sketches, or by selecting colors and textures from menus. The complexity of the image segmentation and analysis tasks prevents application of automatic feature extraction techniques. However, in domains with limited scope automated techniques can be applied, especially when the domain expert can control and guide the process.

Psychological studies have provided evidence that suggest existence of an isomorphism between physical and imagined image transformations (?). Similarly, we can propose a set of primitive computational transformation operations that can form the basis for image adaptation. For example, Ohkawa *et al.* (1996) describe protein classification method using structural transformations, such as deletion or creation, magnification, rotation, movement, exchange or change of kind. In their work, authors compute similarity between proteins on the basis of the cost of individual transformations and their number. Thus, if many transformations are needed or expensive transformation are required then protein structures are marked dissimilar.

Image Analysis and Feature Extraction

Image analysis can be used to extract features from images and use them either for more efficient image retrieval or for decision support. Recognized features can enhance case-based reasoning and knowledge discovery. Combination of image analysis techniques and case-based reasoning can thus serve as:

1. feature extraction technique, which enables us to use traditional retrieval algorithms for fast image access;
2. indexing approach, which makes content-based image retrieval scalable; and
3. analysis tool, which brings additional insight into relations among images and between image and symbolic features.

Application of decision-support systems to biomedical domains is limited without support for similarity-based image retrieval and image analysis. Computational vision offers many techniques that can be applied. In general, there are two possible integrations of such techniques to CBR, *(1)* to combine CBR system with computational vision system or *(2)* to use image analysis techniques to extract important features from existing images and store them in a symbolic form.

Many approaches have been proposed for the problem of identification of image features. They include: *(1)* Polynomials of fitting flexible curves (McInerney & Terzopoulos 1996) or planes (Leclerc 1997); *(2)* similarity invariant coordinate system (SICS) that represents images as points and vectors (Li 1997); *(3)* attributed relational graph (ARG) (Petrakis & Faloutsos 1997); and *(4)* set of transformations (Basri & Weinshall 1992; ?; Ohkawa *et al.* 1996).

Deformable Models Deformable models are model-based techniques for image analysis. They have been succesfully used for image segmentation, matching and deriving image object size, shape and location (McInerney & Terzopoulos 1996). Thus, they play a significant role in medical image analysis.

Possible tasks where deformable models can be a useful enhancement of CBR include: representation and compression, storage and archiving, comparison direct and via extracted features, indexing, analysis, feature extraction, abstraction of images, segment identification, track motion or evolution.

Current systems for content-based image retrieval concentrate either on using expert's abstractions or only simple image characteristics (i.e., color, shape, or shade). This obviously has only a limited applicability. Retrieval by image content involves the problem of obtaining image attributes. This problem can be solved by applying model-based reasoning with deformable models. Here, available models are recognized images and the task of deformable models is proper image alignment and thus recognition. For example, the system will have a repository of models of embryos with different quality. Then the task of the system is to align the new embryo with existing models.

Another important use of deformable models is automated image feature extraction. Here, deformable model is used to find image features, such as diameter of an embryo. This can be used to classify the quality of the emryo and analyze its morphology, which in turn can be used in conjunction with other symbolic attributes during decision making. Image feature extraction is identification of image metadata, which can be used as:

1. indexes to the image database, supporting scalable similarity-based retrieval;
2. models of prototypical features (e.g., tumors in brain scans), implementing model-based retrieval;
3. a mechanism for content-based compression (i.e., prototypes and differences are stored).
4. auxiliary information in combination with CBR and knowledge-discovery techniques.

Deformable models can also be applied to identifying dynamic properties of images. Namely, sequence (or group) of models may be compared to another group to identify dynamic or evolving images (e.g., development of an embryo over a period of time). Alternatively, a spatio-temporal similarity measure could be used to identify segments on sequence of images (Choi, Lee, & Kim 1997).

There are two possible scenarios of incorporating snakes into a CBR system:

1. Symbolic information (CBR) will be used to find a subset of all potential images (e.g., only patients with tumor are interesting). Deformable models can be used to find a distinctive feature. Knowledge-discovery tools can then be used to find correlation among features and images.

2. Problem image with a model prototype library will locate a sub-image match that will lead to subsequent image and symbolic information retrieval.

An Example: ***In Vitro*** **Fertilization** Our previous studies showed that CBR can successfully be applied to treatment prediction in complex medical domains (Jurisica *et al.* 1998). In this study, we have also presented an attribute-oriented knowledge-discovery algorithm. However, because the system was using only symbolic information, the potential of information present in embryo development images could not been explored.

Morphometry comprises techniques for measurement of the size and shape of biological structures. In *in vitro* fertilization, morphometry is used to assess quality of embryos (Garside *et al.* 1997; Roux *et al.* 1995). However, there are several problems with analyzing morphology of embryos:

1. Measurement of embryo and oocyte size is hampered by segmentation, i.e., difficulties to detect and localize the boundaries of structures in images.

2. Time-series analysis is limited by the ability to accurately find corresponding points in scans taken at different intervals (registration problem).

We suggest to use computer-based morphometry to precisely and objectively identify quality of oocytes and embryos. Extracted morphological information can be linked with symbolic information to better predict pregnancy outcome, because the embryo quality will be objectively characterized. It is believed that embryo morphology is an important factor during planning the treatment and during predicting the treatment outcome. In addition, linking embryo morphology to clinical results may bring inside into which morphological features of embryos are important factors.

Figure 2 shows how deformable models, called snakes (McInerney & Terzopoulos 1996) are used to identify shape of the embryo. Morphological analysis is performed in steps, eahc of which requires different paramenters to be chosen for the snakes. First, embryo's diameter is identified. In the subsequent step, zona pellucida that surrounds the embryo can be detected and its thickness can be computed. Thickness of zona pellucida affects the fertility results (Ducibella 1998; Garside *et al.* 1997) and thus its objective calculation is important.

Embryo image analysis evaluates morphology and developmental features of oocytes and embryos (including cell number, fragmentation, cellular appearance, zona thickness, etc.). Although individual steps during morphological analysis require different parameters of the snake to be used, the number of analysis tasks is limited and thus these parameters can be preset for individual tasks (e.g., to recognize embryo shape, recognize zona pellucida).

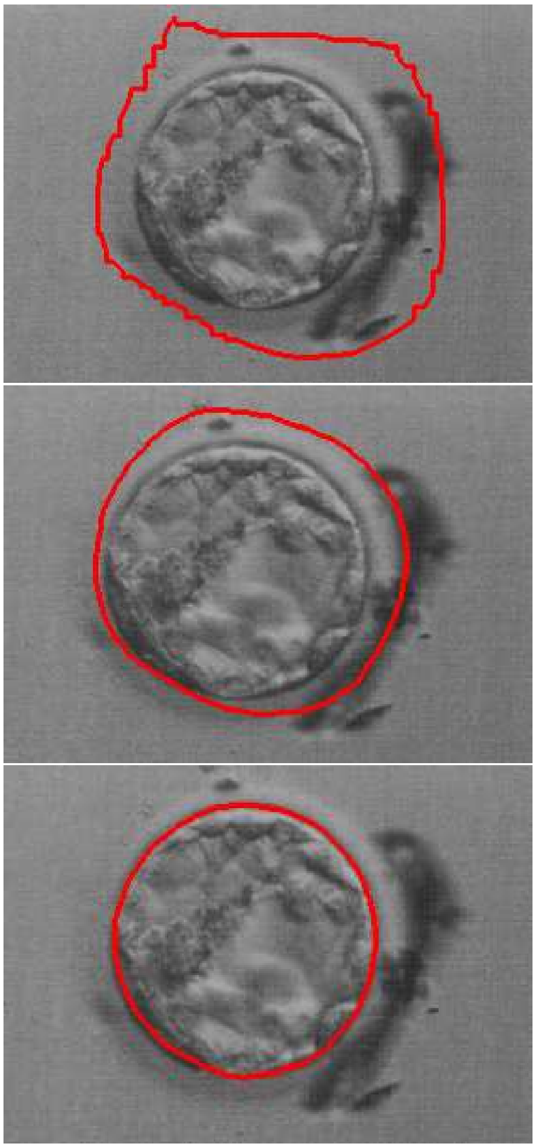

Figure 2: Feature extraction in IVF. Embryo morphology analysis by applying deformable models to find important image features. The first image shows the initial placement of the snake around the area of interest. The second image shows an intermediate result. The last image shows how the snake recognized the embryo boundary.

Concluding Remarks

The idea of combining image-based reasoning and CBR is new, and there are many avenues that need to be explored. Above we have presented just a brief glimpse at some of the issues involved in integrating these two approaches to reasoning and problem solving. In particular, we have focused on how CBR could be applied in image domains.

We are currently considering the use of CBR in several domains involving image data. In particular, we have considered CBR for the problem of *molecular scene analysis* (?). This work focuses on determining how structural protein data can be organized to permit efficient and rapid retrieval from a case base of molecular scenes. In particular, CBR is used to anticipate 3D substructures that might occur within a novel protein image (constructed from an X-ray diffraction experiment). CBR is also being considered as an approach for planning crystallization experiments for proteins, where a visual image of the potential crystal resulting from an experiment is stored in the case and potentially used in the retrieval process.

Medicine is another area with potential for integration of CBR and image-based reasoning. Earlier we showed that CBR can be successfully applied for prediction and diagnosis in medical domain (Jurisica *et al.* 1998). The early prototype of our system worked only with symbolic patient data. Later, more detailed information was collected, including oocyte and embryo images. These images are analyzed by embryologists and the extracted information is used by doctors to potentially provide an explanation of multiple failed implantations. Image analysis evaluates morphology and developmental features of oocytes and embryos (including cell number, fragmentation, cellular appearance, zona thickness, etc.). Although humans can analyze image more flexibly, computer vision helps to make the process more objective and precise.

References

Adam, M., and Gangopadhyay, A. 1998. Content-based retrieval in digital libraries. *Computer* 31(1):93–95.

Agam, G., and Dinstein, I. 1997. Geometric separation of partially overlapping nonrigid objects applied to automatic chromosome classification. *IEEE Transactions on Pattern Analysis and Machine Intelligence* 19(11):1212–1222.

Ahmed, I., and Grosky, W. I. 1997. Spatial similarity-based retrievals and image indexing by hierarchical decomposition. In *International Database Engineering and Application Symposium, IDEAS*97*, 269–278.

Basri, R., and Weinshall, D. 1992. Distance metric between 3D models and 2D images for recogntion and classification. Technical Report AIM-1373, MIT, AI Lab.

Choi, J. G.; Lee, S.-W.; and Kim, S.-D. 1997. Spatio-temporal video segmentation using a joint similarity measure. *IEEE Transactions on Circuits and Systems for Video Technology* 7(2):279–286.

Ducibella, T. 1998. Biochemical and cellular insights into the temporal window of normal fertilization. *Theriogenology* 49(1):53–65.

Faloutsos, C., and Christodoulakis, S. 1984. Signature files: An access method for documents and its analysitical performance evaluation. *ACM Transactions on Office Information Sysmtes* 2(4):267–288.

Flickner*et al.*, M. 1995. Query by image and video content: The QBIC system. *IEEE Computer* 23–32.

Garside, W. T.; Mola, J. R. L. d.; Bucci, J. A.; Tureck, R. W.; and Heyner, S. 1997. Sequential analysis of zona thickness during in vitro culture of human zygotes: Correlation with embryo quality, age, and implantation. 47(1):99–104.

Haigh, K. Z., and Shewchuk, J. R. 1994. Geometric similarity metrics for case-based reasoning. In Aha, D. W., ed., *Proc. of AAAI-94, Workshop on Case-Based Reasoning*, 182–187.

Jurisica, I.; Mylopoulos, J.; Glasgow, J.; Shapiro, H.; and Casper, R. F. 1998. Case-based reasoning in IVF: Prediction and knowledge mining. *Artificial Intelligence in Medicine* 12(1):1–24.

Leclerc, Y. G. 1997. Continuous terrain modeling from image sequences with applications to change detection. In *Workshop on Image Understanding*.

Li, S. Z. 1997. Invariant representation, matching and pose estimation of 3D space curves under similarity transformation. *Pattern Recognition* 30(3):447–458.

Macura, R. T., and Macura, K. J. 1995. Macrad: Radiology image resource with a case-based retrieval system. In Veloso, M., and Aamodt, A., eds., *ICCBR-95. Lecture Notes in Artificial Intelligence 1010*, 43–54. Springer, Berlin.

McInerney, T., and Terzopoulos, D. 1996. Deformable models in medical image analysis: A survey. *Medical Image Analysis* 1(2):91–108.

Ogle, V. E., and Stonebraker, M. 1995. Chabot: Retrieval from a relational database of images. *IEEE Computer* 40–48.

Ohkawa, T.; Namihira, D.; Komoda, N.; Kidera, A.; and Nakamura, H. 1996. Protein structure classification by structural transformations. In *Proc. of the IEEE International Joint Symposia on Intelligence and Systems*, 23–29.

Petrakis, E. G. M., and Faloutsos, C. 1997. Similarity searching in medical image databases. *IEEE Transactions on Knowledge and Data Engineering* 9(3):435–447.

Roux, C.; Joanne, C.; Agnani, G.; Fromm, M.; Clavequin, M. C.; and Bresson, J. L. 1995. Morphometric parameters of living human in-vitro fertilization embryos; importance of the asynchronous division process. 10(5):1201–1207.

Tresp, C.; Jager, M.; Moser, M.; Hiltner, J.; and Fathi, M. 1996. A new method for image segmentation based on fuzzy knowledge. In *Proc. of the IEEE International Joint Symposia on Intelligence and Systems*, 227–233.

Xu, Y.; Olman, V.; and Uberbacher, E. C. 1996. A segmentation algorithm for noisy images. In *Proc. of IEEEE International Joint Symposium on Intelligence and Systems*, 220–226.

Zheng, Z. J., and Leung, C. H. C. 1996. Automatic image indexing for rapid content-based retrieval. In *Proc. of IEEEE International Workshop on Multimedia Database Management Systems*, 38–44.