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December 2002

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Dongming Xu

State University of New York

Chang Zhang

Virginia Polytech

Dan Zhu

Iowa State University

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Recommended Citation

Xu, Dongming; Zhang, Chang; and Zhu, Dan, "ANALOGICAL REASONING FOR INFORMATION RETRIEVAL: A CASE STUDY" (2002). *AMCIS 2002 Proceedings*. 15.

<http://aisel.aisnet.org/amcis2002/15>

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ANALOGICAL REASONING FOR INFORMATION RETRIEVAL A CASE STUDY

Dongrong Xu

Department of Computer Science
State University of New York

Chang Zhang

Department of Computer Science
Virginia Polytech

Dan Zhu

Iowa State University
dzhu@iastate.edu

Abstract

The objective of this paper aims to propose an efficient method for recognizing and retrieving information from large image databases. We first provide an overview of current research on image information systems. We then propose a similarity calculation method based on multi-source analogy. To illustrate these ideas, a case study of the Dunhuang Frescoes retrieval and analysis system is presented. We demonstrate that calculating the similarity between images can retrieve the Dunhuang Frescoes information.

Introduction

Digital image processing plays an important role in an information age. Computer processing methods such as image compression, recovery, and segmentation have found applications in a variety of fields such as Geographic Information Systems, remote sensing, medical image archives, multimedia, and digital libraries. As the prevalence and size of multimedia databases increases, automated recognition techniques that can extract useful and comprehensible features become a critical part of a successful information retrieval process. Significant research has been conducted in image database retrieval, focusing on feature vector computation from an image and generating the feature distance based on certain image measurements. Image database retrieval differs from some traditional classification tasks, including face detection and character recognition. Common data mining or knowledge discovery methods are less effective as they generally require large number of examples and few classes (Rowley et al. 1998). The objective of this paper aims to propose an efficient method for recognizing and retrieving information from large image databases. In this study, we borrow some concepts from cognitive science in analogical reasoning to facilitate information retrieval. Analogical reasoning represents an efficient way of using past experience (Gentner 1983, Carbonell 1983). The process raises several important questions. First of all, what are the significant aspects shared by old and new problems? Secondly, how is the past successful experience selected from a possibly large long-term memory? Thirdly, what knowledge is to be transferred from the past experience to the new solutions? Finally, how does the knowledge transformation process occur?

Background

Much of the research in image retrieval focuses on extracting and retrieving images by comparing features and choosing the one that is most similar. Generally, texture features are used to represent images. One method preserves the spatial information of the images into texture features, keeping the images in a very narrow domain. Primarily used to perform facial image retrieval and recognition, this technique has a relatively higher hit rate and is more mature and practical than other techniques. Recent research has focused on using multi-feature operations to develop new image retrieval methods. The use of multi-feature functions improves matching accuracy and reduces image information loss through feature extraction, therefore overcoming the disadvantage of image retrieval by a single feature. The QBIC™ of IBM is a system that allows users to query large image databases based on visual image content, i.e. properties such as color percentages, color layout, and textures occurring in the images (Flickner et al. 1995).

Analogical Generation and Similarity Calculation

Analogy is an important aspect of human learning and thinking. Facing a new task, people tend to recall similar situations and adapt one or more previous solutions to fit the new situation. Analogical reasoning occurs when people recall and use information from prior experiences to solve a new problem (Mayer 1992). Research on analogical problem solving is rooted in cognitive psychology (Gentner 1983, Holyoak and Thagard 1989&1995, Reed 1987). When employing analogical reasoning, several important issues need to be addressed. First of all, the similarity between old and new problems must be identified. The common aspects shared by the old and new problems serve as the basis of a similarity measure, which can be used to search for solutions. Secondly, retrieving past experience is a search process in which the solutions to old problems are examined and measured by the similarity measures. The way in which past experience is represented has a major impact on the efficiency of the search. In addition, the knowledge to be transferred is determined by the nature of the problem, the type of the analogical reasoning applied, and the results of past experience retrieval. Finally, transferring knowledge from a past experience to a current situation is a problem-solving process in itself. In this paper, we propose the concept of multi-source analogy, which can release the traditional analogy from the limitation of presumed restriction, allowing its newly added sources to be mapped to a more extended target field. The similarity calculation based on multi-source analogy can thus be applied to a variety of domains.

According to the traditional analogical reasoning (AR) theory, AR can be expressed as:

$$B = \{b_1, b_2\}, t = \{t_1, t_2\} \quad (" \sim " \text{ stands for "similar with"}) \quad (3.1)$$

$$b_1 \sim t_1 \Rightarrow b_2 \sim t_2$$

where B and t stand for source and target, respectively. Both B and t consist of two parts. This means that certain similarity between two objects infers further similarity in the other two. In traditional symbolic artificial intelligence systems, the reasoning process is a binary adopt/abandon substitution. In reality, when someone comes upon a new problem, s/he will likely solve the problem based on past experiences. For instance, to create a new piece of upholstered furniture, a designer may think about the most recent fashions, the feeling of the seat of his car, and perhaps the quality and color of his bedroom curtain. He may use some version of these elements in his design. Therefore, the real analogy procedure is multi-source. In addition, he may feel that the color should be more subdued and that the chair should have some interesting trim. The final design will reflect known features (like the color of the designer's curtains) and new touches (like the trim). This example illustrates that the reasoning process does not follow the binary substitution rule but, rather, is a process influenced by all related sources. The power is like a magnetic field or electronic field— it exists and varies with distance.

Our proposed multi-source analogical generation system differs from the traditional AR system in several significant ways: 1) there are more than two sources as analogues; 2) sources effect the result through the power of their gravity field; 3) the sources and their field power establish a reasoning space; 4) the reasoning process is continuous therefore the intermediate area containing potential meaningful objects; 5) the objects relate with all the original sources just in some degree, i.e. the result objects is a hybrid of all sources. These can be formally described as follows:

$$T = f(B_1, B_2, \dots, B_N), \text{ where } B_i \text{ is an analogue.}$$

Let:

$$S = \begin{pmatrix} s_{11} & \cdots & s_{1M} \\ s_{21} & \cdots & s_{2M} \\ \cdots & \cdots & \cdots \\ s_{N1} & \cdots & s_{NM} \end{pmatrix}_{N \times M} = \begin{pmatrix} \bar{s}_1 \\ \bar{s}_2 \\ \cdot \\ \cdot \\ \bar{s}_N \end{pmatrix}$$

$$B = \begin{pmatrix} b_{11} & \cdots & b_{N1} \\ b_{12} & \cdots & b_{N2} \\ \cdots & \cdots & \cdots \\ b_{1M} & \cdots & b_{NM} \end{pmatrix}_{M \times N} = (B_1 \quad \cdots \quad B_N)$$

Above is the standard formation of an N part M source analogical generation (AG), where a_{ij} is the weight of each source standing for its influence power during the reasoning process. As a result, a_{ij} represents the similarity between T and every B_i .

A Case Study

We selected the world renowned Dunhuang Frescoes as our main research objects because of their sharp contrast in color utilization and limning style in different periods and caves. Recently, the artwork in the Dunhuang Grottoes has been studied in more depth (Walker 1995). Analogical problem solving involves retrieving a source that is similar to the target problem and then subsequently using its solution to solve the target problem. One of the keys to successful analogical reasoning lies in ignoring the similarities or dissimilarities of the surface features between problems but recognizing analogies in their structures (Mayer 1992). The procedure described in Section 3 produces results from an original pattern. When it is reversed, it equals the object that is to be recognized. This time, the reasoning space is renamed retrieval space and the sources are now typical figures of some specific patterns. Therefore, if the given object is restricted within the space, the object is classified and thus its pattern can be obtained. In addition, the retrieval and recognition based on semantic description are supported, such as “the limning is very meticulous,” “the fresco's main hue is red,” “fresco mainly use warm color,” etc. It is necessary to convert semantic descriptions to certain data ranges that can be represented by color and limning feature's value. For comparison purpose, results of retrieval using individual feature are also given. More than 100 Dunhuang frescoes are used in this experiment. Preliminary result shows that when a single feature is used to perform the task, its success rate is low. For example, using only the color feature, 2 out of 10 cases failed to determine the era in which the frescoes were created, and 3 of 10 cases failed to determine the cave in which the frescoes were discovered. Using only the texture feature, 14% failed to determine the appropriate dynasty and only 50% succeeded at determining the right cave. However, when both features were considered together, the success rate immediately reaches 80% and 90%. Therefore, using a combination of color and texture features can give more precise judgment in all cases.

Conclusion

In this paper, we present a theory of multi-source analogical generation, primarily proposed to solve problems in the field of design. Its potential power in recognition is explored, and a new, effective framework for image recognition and retrieval is proposed. The results from the Dunhuang Frescoes retrieval and analysis system using similarity calculation of multi-source analogy show that retrieval using the combination of color and texture features yields higher hit rates and accuracy. The research and work presented are in their infancy with tremendous potential for future research. For example, separating the components from the whole object or matching corresponding parts presents interesting directions for future investigation.

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