Journal of Computer Science and Control Systems

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Application of the Progressive Wavelet Correlation in Image Retrieving

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Abstract – In the paper we apply progressive wavelet correlation along with Fourier methods for searching and retrieving images stored in a database. The searching consists of three incremental steps, each of which quadruples the number of correlation points. The process can be halted at any stage if the intermediate results indicate that the correlation will not result in a match. We perform a series of image search experiments that cover the following scenarios: (A) the given image is present in the database; (B) copies of the given image are present but with different names; (C) similar (but not identical) images are present; and (D) the given image is not present. Experiments are performed with data bases up to 1000 images, using the Oracle database and the Matlab component Database Toolbox for operations with databases.

Keywords: database, image retrieval, pixel-based search, progressive wavelet correlation.

I. INTRODUCTION

Images, drawings, photographs as means of communication among people, for sending and receiving messages have been part of everyday life for a long a time. The easy to use World Wide Web, the reduced price of storage devices as well as the increased calculating power allow an essential and efficient management of large quantity of digital information. All of these factors offer a number of possibilities to the designers of real image-browsing and retrieval systems.

However, image digitalization systems do not allow for an easy management of collections of images. A particular form of cataloguing and indexing is still required. The need for efficient storage and retrieval of images was recognized by managers of large collections of images long time ago and was studied at a workshop sponsored by the American National Science Foundation in 1992.

Data representation, feature extractions and indexing, image query matching and user interfacing were identified as areas with a potential for improvement. One of the issues identified was the problem of locating a picture in a large and diverse collection of images.

The earliest and the most sophisticated descriptor-based image search engine is IBM QBIC [1]. Another set of content-based tools for image search have also improved throughout the years. Examples for such tools are WebSEEk [2] and ImageRover [3]. ImageRover uses low resolution for image representation in six regions in order to cover particular information along with the region based descriptors.

All of these techniques improve the accuracy and usefulness of image searching and may have commercial appeal in the future. The accuracy of searching has a tendency to improve by means of increasing the descriptors' resolution and pre-processing images for locating more appropriate descriptors.

The described image search engines are based on compact image representation in order to produce high processing speed. Generally there is no time for image analysis during the search phase.

The main descriptor-based search techniques are limited in two ways: Firstly, they do not contain the details of the image, and secondly, they do not cover the overall features within the frames of the image descriptors. Large complex images can contain many details and as a result a suitable compact presentation will be hard to determine.

On the other side, pixel-based search represents a somewhat different direction that has promise for applications that require high resolution, such as satellite images and medical images, particularly in geosciences. Pixel-based search techniques work by locating a particular pattern in a given image library. Popular criteria for matching are the normalized correlation coefficients [4], which measure the differences between images and patterns from the library. The particular strength of these criteria is that they are insensitive to uniform differences in brightness.

Some of the work done in the area of PWC (Progressive Wavelet Correlation) [4] is outlined in Section 2. Our proposal concerning an application of this method for searching images stored in a database is presented in section 3. Results of experiments that use PWC approaches are presented in Section 4.

II. PROGRESSIVE WAVELET CORRELATION

A. Overview

In this section we summarize the technique described in [4], [5]. Progressive wavelet correlation using Fourier methods is based on four theorems: the Wavelet-Correlation Theorem, the Fourier-Wavelet Correlation Theorem, the Fourier-Wavelet Subband Theorem and the Fourier-Wavelet Multiresolution Theorem. To simplify the discussion all data are assumed to be one-dimensional vectors.

The fundamental operation for searching is the circular correlation $x \otimes y$. The jth entry of the circular correlation is defined as:

$$\left(x \otimes y\right)_j = \sum_{i=0}^{N-1} x_{i+j \bmod N}\, y_i, \ \text{ for } j = 0, 1, \dots, N{-}1 \quad (1)$$

where x and y are column vectors of length N.

The matrix form is $x \otimes y = Xy$, where X is left circulant matrix generated by x:

$$X = \begin{bmatrix} x_0 & x_1 & \dots & x_{N-1} \\ x_1 & x_2 & \dots & x_0 \\ \dots & \dots & \dots & \dots \\ x_{N-1} & x_0 & \dots & x_{N-2} \end{bmatrix} \quad (2)$$

The notation $\left(P\right)_{i \downarrow R}$ denotes subsampling of P by taking components whose indices are equal to i modulo R. For example, if $R = 4$ and $i = 2$, the subsampling operation extracts the elements 2, 6, 10, 14, … from P.

Wavelet-Correlation Theorem:

$$\left(x \otimes y\right)_{0 \downarrow R} = \sum_{k=0}^{R-1} \left(\left(Hx\right)_{k \downarrow R}\right) \otimes \left(\left(Hy\right)_{k \downarrow R}\right) \quad (3)$$

where H is wavelet-packet transform. $\times$ is the Kronecker product of I_M and W, $H = I_M \times W$, where I_M is $M \times M$ identity matrix and W is an $R \times R$ matrix with property $W^T W = I_R$. The wavelet transform packet matrix H has a special structure. H is block diagonal with block size R. For instance, W can be 2x2 Haar matrix:

$$W = \left(\frac{1}{\sqrt{2}}\right)\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}. \quad (4)$$

Fourier-Wavelet Correlation Theorem:

$$\left(x \otimes y\right)_{0 \downarrow R} = F_M^{-1}\left(\sum_{k=0}^{R-1}\left(F_M\left(\left(Hx\right)_{k \downarrow R}\right)\right) * \left(\hat{F}_M\left(\left(Hy\right)_{k \downarrow R}\right)\right)\right) \quad (5)$$

where F_M is the Fourier transform matrix of dimension M and $\hat{F}_M$ is the complex conjugate of F_M.

Fourier-Wavelet Subband Theorem:

$$F_N x = \left(T_{N,M,R} H^{-1}\right)\left(F_{M,R} Hx\right) \quad (6)$$

where $N = MR$. The matrix $F_{M,R}$ is an interlaced Fourier transform matrix with structure $F_{M,R} = F_M \times I_R$, that is it has R interlaced copies of transform of size M. The matrix $T_{N,M,R}$ is a Fourier update matrix that transforms $F_{M,R}$ into F_N: $F_N = T_{N,M,R} F_{M,R}$.

Fourier-Wavelet Multiresolution Theorem:

$$F_{N/R,R} H_1 x = \\ \left(T_{N/R,N/R^2,R} \times I_R\right) U_{2,1}^{-1} F_{N/R^2,R^2} H_2 x \quad (7)$$

$$F_N x = \\ T_{N,N/R,R} H_1^{-1}\left(T_{N/R,N/R^2,R} \times I_R\right) U_{2,1}^{-1} F_{N/R^2,R^2} H_2 x \quad (8)$$

where $N = MR^2$. H_2 is a coarse transform matrix that is block diagonal with block of size R^2 with the structure $H_2 = I_{N/R^2} \times \left(W_1 \times W_1\right)$ and operates on R^2 subbands, each of length N/R^2. W_1 is an RxR wavelet filter matrix with property $W_1^T W_1 = I_R$. H_1 is a fine transform matrix that is block diagonal with block size N/R with structure $H_1 = I_{N/R} \times W_1$. There is an update matrix $U_{2,1}$ that refines H_1 into H_2, $H_2 = U_{2,1} H_1$. The matrix $U_{2,1}$ is block diagonal with block of size R^2 with the following structure:

$$U_{2,1} = I_{N/R^2} \times \left(W_1 \times I_R\right) \quad (9)$$

B. Method for image searching

JPEG compression is based on the discrete-cosine transform (DCT) [6]. The matrix C_8 is an 8x8 DCT matrix that is used to create transforms of 8x8 subimages in a JPEG representation of an image. The multiresolution search process relies on the factorization of the DCT matrix $C_8 = V_{8,4} V_{4,2} V_2$, where V_2 and $V_{4,2}$ are matrices built from Kronecker products of W and the identity matrix.

The matrix $V_2 = I_4 \times W$ consists of 4 interlaced copies of W and is of size 8x8. The matrix $V_{4,2}$ has a structure $V_{4,2} = I_2 \times \left(W \times I_2\right)$.

If we write $C_8 = V_{8,4} V_{4,2} V_2$ where $V_{8,4}$ is a matrix whose coefficients we want to compute, then

$$V_{8,4} = C_8 V_2^{-1} V_{4,2}^{-1} \quad (10)$$

obtain the last expression by multiplying both sides by $V_2^{-1}V_{4,2}^{-1}$. The matrix $V_{8,4}$ satisfies equation $V_{8,4} = V(W \times I_4)$. The inverse of V is

$$V^{-1} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \gamma(2)\gamma(7) & 0 & \gamma(5)\gamma(6) & 0 & \gamma(3)\gamma(6) & 0 & \gamma(2)\gamma(1) \\ 0 & \gamma(6)\gamma(1) & 0 & \gamma(3)\gamma(2) & 0 & -\gamma(5)\gamma(2) & 0 & -\gamma(6)\gamma(7) \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & \gamma(2)\gamma(1) & 0 & -\gamma(3)\gamma(6) & 0 & \gamma(5)\gamma(6) & 0 & -\gamma(2)\gamma(7) \\ 0 & 0 & \gamma(6) & 0 & 0 & 0 & \gamma(2) & 0 \\ 0 & 0 & \gamma(2) & 0 & 0 & 0 & -\gamma(6) & 0 \\ 0 & -\gamma(6)\gamma(7) & 0 & \gamma(5)\gamma(2) & 0 & \gamma(3)\gamma(2) & 0 & -\gamma(6)\gamma(1) \end{bmatrix}$$

(11)

where $\gamma(m) = \cos(2\pi m/32)$.

The matrix H is an NxN matrix with the structure $I_M \times C_8$ where $N = 8M$. It produces the JPEG transform of a vectors of length N. Let x be image stored as a JPEG transform of a vector Hx with an instance of a pattern y with JPEG transform Hy. The algorithm consists of three incremental steps, each of which quadruples the number of correlation points. The process can be halted at any stage if the intermediate results indicate that the correlation will not result in a match.

The three incremental steps are:

1. *Coarse correlation* – Generate the Fourier transforms $F_{M,8}Hx$ and $\hat{F}_{M,8}Hy$. Multiply the transforms point by point and partition them into eight subbands of length M. Add these eights vectors and take the inverse Fourier transform of the sum. Every eighth point of the correlation is generated.

2. *Medium correlation* – Multiply $F_{M,8}Hx$ by $(T_{2M,M,2} \times I_4)(I_M \times ((W \times I_4)V^{-1}))$ and $\hat{F}_{M,8}Hy$ by $(\hat{T}_{2M,M,2} \times I_4)(I_M \times ((W \times I_4)V^{-1}))$. Multiply the resulting vectors point by point and partition them in four subband of length $2M$. Add the subbands and you will create a single vector of length $2M$. Taking the inverse Fourier transform of size $2M$ yields the correlation at indices that are multiples of 4 mod 8 of the full correlation.

3. *Fine correlation* – Multiply the x and y transform from the preceding step by $(T_{4M,2M,2} \times I_2)(I_M \times V_{4,2})$ and $(\hat{T}_{4M,2M,2} \times I_2)(I_M \times V_{4,2})$, respectively. Multiply the resulting vectors point by point and partition them in two subbands of length $4M$. Add the subbands and you will create a single vector of length $4M$. Take the inverse Fourier transform of size $4M$ to obtain the correlation at indices that are multiples of 2 mod 8 and 6 mod 8 of the full correlation.

4. *Full correlation* – Multiply the x and y transform from the last step by $I_{8M,4M,2}(I_M \times V_2)$ and $\hat{T}_{8M,4M,2}(I_M \times V_2)$, respectively. Multiply the resulting vectors point by point and take the inverse Fourier transform of size $8M$ to obtain the correlation at odd indices.

Fig.1 is a flow diagram showing the steps performed for an image search according to the PWC method.
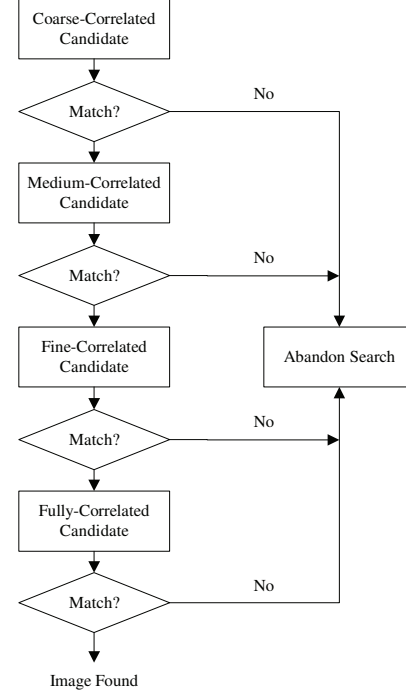

Fig. 1 Flow diagram of PWC method

We investigate what happens in the two-dimensional case. Let the image size be N by N. In step 1, we have 64 subbands of length $N^2/64$. We perform one step of the inverse 2D JPEG transfer function, and one 2D step of the forward Fourier transform function. The next step includes adding the 64 subbands point by point to create a 2D array of size $N/8$ by $N/8$. Taking the inverse Fourier transform, we obtain the correlations at points that lie on a grid that is coarser than the original pixel grid by a factor of 8 in each dimension. In step 2, we obtain 16 subbands of size $N^2/16$ by adding the 16 subbands point by point, and taking the Fourier inverse. We will obtain the correlation values on a grid that is coarser than the original grid by a factor of 4 in each dimension. In step 3, we obtain 4 subbands of size $N^2/4$. Finally, in step 4, the full resolution is obtained.

Formulas for calculating normalized correlation coefficients that measure differences between images and patterns are given in [4]. Normalized correlation coefficients can be computed from the correlations described above. The normalization is very important because it allows for a threshold to be set. Such a threshold is independent of the encoding of the images.

The normalized correlation coefficient has a maximum absolute value of 1. Correlations that have absolute values above 0.9 are excellent, and almost always indicate a match found. Correlations of 0.7 are good matches. Correlations of 0.5 are usually fair or poor. Correlations of 0.3 or less are very poor. There is a tradeoff between the value of the threshold and the likelihood of finding a relevant match. Higher thresholds

reduce the probability of finding something that is of interest, but they also reduce the probability of falsely matching something that is not of interest.

III. PRACTICAL IMPLEMENTATION

The progressive wavelet correlation provides guidelines on how to locate an image in the image library. To make this method practical, we must first decide how to store the images. The initial choice is to store them in a disk file system. This can be seen as the quickest and simplest approach. A better alternative that should be considered is to store those images in a database. In the past five years, with changes in database technology and improvements in disk performance and storage, the rules have changed and it now makes business sense to use the database to store and manage all of an organization's digital assets. Databases offer several strengths over traditional file system storage, including manageability, security, backup/recovery, extensibility, and flexibility.

We use the Oracle Database for investigation purposes. There are two ways of storing an image into the Oracle Database. The first one is the use of Large Objects – LOB [7], and the second one is the use of Oracle *inter*Media [8]. To store images into the database we use the BLOB datatype. After creation of one BLOB column defined table we also create a PL/SQL package with loading of images procedure (load named) included. This procedure is used to store images into the database. The implementation of the progressive wavelet correlation in Matlab and connection of the algorithm with the database are the next steps. The Database Toolbox is one of an extensive collection of toolboxes for use with Matlab. The Database Toolbox enables one to move data (both importing and exporting) between Matlab and popular relational databases. With the Database Toolbox, one can bring data from an existing database into Matlab, use any of the Matlab computational and analytic tools, and store the results back in the database or in another database.

Before the Database Toolbox is connected to a database, a data source must be set. A data source consists of data for the toolbox to access, and information about how to find the data, such as driver, directory, server, or network names. Instructions for setting up a data source depend on the type of database driver, ODBC or JDBC. For testing purposes JDBC drivers were usually used [9], [10].

After setting up the data source for connecting to and importing data from a database we have used several standard functions of the Matlab Database Toolbox. We can retrieve BINARY or OTHER Java SQL data types. However, the data might require additional processing once retrieved. For example, data can be retrieved from a MAT-file or from an image file. Matlab cannot process these data types directly. One needs knowledge of the content and might need to massage the data in order to work with it in Matlab, such as stripping off leading entries added by the driver during data retrieval.

The last step in the adaptation is to create Matlab applications that use the capabilities of the World Wide Web to send data to Matlab for computation and to display the results in a Web browser. The Matlab Web Server depends on TCP/IP networking for transmission of data between the client system and Matlab. In the simplest configuration, a Web browser runs on your client workstation, while Matlab, the Matlab Web Server (matlabserver), and the Web server daemon (httpd) run on another machine. In a more complex network, the Web server daemon can run on a separate machine [11].

The input mask of our application consists of three parameters: the image size N, the threshold *thr*, and the name of the image that we are looking for (Fig.2).

The practical implementation of progressive wavelet correlation includes two main subsystems: the server sub-system and the client subsystem. The server subsystem handles the processes of image storing in a database and similarity measure. The client subsystem handles the process of querying. In addition, we present here the system architecture of the system (Fig.3).

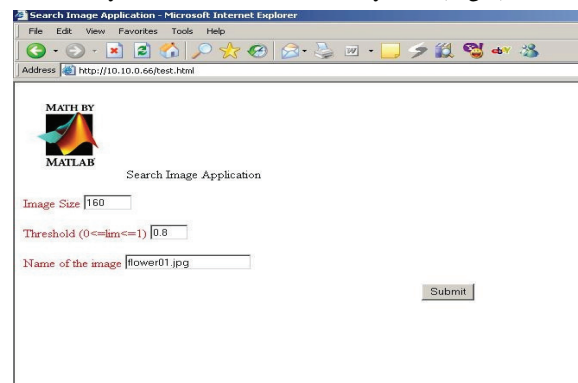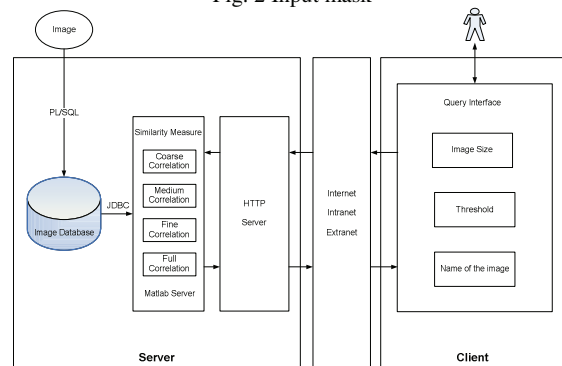Fig. 2 Input mask

Fig. 3 System Architecture

IV. EXPERIMENTAL RESULTS

This section represents experimental results obtained by means of image retrieval through an algorithm of progressive wavelet correlation.

Different experiments were set up as follows:
A. The required image is included several times in the database with different names;
B. The image is included only once in the database;

C. Aside from the required image, the database also contains an image very similar to the required one (smudged in some parts or an image generally slightly different);

D. The required image is not present in the database.

The experiments are carried out upon databases including between 250 and 1000 store images. Oracle 10g version 10.1.0.2.0, served as our database, while we used Matlab version is 7.0.4.365 (R14) Service Pack 2 for image search.

A. The required image is present several times in the database

Two images, called flower01.jpg and flower10.jpg, served as search targets. Image flower01.jpg appears eight times under different names in the database, while the image flower10.jpg appears six times. The database contains images that are more visually similar to the image flower10.jpg. The analysis of results indicates that for lower correlation thresholds values (0.5 or 0.6) there appear to be more retrieved images which increases the time needed for processing. Thus, for example, for the image flower10.jpg, when searching a database containing 1000 images, 79 images are selected when the adopted threshold value is 0.5 and 18 images when the threshold value is 0.6. We observe that the number of retrieved images for flower01.jpg (19) and flower10.jpg (79) differs significantly. This difference arises from the existence of many images in the database which are visually similar to flower10.jpg, which is not the case with flower01.jpg. Visually similar images exceed the correlation threshold of 0.5.

Evaluation of the quality of the system concerning its precision p is estimated using the following the definition:

$$p = \frac{|A(q) \cap R(q)|}{|A(q)|} \tag{12}$$

where q stands for query, $R(q)$ signifies a set of relevant images for the query in the database, while $A(q)$ stands for the set of images returned as a response to the set query q.
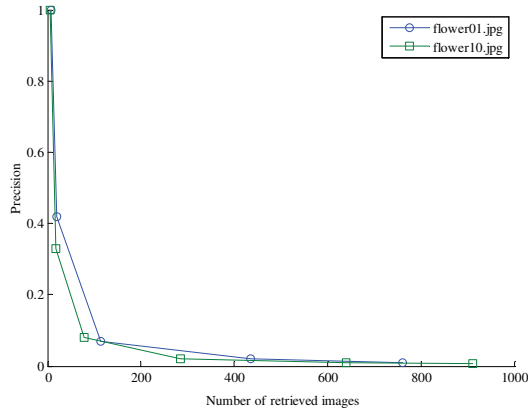

Fig. 4 Relationship of precision and the number of retrieved images for the images flower01.jpg and flower10.jpg

Fig. 4 demonstrates the accuracy regarding the number of retrieved images, which are obtained for different correlation threshold values ranging from 0.2 to 0.7 with step 0.1. The number of images in the database is 1000.

B. The required image is present only once in the database

The results presented in this part refer to two different images 21.jpg and 40.jpg. Each of these images is included only once in the searched database.

Considering the diagrams given in Fig.5, it can be concluded that a high accuracy value can be obtained for correlation threshold values greater than or equal to 0.7.
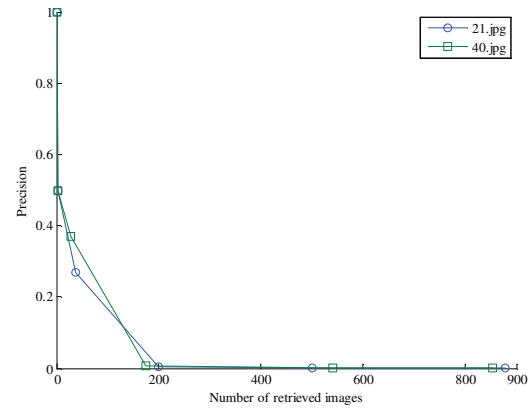

Fig. 5 Relationship between precision and the number of retrieved images for the images 21.jpg and 40.jpg

C. The database contains two very similar images

The next example refers to image 181.jpg. This example is specific because the database contains a similar image 183.jpg with its vertical sides slightly smudged. The similar images are shown in Fig. 6 and Fig.7.

Fig. 6 181.jpg

Fig. 7 183.jpg

It is evident from Table 1 that when correlation threshold values are 0.7 and 0.8, both the images 181.jpg and 183.jpg are retrieved. If the correlation threshold is equal to or greater than 0.9 only image 181.jpg is retrieved.

TABLE 1. 181.jpg

Threshold	Retrieved images	Precision
0.3	672	0.003
0.4	332	0.006
0.5	77	0.03
0.6	3	0.67
0.7	2	1
0.8	2	1
0.9 – 1	1	1

D. The required image is not present in the database

Table 2 gives the number of retrieved images for different value of the correlation threshold for image 50.jpg, which is not present in the database.

TABLE 2. 50.jpg

Threshold	Retrieved images
0.3	719
0.4	412
0.5	119
0.6	14
0.7	2
0.8 – 1	0

For correlation threshold values greater than or equal to 0.8 there aren't any images retrieved from the database. Therefore if the correlation threshold is set sufficiently high, the system correctly predicts the absence of the image.

V. CONCLUSIONS

Based on our experience and experimental evidence we conclude that PWC is a useful tool for image search from databases.

The main feature of PWC is its high accuracy. With the choice of an adequate correlation threshold it is possible to conclude whether the given image is present in the database, whether there are images similar to the required one with different names, whether there are images slightly different from the required one, and whether the required image is actually included in the database.

The examples studied imply that with the selection of a threshold greater than or equal to 0.7 it can be established that the required image is included in the database. Such selection of threshold gives the accurate number of images identical to the required one comprised in the database. With a correlation threshold greater than or equal to 0.9 a slight difference between two very similar images can be ascertained. In our examples, when the minimal threshold value is 0.8 it is established that the required image is not included in the database.

Owing to the large number of operations, the pixel-based methods for image search and retrieval are slow compared to commercially available content-based systems. We believe that in the coming years PWC based methods will be able to achieve detailed analysis of thousands of images per second.

According to the future researches, focused on the construction of image search and retrieval system, regardless of the technique that the system uses, only the issue concerning system quality assessment from the aspect of efficiency and applicability is to be tackled. Retrieval systems should be comparable for the purpose of identifying the good techniques.

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