

Contextual Distance Refining for Image Retrieval

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Abstract: Recently, a number of methods have been proposed to improve image retrieval accuracy by capturing context information. These methods try to compensate for the fact that a visually less similar image might be more relevant because it depicts the same object. We propose a new quick method for refining any pairwise distance metric, it works by iteratively discovering the object in the image from the most similar images, and then refine the distance metric accordingly. Test show that our technique improves over the state of art in terms of accuracy over the MPEG7 dataset.

Keywords: Contextual distance, image distance, image retrieval.

1. INTRODUCTION

The problem of image matching have been previously investigated by studying the features of a pair of images, this goes by extracting features from both images and calculating a numerical similarity measure accordingly, examples of these are the bag-of-features method [1, 2], non-negative matrix factorization-based approaches [3-6], and the inner distance shape context (IDSC) [7].

However, pairwise image matching only considers the image of the object and not the contextual data [8-10]. The idea is that for an image (A) containing an object, an image that has the same object (B), might look less similar than another image for another object (C), because of the different perspective and orientation. A better pairwise similarity measure in this case will (and should) recognize image B as more similar to A than C is.

Recently, the importance of the context of the shapes has been recognized to improve the performance of shape matching. Jegou *et al.* [11] have proposed the Contextual Dissimilarity Measure (CDM) by assuming that a good image ranking is asymmetrical. Bei *et al.* [12] proposed a new method for context-sensitive shape similarity using Graph Transduction (GT), which is further improved by Wang *et al.* [13, 14] by using Shortest Path Propagation (SSP) on the graph [13], and using multiple graph instead of one single graph [14]. Lately, Wang *et al.* [15] developed the first supervised contextual similarity learning algorithm.

All the previous methods, besides the one proposed in [15], have the advantage of being unsupervised methods. The GT method performs well for being customized for each query object, however, as we will show in this paper, their

method is costly, and we proposed a more efficient way of context-aware shape retrieval. Our method Contextual Distance Refining (CDR) takes a pairwise distance criterion and alters the distances by injecting the context information. Our method is still unsupervised and the context will be based on an iterative and dynamic consideration of the neighbors.

The rest of the paper is organized as follows: we lay down the basis for our method and describe the implementation algorithm in Section 2. Experimental results on are presented in Section 3. Finally, conclusive remarks are presented in Section 4.

2. CONTEXTUAL DISTANCE REFINING

In this section our method for contextual image retrieval is described. First a description of the basis of idea is provided. Then, a mathematical and algorithmic approach is proposed. And we finish with a discussion of the approach in terms of complexity, parameter dependence and how it differs to other proposed methods.

2.1. Context Deduction

The pairwise similarity measures fail to take into consideration the contextual information [16, 17], for example in (Fig. 1), the constellation of points represent the similarity measures of the images, the closer the points the more similar are the images. We can see that a point is more relevant to point than point despite being further (less similar) from.

The figure is a much more simplified representation of the distances, showing the points in a 2-dimensional plan which might suggest that distances between some points are dependent thus, can be projected on a plan. While this is not the case, the figure still shows how we can derive the context of a shape from the neighboring shapes. This extends the definition of "similar" images by considering two

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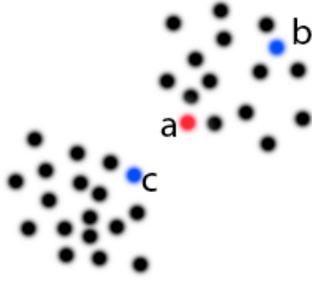


Fig. (1). A figure showing how context information improve accuracy.

parameters, in the context of this paper, an image x_i is similar to an image x_j if:

- Image B depicts the same object in A , and
- Image B is visually similar to image A .

The idea behind our approach is this: assume a query image x_i for a certain object, and the top N images depicting the same object are to be retrieved. We denote the image database as a collection of image features $\mathbf{X} = \{x_i\}_{i=1}^I$, while query image feature as x_o . A distance measure d_{ij} is defined between a pair of images x_i and x_j , $i, j = 1, \dots, I$. The distance is smaller for similar images. Now a naive context-unaware approach of retrieving similar images is to rank them in ascending order according to d_{i0} , and take the first N . Now assume a different image x_k depicting the same object as x_o , then images x_i similar to x_k should also be considered similar to x_o even if $d(x_i, x_o)$ of these images is high. So now all the values of d_{ik} can be considered as contextual information that can be embedded in d_{i0} . The new refined distances will provide a better distance measure.

2.2. Distance Refining

Now a method has to be defined to include the determined contextual information within the distance measure, let's define d_{ij}^* as the new distance metric and can be determined by (1). Since both distances are based on the same metric, they can be added without scaling, the α factor represents our confidence on whether image x_k depicts the same object as x_i or not.

$$d_{ij}^* = d_{ij} + \alpha d_{kj} \quad (1)$$

To grantee the symmetry of the new distance matrix, we also used another image x_l from the same class as x_j to regularize the distance as

$$d_{ij}^* = d_{ij} + \alpha(d_{kj} + d_{il}) \quad (2)$$

Now we can generalize the equation given a set of images N_i similar to image i :

$$d_{ij}^* = d_{ij} + \alpha \left[\frac{1}{|N_i|} \sum_{k \in N_i} d_{kj} + \frac{1}{|N_j|} \sum_{l \in N_j} d_{il} \right] \quad (3)$$

We call N_i as *context* of x_i here. Now the problem is how to find such an context N_i ? We define the context of x_i as its N nearest neighbors from X :

$$N_i = N - \underset{x_k \in X}{\operatorname{argmin}} d_{ik} \quad (4)$$

However, the context size N is very difficult to find. At one hand, if N is too large, some irrelevant images will be included within N_i since d_{ij} is not a credible distance metric itself, thus degrade the quality of d_{ij}^* . At the other hand, if N is too small, the effect of N_i will be limited. To solve this problem, instead of finding the context one time using d_{ij} , we propose a new iterative approach to refine the distance metric d_{ij} while approximating the contexts N_i alternately.

2.3. Iterative Refining Algorithm

We propose an iterative approach for refining. Define a distance function d_{ij}^t , where t is the iteration number. In each iteration, the image excluded by N_i while minimizing d_{ij}^t is added to the context N_i of x_j , and then distances are updated according to (3). The algorithm is summarized in Algorithm 2.3.

Contextual Distance Refining (CDR) Algorithm.

Original distance matrix $D = [d_{ij}^0]_{i,j=0}^N$; Balance parameter α ; Iteration number T ;

$t = 1, \dots, T$

Update the distance matrix

$$d_{ij}^t = d_{ij}^{t-1} + \alpha \left[\frac{1}{|N_i^{t-1}|} \sum_{k \in N_i^{t-1}} d_{kj}^{t-1} + \frac{1}{|N_j^{t-1}|} \sum_{l \in N_j^{t-1}} d_{il}^{t-1} \right] \quad (5)$$

Find the new context item R_i

$$R_i^t = \underset{x_k \in N_i^{t-1}, x_k \in X}{\operatorname{argmin}} d_{ik}^t$$

$$N_i^t = N_i^{t-1} \cup R_i^t \quad (6)$$

Output distance matrix $D^t = [d_{ij}^t]$.

An important feature of our algorithm is that the size of context is not fixed like CDM [11] or TG [12]. The context and distance matrix are refined step by step coherently.

2.4. Discussion

It can be noticed from the algorithm that it can be applied on any pairwise distance measure to improve it. The algorithm will return a new set of distances that are improved based on the locality and context of a certain query. Then the top entries can be picked according to the ascending order of the elements.

One major improvement over the Graph Transduction method [12] is the method by which context is extrapolated from the distance matrix. In their paper they first they have to select a certain number of candidate neighbors, these are the top n images according to the original distance metric,

then their algorithm is applied on these n candidates. It can be shown that their algorithm is $O(TI^2)$, where T is the number of iterations and I is the number of images in the database. While the algorithm we propose is $O(T^2I)$, since T is usually chosen a small fixed number (as we will show in the experiment section) and $T = I$, the algorithms end up being $O(I^2)$ and $O(I)$ respectively, which allows our method to work on the square number of initial candidates preserving the same performance. And, as will be shown in the Experimental Results Section below, there is no sacrifice in retrieval rates too.

3. EXPERIMENTAL RESULTS

In this section we examine the accuracy improvement of our algorithm applied on a pairwise distance metric, this is done against other context-aware algorithms. Then, we show experiments on the parameter values, with a brief description of what they affect.

3.1. MPEG7 Dataset

The MPEG7 Core Experiment CE-Shape-1 data set [18], the dataset contains 1400 images arranged as 70 classes 20 images each. To compare our results with the state of art, we use the IDSC distance [7], which is used as the base distance for Bai *et al.* [12]. The results are shown in the (Fig. 2) below.

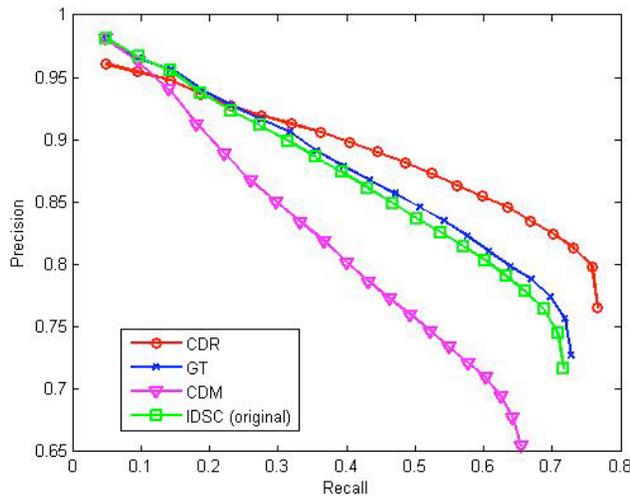


Fig. (2). Precision/recall values for: **a)** CDR: our proposed method **b)** GT: Graph transduction **c)** CDM: Contextual dissimilarity measure and **d)** IDSC: original distance metric.

The compared distances are: the original distance (IDSC), the distance after applying Graph Transduction, the distance after applying CDM [11] and our distance CDR. CDR gave more improvement for most of the precision/recall values and a significant improvement over Graph Transduction overall. CDM did not perform well in this case because their basis assumption of CDM is that the distance between a data sample and its neighbors should be consistent. However, due to the variance of local distribution of shape database, this assumption will degrade the retrieval performance.

3.2. Choice of Parameters

Next we show results of changing the algorithm parameters T and α . (Fig. 3) shows the effect of changing α on the average accuracy of the algorithm (area below precision/recall curve). Note that a smaller α is used when the images of different classes are close in terms of original distance; a smaller α means that the contextual information derived from neighbors should not be trusted with high probability. A higher α is ideal for more clustered data, which results in even more clustering and dispersing non relevant images.

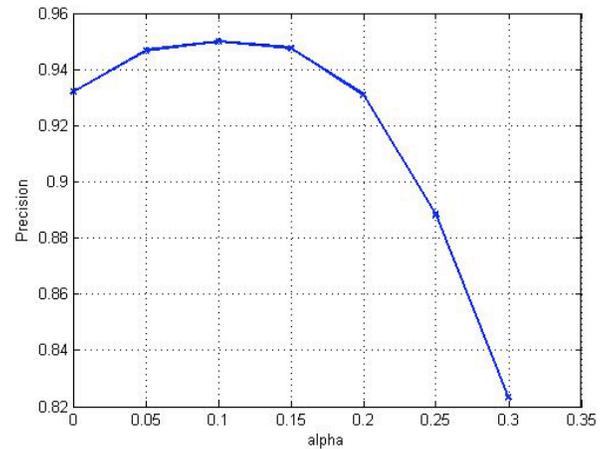


Fig. (3). Effect of varying α on precision.

Experiments on different values of T showed similar results in (Fig. 4); at first, more improvement is gained by including more neighbors and adjusting the distances accordingly. But as we include more neighbors the performance starts to degrade because less relevant neighbors are included. T is usually picked according to how many images we expect to belong to the same cluster.

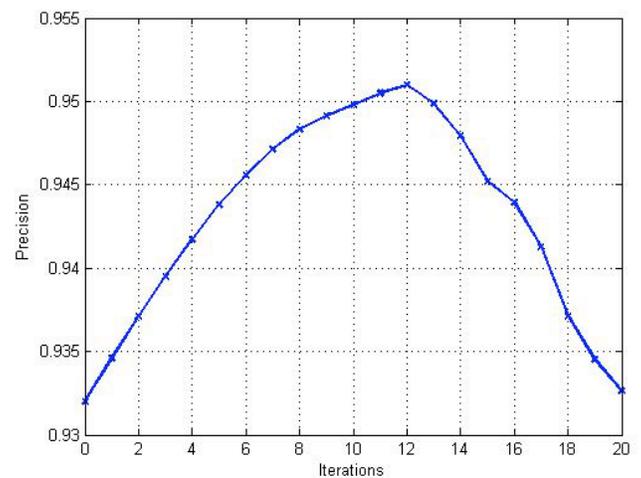


Fig. (4). Effect of varying T on precision.

4. CONCLUSION

Our method can be integrated with any pairwise distance metric to improve accuracy; it iteratively captures contextual information from a set of close images. The tests show a

significant improvement of accuracy for image retrieval. The effect of the choice of parameters is investigated. Our future work will focus more on automating and dynamically changing the parameters, depending on the Image Distance Matrix to improve accuracy and enhance automation, which is important in unsupervised search.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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